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DEPARTMENT OF AGRICULTURAL ENGINEERING

MSc FOOD AND POST HARVEST ENGINEERING

DESIGN, CONSTRUCTION AND EVALUATION OF AN EVAPORATIVE COOLER FOR THE STORAGE OF MANGO IN THE BAWKU WEST DISTRICT OF THE UPPER EAST REGION OF GHANA.

PRESENTED TO: THE DEPARTMENT OF AGRICULTURAL ENGINEERING

BY:

MAHAMUDU IDDI (PG5944911)

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by

IDDI MAHAMUDU

(PG5944911)

A Thesis submitted to the Department of Agricultural Engineering, Kwame Nkrumah University of Science and Technology, Kumasi.

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College of Engineering

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DECLARATION

I hereby declare that this submission is my own work towards the MSc degree and that, to the best of my knowledge, it contains no material previously published by another person or material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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Head of Dept. (Name)	Signature	Date

DEDICATION

This project is dedicated to my late brothers, IddiFuseini and Iddi Mohammed, and to my late daughter, IddiAakilatuWumpini, who believed in me and always encouraged me to stay focused and never give up on any challenge.

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ABSTRACT

The design, construction and evaluation of a conventional evaporative cooler were carried out in the Bawku West District of the Upper East Region of Ghana for the storage of mango. The hexagonal shaped, sloped roofed non-circulating conventional evaporative cooler is of area $3.9m^2$ and height of 2.5m with a capacity of about 1.6MT. It was made from neem poles and sawn wood, a spear grass roof and a cemented floor. The cooler had a door of about 1.5m × 0.7m dimension, a 25 litres vegetable oil container as a water reservoir and a U-shaped header on top of walls of about 1.5m long and 20cm base diameter to supply water evenly throughout the walls. It has a total constructional cost of about three hundred and sixty-four Ghana Cedis, fifty Ghana pesewas (GH¢ 364.50). The daily ambient and internal temperatures were recorded using wet and dry bulb thermometer, and relative humidity of ambient air, inside the cooler and storage room was measured with a hygrometer. The results indicated that the evaporative cooler's water requirement was about 8.79 litres of water per hour, with about 82% of the water applied evaporated. The wet bulb depression of the working air was 8.3 and the temperature drop inside the cooler was 7.6℃ resulting in a cooling efficiency of 91%. There was about 4.8℃ drop in product air temperature and 9.6% humidity increase when compared with the storage room. For Jaffna mango fruits stored in both storage roomand evaporative cooler, out of 300 fruits stored in the storage room 206 well ripened fruits were obtained at the end of a storage period of 11 days, as against 260 out of 300 stored in evaporative cooler at the end of 17 days. Eighty-eight (88) fruits showed signs of rot as against 40 fruits stored in the evaporative cooler, and 19 fruits showed signs of water loss as against zero in the evaporative cooler respectively during the storage period. Out of 300 Keitt mango fruits stored in the storage room,

173 well ripened fruits were obtained at the end of a storage period of eight (8) days, as against 219 fruits obtained from those stored in the evaporative cooler for a period of 13 days. About 101 fruits stored in the storage room showed signs of rot for the same storage period, as against 81 fruits stored in the evaporative cooler.About 16 fruits from the storage room showed signs of water loss as against zero from the evaporative cooler over the period.

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CHAPTER ONE

1.0 INTRODUCTION

Fruit and vegetables form an essential part of a balanced diet. They are an importantpart of world agricultural food production, even though their production volumes aresmall compared with grains. Fruit and vegetables are important sources ofdigestible carbohydrates, minerals, and vitamins, particularly vitamins A and C. In addition they provide roughage (indigestible carbohydrates), which is neededfor normal healthy digestion (Salunkhe and Kadam,1995).Collectively, fruits constitute a very important dietary supplement in West Africa(Tweneboah, 2000). According to Salunkhe and Kadam, (1995) technology has enabled exporters to supply markets around the world with highquality products, and, in some cases,to introduce and develop new markets. This hasincluded introducing new crops and often defining the quality standards for these crops.The agricultural engineer has an important role to play in enabling producers to defineand meet quality requirements (Salunkhe and Kadam,1995).

Fruits are perhaps man's earliest food and have been important to him as food supplement since pre-historic and pre-agricultural times. Today fruits are no longer regarded as a luxury for there is growing awareness among dieticians and nutritionists of their importance in the diet of man as "protective" foods which are essential for the promotion and maintenance of good health and prevention of diseases (Tweneboah, 2000).The production of fruits and vegetables can improve the living standards of farmers. Horticultural production gives a higher net value return to farmers in developing countries compared to other crops(Tilahun, 2010).

Where fresh food is concerned, most people can decide the difference between aproduct that is of good quality and one that is not. Quality is an importantfactor in the production and marketing ofbiological products. Consumers in many countriesare becoming morediscerning as their affluence increases, and would-be suppliersof products must meet these demands if they are to maintain or increase market share.

Producing the consistently high-quality produce that spells success in a highly competitive market does not stop at the end of the harvest. The ability to deliver a quality product to the market and ultimately to the consumer commands buyer attention and gives the grower a competitive edge. Proper postharvest cooling and handling can help to ensure that quality is maintained until the product reaches the consumer (Boyette*et. al*., 1991).However, the perishable nature of fruits and vegetablesneeds effective postharvest handling systems, the main reason for high postharvest losses in the tropical regions of Africa(Tilahun, 2010).

Postharvest cooling rapidly removes field heat from freshly harvested commodities before shipment, storage, or processing and is essential for many perishable crops. Proper postharvest cooling can suppress enzymatic degradation and respiratory activity (softening), slow or inhibit water loss (wilting),slow or inhibit the growth of decay-producing microorganisms (moulds and bacteria), and reduce production of ethylene (a ripening agent) or minimize the product's reaction to ethylene (Boyette, *et al.*, 1991).Mangoes are climacteric, harvested at a mature green stage (Farzana, 2005)is one of the finest fruits of the world with a great market value (Chandy, 2013). Postharvest changes are principally concerned with events associated with ripening and senescence and the effect of postharvest handling techniques devised to control the occurrence and rate of these events (Farzana, 2005).

According to Samson (1986), mango (*Mangiferaindica*) belongs to the Anacardiaceae family to which cashew nut and some other fruit crops belong. The genus is a native to South-East Asia and consists of 62 species. About 16 of these have edible fruits but apart from mango, only *M. caesia*, *M. foetida* and *M. odorata*are regularly eaten, although they strongly taste of turpentine (Samson, 1986).

The mango is an important fruit grown in many tropical and subtropical regions of the world (Gill, 2005).It is the most important fruit of Asia and currently ranks in total production among major fruit crops, worldwide, after musa (banana and plantain), citrus (all types), grapes and apples (Murkherjee, 1997). According to Gill (2005),India is the largest producer of mango which covers about 35 per cent of area and accountsfor 22 per cent production of total fruits in the country and has been acclaimed as "King of fruits".Total world production was 24 420 116 Mt in 1999,and in Ghana it was 4000 Mt for the same year (De La Cruz Medina and Garcia, 2002).Some of the most important producers include India (11.5m MT), China (3.2m MT), Mexico (1.5m MT), Thailand (1.4m MT), Pakistan (0.90m MT), The Philippines (0.88m MT), Nigeria (0.73m MT) and Brazil (0.54m MT) (Yahia, 2005).

In many West African countries, mango fruits are second only to sweet oranges in terms of total production, volume consumed, and form a very important dietary supplement in both rural and urban areas during the periods it can be procured (Tweneboah, 2000). Besides delicious taste, excellent flavour and attractive aroma, mango is rich in vitamin A and C. Unfortunately, 25 to 30 per cent of mango produce is lost due to improper postharvest operations (Gill, 2005). Statistically, postharvest losses have been generally estimated in developed countries, in fruits to range from 5 to 25% while in developing countries it is 20 to 50% depending upon the commodity. This continues to cause heavy losses in revenue for the grower, wholesaler, retailers and exporters of mangoes (Akurugu, 2011). As a result, there is considerable gap between the gross production and the net availability (Gill, 2005).

Yahia (2005) indicated that the mango trade is becoming increasingly important in recent years. According to Gomez-Lim (1997), domestic and international trade of fresh mangoes has been limited by its highly perishable nature and its susceptibility to postharvest diseases, extremes of temperature and physical injury. The fruit may require 3 to 9 days to ripen and this short period seriously limits its commercialisation in distant markets.In many countries, there is an annual glut followed by famine. For all these reasons, mangoes are still considered as luxurious and expensive items in many industrialized countries (Gomez-Lim, 1997). If proper care is taken from harvesting to final marketing, considerable loss can be minimized and better quality fruits can reach consumers ensuring higher returns to the grower (Gill, 2005)

Ghana has excellent potential for the development of a very prosperous mango industry. The mango is not indigenous to Ghana so that the term "local mango" is a misnomer (Godfrey and Abutiate, 2014).However, there is a long tradition of mango cultivation, and the fruit is extremely popular in the local market, both fresh and processed. According to Wih (2008), Ghana has ideal sites for the production of mangoes in the north and some parts of the south, as the crop develop well under conditions ranging from semi-humid to semi-arid. In northern Ghana, the Integrated Tamale Fruit Company (ITFC), a non-governmental organization, has created a scheme that allows participating farmers to grow 0.4ha^{-1}of mango with support provided on credit and technical advice (Wih, 2008).Varieties being cultivated by the farmers in the Northern Region for both export and local markets areKeitt, Amelie, Kent and Zill. It was also realized that sellers purchase these varieties at the full ripe stage, therefore compelling farmers to harvest at that stage and causing fruits to deteriorate faster. Besides, both the farmers and sellers store the harvested mango fruits in baskets, boxes, spread on floor or heaped on the ground, which cause fruit to senescence early(Akurugu, 2011).

In the Bawku West District, mangoes are produced abundantly during peak seasons but due to lack of proper storage and preservation facilities, coupled with high temperatures, the market becomes overstocked during such seasons and a large proportion gets rotten before reaching the final consumer.

Mango ripens rapidly and have low tolerance to cool temperatures (<10^{o}C). Postharvest handling of mango aims to minimize premature ripening and fruit damage (Gomez-Lim, 1997).Gill (2005) reported that many attempts have been made to maintain postharvest health of fruits which include hot water treatment, irradiation, use of growth regulators and chemicals, storage at low temperature, modified atmosphere packing and controlled atmosphere. Most of the postharvest technology for mango has been developed for controlling diseases and insectand for protection against injury during packaging and transport. Mangoes have poor storage qualities,and technologies for long term storage, such as controlled or modified atmospheres, have been applied successfully to this fruit (Akurugu, 2011). Storage methods for mango have been characterized by variable results and occurrences of physiological disorders. Fruits stored in modified atmospheres often show undesirable characteristics, (poor colour and eating qualities, and the presence of undesirable flavours). In addition few studieshave shown clear evidence that mango ripening can be delayed satisfactorily. Clearly, other alternatives are therefore required to delay ripening and softening (Gomez-Lim, 1997).

Manytechnological procedures are used commercially as supplements to temperature management. None of these procedures alone or in their various combination, can substitute for maintenance of optimum temperature and relative humidity, but they can help extend the shelf life of harvested produce beyond what is possible using refrigeration alone (Kader, 1992).

While refrigerated cool stores are the best method of preserving fruits and vegetables they are expensive to buy and run. Consequently, in developing countries there is an interest in simple low-cost alternatives, many of which depend on evaporative cooling which is simple and does not require any external powersupply.

The Evaporative Cooler is designed to provide an environment which is both lower than ambienttemperature and at a higher level of relative humidity for the storage of fresh produce (Ngoni, 2000).Over the past decades, evaporative cooling, utilizing the principle of water evaporation for heat absorbing, has gained growing popularity for use in air conditioning, owing to its simplicity in structure and good use of natural energy (i.e., latent heat of water) existing in ambient (Renewable and Sustainable Energy Reviews (RSER) 16, 2012).

It works on theprinciple of a porous structure to which water is added; as air flows across this "wet wall" the airtemperature is decreased due to the loss of heat through the evaporation ofwater. The temperature isnormally lowered by about 5 to10 °C, depending on the relative humidity of the ambient air. EvaporativeCoolers can be used for all types of produce but subtropical fruits respond best because their optimumstorage temperatures are closer to those achieved by Evaporative Coolers (Ngoni, 2000).

The heart of a portable evaporative cooler is the cooling media or the pad that is soaked with water and provides the cooling effect. Because hot air is forced through these pads the thickerthe pads are, the more surface area there is available to cool the air which increases the temperature drop in the work area needed to be cooled.

Evaporative coolers do not use potentially hazardous Freon (only water) to cool the air. They are therefore recognized as a green product and a natural choice for environmental friendly use.

Main objective

The objective of this project was to design and construct an evaporative cooler for mangostorage to ensure an all yearsupply in the Bawku West District in the Upper East Region of Ghana.

Specific objectives:

1. To compare the storage life of mangoin the traditional storage room against the evaporative cooler.
2. To evaluate percentage losses of mango in the two storage systems.
3. To determine which storage structure performed better.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Mango

2.1.1 History and Botany

Mango is the most ancient among the tropical fruits and is believed to have originated in the Indo-Burma region (Chandy,2013) and was in cultivation before 2000 BC. However, the crop spread to worldwide cultivation in relatively recent times, when the Portuguese opened the sea route to the Far East. Although the fruit appears to have reached East Africa by the 9th Century through Arab incursions, recorded history indicates the mango was first taken to South Africa from Goa near Bombay by the Portuguese in the 17th Century, and spread throughout West Africa by the middle of the 19th Century (Tweneboah, 2000).

The mango is a member of the family *Anacardiaceae*. This family comprises many other valuable trees such as the cashew and the pistachio nut. The genus*Mangifera*includes 25 species (as cited in Mabberly, (1997)), with edible fruits such as *Mangiferacaesia*, *M. foetida*, *M. odorata* and *M. pajang*, although *M. indica*, the mango, is the only species that is grown commercially on a large scale. The mango is a deep-rooted, evergreen plant which can develop into huge trees, especially on deep soils. Seedling trees can reach more than 20 m in height while grafted ones are usually half that size. The mature leaves are simple, entire, leathery, dark green and glossy; they are usually pale green or red while young. They are short-pointed, oblong and lanceolate in shape and relatively long and narrow, often measuring more than 30 cm in length and up to 13 cm in width. New leaves are formed in periodic flushes about two to three times a year. The greenish-white or pinkish flowers are borne in inflorescences, usually placed terminally on current or previous year's growth—in large panicles of up to 2000 or more minute flowers. Male flowers usually outnumber the bisexual or perfect flowers (Juergen, 2013).According to NIIR Board of Consultants and Engineers, although the Indian mango was commonly believed to be monoembryonic, a number of cultivars were discovered in south India.

2.1.2 Cultivars and Characteristics

Mango cultivars are many and commonly classified into two groups depending on their ability to reproduce from seeds to monoembryonic and polyembryonic. Monoembryonic cultivars are hybrid in origin and must be reproduced by asexual propagation. Polyembryonic cultivars are those where many embryos may develop from diploid parent nucellar tissue after fertilization of the egg cell. There are more than a thousand cultivar in India, but only about 25 to 40 cultivars are grown commercially. In the region of ASEAN (Philippines, Malaysia, Indonesia, Singapore, Thailand) there are over 500 cultivars. In Mexico, Manila, Ataulfo, Keitt, Kent, Haden, and Tommy Atkins are the most important commercial cultivars. In South Africa, Zill, Kent and Haden are the most important grown cultivars (Yahia,2005). However, cultivars introduced over 50 years ago into Ghana included Peter, Blackman, Kensington, Divine, Julie, Ceylon 1 and Ceylon 2 from Trinidad, Jaffna and Rupee from Ceylon and other Indian cultivars(Godfrey and Abutiate, 2014).

2.1.3 Fruit maturation and ripening

Fruit set in mango occurs when the conditions for cross pollination are favorable. After setting, mango fruit takes approximately 3 months to reach maturity with marginal varietal. There are large differences in size, shape, appearance and physiological characteristics. For example, the average weight of different mango fruit cultivars ranges between less than 80g to more than 800 g (Yahia, 2005).

Mango produces a small but noticeable peak of ethylene during ripening. In all cultivars that have been studied, ethylene production is low in pre-climacteric fruits but increases considerably during the climacteric period. Mangoes produce ethylene prior to full maturity and that the highest rate ($125 nlg^{-1}h^{-1}$) occurred in the outer mesocarp , although the levels of ethylene were comparable in the entire mesocarp. Mature but unripe mangoes have high levels of ethylene ($1.87 \mu ll^{-1}$) while they are attached to the tree (Gomez-Lim, 1997). Respiration is very high after fruit set and then declines and maintains low until the fruit starts to mature. The rise in respiration and ethylene production (during the rise in the climacteric) is related to fruit maturation and ripening. All metabolic changes mentioned are part of the natural senescence of the fruit. This is an irreversible process that contributes to losses of organelles, chemical constituents, and thus the quality and postharvest life of the fruit. Natural senescence is aggravated and promoted by factors such as ethylene, mechanical injury and high temperature. This process can be delayed by lower temperature, elimination of mechanical damage and reducing of ethylene production(Yahia, 2005).

Ripening of many fruits is characterized by softening of the flesh. Softening is thought to be brought, about among other factors, by the concerted action of different cell wall hydrolase, whose activities change during ripening and alter the properties of many cell wall constituents (example; pectin) (Gomez-Lim, 1997).Changes associated with mango fruit ripening include: 1) skin color changes from green to yellow in some cultivars, 2) flesh color changes from greenish yellow to yellow to orange, in all cultivars, 3) decrease in chlorophyll and increase in carotenoid contents, 4) decrease in flesh firmness and increased juisiness, 5)conversion of starch into sugars, 6) increase in soluble solids content, 7) decreased titratable acidity, 8) increase in characteristic aroma volatiles, 9)increase carbon dioxide production rate from 40-50 to 160-200 mg/kg.hr at 20°C and ethylene production rate increases from 0.2-0.4 to 2-4 □l/kg.hr at 20°C (Yahia, 2005).

2.1.4 Harvesting

When to harvest is one of the most important decisions a grower faces when it comes to providing the marketplace with superior-quality fruit (National Mango Board (NMB), 2010). Mangoes harvested at the mature and halfmature stages ripen to good-quality fruit while immature fruits do not ripen normally (Yahia, 2005). According to the NMB (2010), mangos picked before their optimum maturity may eventually ripen, but will develop inferior flavor and aroma, show increased susceptibility to chilling injury caused by low temperatures during transport, and have shortened shelf life. Fruits harvested after optimum maturity will have a shorter postharvest life. Fruits harvested medium-ripe or ripe and stored for short period showed lower contents of sugar and carotenoids. Physiological maturity in climacteric fruits is the stage at which the fruit can continue its processes of ripening and can reach its optimum eating quality off the tree. Fruit harvested before reaching physiological maturity will not ripen off the tree or will ripen with very poor quality (Yahia, 2005).

Generally, harvest maturity in mango is reached in about 12 to 16 weeks after fruit set depending on cultivar. Computing the age of the fruit is one of the simplest factors that can be used for harvest. Selection of the appropriate fruit maturity can be based on several parameters, including fruit shape, peel color, peel texture, flesh firmness, flesh color development, soluble solids content, and latex content (NMB, 2010). On the basis of shape and form, external four maturity stages can be defined during mango fruit development: 1) shoulders in line with the stem end and green olive color, 2) shoulders outgrowing the stem end and olive-green color, 3) shoulders outgrowing the stem end and light color, 4) flesh becoming soft and blush developing. Fruits are recommended to be harvested at stages 3 and 4. However, the change in the shape of the shoulder may not apply to all cultivars (Yahia, 2005). Although the parameters employed for each variety of mango grown commercially might vary somewhat, all commercial growers use one or more of these parameters as an aid to harvest (NMB, 2010).

Ripening in mango fruit is associated with loss of firmness, although no definite commercial application is widely used. Skin color is variable for the different cultivars. Yellow cultivars develop their skin color somewhat uniformly.However, cultivars with red blush are not uniform in their skin color development. In addition, some cultivars do not change their green color upon ripening. Even in yellow cultivars, when the skin color changes the fruit is usually advanced in maturity.Fruit position on the tree can affect peel color development. Nitrogen fertilization significantly affects the development of yellow and red colors. Therefore, skin or peel color is not an optimum maturity index for many mango cultivars. On the other hand, in most mango cultivars pulp color changes are somewhat uniform when fruit advances in maturity (Yahia, 2005).

In commercial operations, the use of harvest aids, such as ladders, clippers, nets, and harvest baskets, is very common and helps speed up harvest. Harvested mangos should be protected from exposure to direct sunlight while they await transport to the packinghouse. Direct exposure to sunlight results in higher flesh temperatures, which in turn accelerate metabolism and shorten potential shelf life (NMB, 2010).

2.1.5 Production output and Socio-economic impact

Yield fluctuate annually, abnormally high yields often preceding very low yield the following year. Low yields, often attributed to low food reserves in the plant, may also be due to flower shedding even when food reserves are adequate (Tweneboah, 2000).

Global production of mangoes is concentrated mainly in Asia and more precisely in India that produced 12m MT. Mangoes are grown in 85 countries and 63 countries produce more than 1 000 MT a year. Total world production was 24 420 116 MT in 1999,and in Ghana it was 4000 MT for the same year. In recent years, mangoes have become well established as fresh fruit and processed products in the global market. World demand for mango is now increasing however, particularly from temperate countries, where mangoes are rapidly gaining in popularity. The increase in mango production in non-traditional mango-producing areas has been notable and includes parts of Asia, West Africa, Australia, South America and Mexico. International trade of mangoes is dominated by varieties like Keitt and Tommy Atkins (De La Cruz Medina and Garcia, 2002).

2.1.6 Pre-harvest and Postharvest problems

Like post-harvest management, the pre-harvest and subsequent harvesting of the fruits also plays an important in role in enhancing the shelf life and quality of the fruits. The pre-harvest cultural practices like use of fertilizers, pest control, growth regulators, climatic conditions like wet and windy weather and tree conditions influence the fruit potentiality for storage by modifying physiology, chemical composition and morphology of fruits (Government of India, 2013). The climacteric rise in mango fruit is marked by an appreciable increase in the activity of several enzymes. However, this fruit is susceptible to internal physiological disorders that causeappreciable losses to producers (Lima *et al.*, 2001).Postharvest development of mangoes will be influenced by at harvest attributes. Key issues include; fruit maturity, colour (internal and external), shape, size, sweetness, position on tree, vitality, occurrence of pest and disease infestation, biotic/abiotic damage, weather conditions at harvest, irrigation frequency and nutrient content (Gomez-Lim, 1997).

Some disorders, such as chilling injury and high CO_2 injury, are induced after harvest, while others are inherent. Inherent disorders occur intermittently, and are unpredictable, such as jelly seed, which results in watery, translucent tissue around the seed giving an over-ripe appearance. It does not develop after harvest unless it was present at harvest. Soft nose and internal breakdown (or spongy tissue) are other disorders, though it is possible these are one in the same. Sap burn is a major problem with some cultivars, such as Kensington, while Irvin is less susceptible. Water/detergent washing helps to avoid damage (Paull and Chen, 2014). The disorder, also known as flesh breakdown or internal flesh breakdown, is referred to as jelly seed, soft nose, or stem-end cavity (SEC) (Raymond *et al*., 1998).

Chilling susceptibility varies with cultivar; Haden and Keitt are particularly susceptible. Most cultivars show injury below 10 °C (50 °F), especially if fruit have just reached maturity. Tolerance to chilling increases during ripening. Heat treatment prior to storage reduces injury in ‘Keitt’ (Paull and Chen, 2014). Chilling injury symptoms are: dark scaled-like discolorations in the peel and pitting or sunken lesions (Farzana, 2005).

Vapor heat disinfestations treatment in which seed surface temperature was held at 47°C for 15 min. increased the severity of lenticel spotting and skin browning in ‘Kensington’ mangoes from two production zones stored at 10°C for 5 days followed by 22°C for 5 days. Both secondary disease incidence and level of injury increased in ‘Kensington’ mangoes treatedwith hot water or vapor heat to a fruit core temperature of 47°C with increasing time from 7.5 to 30 min (Yahia, 2005).

The ‘black tip’ disorder is characterized by yellowing of tissues at the distal end of the fruit, and the color intensifies into brown and finally black, the mesocarp and seed being unaffected (Yahia, 2005). At this stage, further development is retarded and the black spot at the tip gradually extends towards the upper part of the fruit. Such fruits prematurely drop off and become unmarketable (Chandy, 2013).

Postharvest decay is one of the most important causes of postharvest losses in mango, and the major problem during storage and marketing(Yahia, 2005). Anthracnose (*Colletotrichumgloesporioides*), that is due to pre-harvest infection and does not spread postharvest, and the postharvest stem end rots caused by several fungi that infect before and after harvest (often as wound invaders that spread postharvest), are the two most common diseases. Anthracnose appears as fruit ripen and first appear as superficial black spots and streaks that then become sunken (Paull and Chen, 2014).

Alternaria rot (*Alternariaalternata*), a pre-harvest infection, can sometimes be a problem, while the postharvest wound infections can occasionally be severe such as Black Mold (*Aspergillus spp.*) and transit rot (*Rhizopusspp*)(Juergen, 2013).

Different types of fruit flies are known to attack ripening mangos in almost all mango-producing areas. Yield losses of more than 50% have been reported (Juergen, 2013). Losses due to fruit flies in Ghana are estimated at between 60% and 80% of crop depending on the cultivar and season (Wih, 2008).The females lay their eggs under the surface of the fruit skin. After hatching, the maggots penetrate the flesh and destroy the fruit from inside (Juergen, 2013).Later, a brownish rotten patch makes its appearanceon the surface of the attacked mango fruits with the characteristic oozing of fluid after the maggots have eaten the pulp (Chandy, 2013).

2.1.7 Postharvest handling of mango

2.1.7.1 Latex staining and control

Latex (sap), with low pH and high oil content exudates can stain the fruit, burn the skin and reduces its quality (Yahia, 2005). Latex dripping from mango stems at harvest or during accumulation and transport causes peel damage that is aggravated when mangos are exposed to heat treatment. To prevent latex damage to peels, the following procedures are recommended: Harvest mangos with a long stem (5 cm or longer) and accumulate the fruit in field boxes. Latex does not drip from fruit with a long stem attached. Trim stems to the abscission zone (approximately 1 cm) and immediately place the fruit with the stem end down to allow latex to drip without touching the fruit's peel. Various rack-like structures have been devised to hold the mango fruit while the latex drips and to protect the fruit from direct contact with the ground. The duration of latex removal varies from 20 minutes to up to 4 hours, depending on how long it takes for the latex to stop dripping (NMB, 2010).

2.1.7.2 Grading process and Packing

Fruit should be selected, and only good quality fruit should be packed (Yahia, 2005). The fruits graded according to their size, weight, colour and maturity benefits both the producer and consumer. It has been observed that bigger size fruits take 2-4 days more time in ripening than smaller ones and hinder to achieve uniform ripening. Therefore, grading according to size play an important role in packaging of the fruits (Government of India, 2013).Defective fruit should be eliminated. This is done manually by trained persons (Yahia, 2005).

Packaging is done manually. Exported fruit are commonly packed in a single layer in corrugated boxes. Size and weight ofpackages depend on the requirements of the importer, but mango is commonly packed in boxes with a capacity of 4 to5 kg(Yahia, 2005).

2.1.7.3 Precooling

Pre-cooling can immediately lower the field heat of commodity following harvest and slow down metabolism and reduce deterioration prior to transport or storage (Basavaraj, 2009). Precooling also decreases the refrigeration demand during cold storage or refrigerated transport. The delay in cooling mango fruit results in accelerated ripening and in short postharvest life and deteriorated quality. Mango fruit is commonly precooled after packing (Yahia, 2005).

Fruit are normally forced-air or room-cooled, preferably within 24 h of harvest (Paull and Chen, 2014). With this method the temperature of the fruit can be reduced from about 35°C to about 14°C (temperature when pre-cooling should be terminated) in 2 to 5 hours(Yahia, 2005).

2.1.7.4 Storage

Mango is not commonly stored for prolonged periods. However, after precooling the fruit should be moved immediately to the cold room or to the transport container.Cold storage room should be set at 10-14°C (depending on cultivar and holding period) and 85-90% relative humidity, should be equipped with adequate systems of air circulation, air exchange, and should be clean. Fruit should be stacked in a way that can permit an adequate circulation of cold air. Air circulation should be enough to establish a uniformity of temperature and gases in the room (Yahia, 2005). In natural storage the product is left in the field and harvesting is delayed, while in artificial storage favorable conditions are provided which help to maintain product freshness and nutritional quality for a longer period (Akurugu, 2011).

2.1.7.5 Temperature Management

Temperature is one of the most important environmental factors that influence the deterioration of harvested fruits and hence its management during various postharvest operations like - pre-cooling, pretreatments and storage plays a major role for extending the shelf-life (Basavaraj, 2009).. Low temperature is needed to reduce metabolic activity, delay ripening and senescence, reduce water loss, prevent or reduce disease and insect activity, and thus the maintenance of postharvest life and quality (Yahia, 2005). However, there is a limit to the low temperature that mangos can tolerate due to their susceptibility to chilling injury, a disorder that results in flavor loss, surface blemishes (lenticels darkening, scald, and pitting), and inhibition of ripening. The lowest safe temperature for long-term exposure (2 weeks or more) of *mature*, green mangos is 12°C; immature fruit can be injured even at temperatures above 12°C. As mangos ripen, they are able to tolerate progressively lower temperatures; however, the exact effects of time, temperature, variety, and ripeness stage on the development of chilling injury, especially related to flavor loss, are still not clear (NMB, 2010).

2.1.7.6 Humidity Control

Mango fruit should be maintained at high humidity. Optimum RH is 85-90%. Lower RH will promote water loss, shriveling, uneven ripening and quality deterioration(Yahia, 2005).

2.1.8 Quality Assurance

The Organization for Economic Co-operation and Development provides guidelines in defining international marketing requirements (Yahia, 2005).Skin coloration, size, shape for variety, appearance, freedom from defects and decay, absence of fiber in the flesh and a turpentine-like flavors are the most common quality parameters. Wilted, grayish discoloration and pitting are undesirable (Paull and Chen, 2014). Class standards are defined as “extra”, “good quality” (Class I) and “marketable” (Class II). Fruit sizes defined are A: 200-350 g, B: 351-550 g, and C: 551-800 g. The maximum permissible differences allowed within each size groups are 75, 100, and 125 g, respectively.Import markets have established quality standards. The three important quality standards developed are:

1. Codex Alimentarius. Worldwide Codex Standard for Mangoes, Codex Stan 184 1993.

2. Mexico. NOM-FF-58-1985.Mexican official Standard for Mango (Norma official Mexicana).

3. Europe. UN/ECE standard FFV-45.Concerning the marketing and commercial quality control of Mangoes (Yahia, 2005).

Quality-control personnel should sample mangoes (at least 25 fruits) from each load to assess fruit maturity and defects prior to packinghouse reception. It is strongly recommended that quality-control data from each load be used as a guide to adjust packinghouse practices (extent of sorting by maturity and defects) in order to assure optimum quality at retail markets (NMB, 2010).The purpose of postharvest handling is delivery of a product that closely matches buyer specification and complies with mandatory regulatory requirements. Satisfying customers underpins quality assurance which aims to produce a product of the desired standard, encouraging regular, larger and more frequent purchases, and brand loyalty. As export market becomescompetitive, responsive quality assurance can be a vital strategy of maintaining and expanding market niche (Gomez-Lim, 1997).

2.2 Evaporative Cooling

2.2.1 History of Evaporative cooling.

Evaporative cooling is a process that reduces the temperature of air by the evaporation of water in the air stream. Heat in the air which is blown across a wet surface (pad) is utilized to evaporate the water, resulting in a reduction in the dry bulb temperature of air and a corresponding increase in the relative humidity

(Ganhan*et al.*, 2007).The utilization of water evaporation for cooling purposes has its origins well entrenched inHistory (Saman*et al.*, 2009). Appearance of evaporative cooling occurred at around 2500 B.C., during which the ancient Egyptians made use of water- containing porous clay jars for purpose of air cooling (RSER 16, 2012). Evidence of evaporative cooling applications by ancient people of the Middle East iswidely documented and some of these applications are still in use in the Middle East today.

They include the use of porous water vessels, the wetting of pads made of dried vegetableswhich cover the doors and windows facing the prevailing wind and directing the prevailingwind into pools of running water in underground rooms. Early Australians alsoused different forms of evaporative air cooling to obtain some comfort in the hot dry climatesof outback Australia.

The modern evaporative cooling devices were originated from USA. In early 1900s, air washers were invented at New England and Southern Coastline and used for cleaning and cooling air in textile mills and factories. During that period, several air cooling devices including the direct and indirect coolers were also found in Southwest (Arizona and California) region (RSER 16, 2012).

2.2.2 Evaporative Cooling Principles

The rudimentary basis for understanding any air conditioning, dehumidification andevaporative cooling is psychrometrics. Psychrometry consists of the interactions betweenheat, moisture and air. It is basically the study of air-water mixtures and is an essential foundation for understanding, how to change air from one condition to another (Bhatia, 2012). When air blows through a wet medium, a T-shirt, aspen fibers (excelsior), or treated cellulose, fiberglass, or plastic, some of the water is transferred to the air and its dry bulb temperature is lowered (Larry, 2004).Evaporative cooling occurs when moisture is added to air that has a relative humidity of less than 100%. The lower the relative humidity, which is dependent on the airs dry and wetbulb temperatures, the greater the potential for evaporative cooling (Technical Report, 2004). The cooling process works on the principle of evaporation of moisture. The evaporationof the water lowers the temperature of the air passing through the wet pads of the cooler (Martin and Mary, 1991).

The cooling sensation felt by a person when a breeze passes overand evaporates perspiration on their skin, is doubtless the most common human experience with thephenomenon (Technical Report, 2004).The cooling effect depends on the temperature difference between dry and wet bulb temperatures, the pathway and velocity of the air, and the quality and condition of the medium (Larry, 2004). Using an electric fan to cool air by forcing it through wetted media, asoccurs in moderndirect evaporative coolers, is an obvious extension of this concept (Technical Report, 2004).

Drybulb temperatures, widely reported values measured with typical mercury-bulb thermometers, impactevaporative potential. The temperature of air measured with a thermometer whose sensing element is dry is known as “dry bulb temperature.” If a thermometer’s sensing element is surrounded by a wet wick over which air is blown, the sensor is evaporatively cooled to its “wet bulb” temperature (Larry, 2004). Relative Humidity or RH is the actual amount of moisture in the air compared to the total or maximum moisture the air can hold at a given temperature (Bhatia, 2012). When the relative humidity is at 100%, there is no difference between dry and wet bulb temperatures, but as the relative humidity of the air drops, so does the wet bulb temperature with respect to dry bulb temperature. The greater the difference between dry and wetbulb temperatures ("wetbulbdepression"), the greater the temperature drop achievable in an evaporative process. (Larry, 2004).

2.2.3 The Cooling Processes on Psychrometric Chart

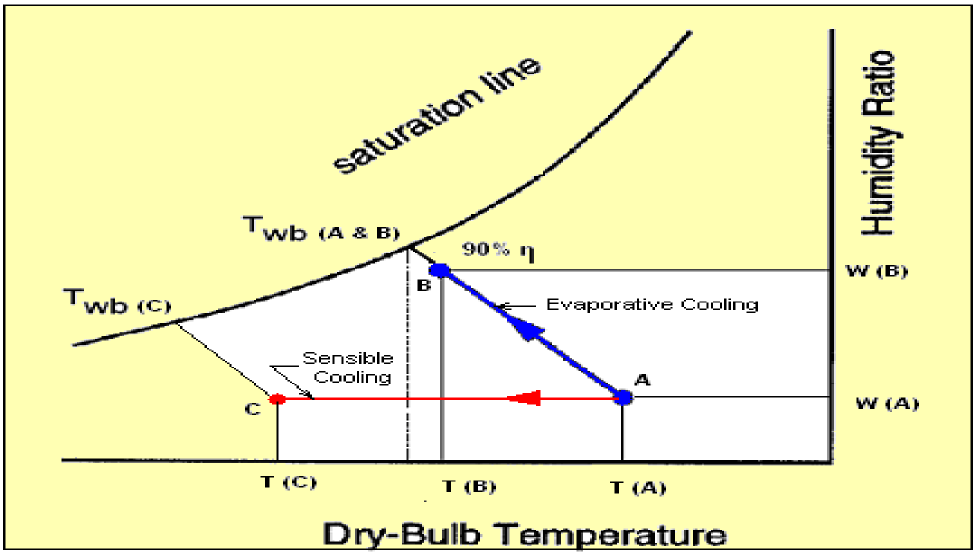


Figure 2.1 The cooling processes in a Psychrometric Chart (Bhatia, 2012)

2.2.3.1 Sensible Cooling

In sensible cooling process, the temperature of air changes from a point 'A' to point 'C', maintaining constant humidity ratio. The temperature is reduced by [T (A) – T (C)] and the wet bulb temperature is also reduced. The humidity ratio remains same since there is no addition or loss of moisture(Bhatia, 2012).

2.2.3.2 Evaporative Cooling

In evaporative cooling process, both temperature and humidity of air changealong the line of constant wet bulb temperature (shown as line AB). There is no change in heat content and the energy is merely converted from sensible energy to latent energy.

In evaporative cooling process, changes occur in dry bulb temperature, specific volume, relative humidity, humidity ratio, dewpoint temperature, and vapor pressure of the moist air. No change occurs in wet bulb temperature and enthalpy. The evaporative cooling is a constant enthalpy process (technically termed as adiabatic process) (Bhatia, 2012).

2.2.4 Types of Evaporative cooling

2.2.4.1 Direct evaporative coolers

Direct evaporative air conditioning is ideal for arid climates where water is available.

Outside air is drawn through wetted filter pads, where the hot dry air is cooled and humidifiedthrough water evaporation. The evaporation of water takes some heat away from the airmaking it cooler and more humid. The dry-bulb temperature of the air leaving the wetted padsapproaches the wet-bulb temperature of the ambient air.(Saman*et al.*, 2009).

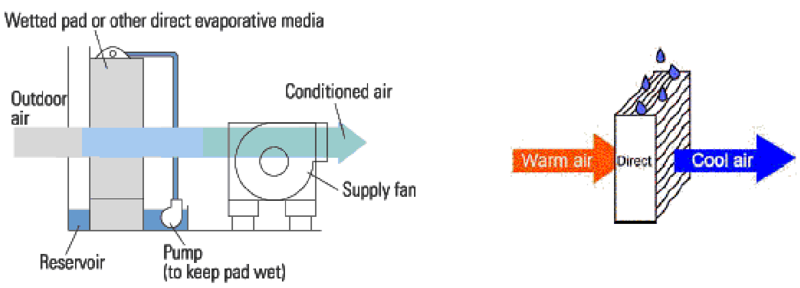


Figure 2.2 Diagram illustrating direct evaporative cooling (Bhatia, 2012)

The resulting fresh, cool, humidified air is blown into buildings where the pattern of flow (and cool air delivered) is determined by the location and extent of openings in the conditioned envelope such as windows or special dedicated ducts. Modern evaporative coolers couple high-performance media with low-velocity air flow. They maximize moisture transfer as the air traverses the media to enhance "direct saturation effectiveness," which is analogous to cooling efficiency. Direct evaporative cooler performance is measured relative to the wet bulb depression (Larry, 2004).

2.2.4.2 Indirect evaporative coolers

Indirectevaporative coolers take advantage of evaporative cooling effects, but cool without raising indoor humidity (Larry, 2004).Indirect Evaporative Cooling (IEC) systems can lower air temperature without adding moisture into the air. In an indirect evaporative air cooling system, the primary (product) air passes over the dry side of a plate, and the secondary (working) air passes over the opposite wet side. The wet side air absorbs heat from the dry side air with aid of water evaporation on the wet surface of the plate and thus cools the dry side air; while the latent heat of the vaporized water is transmitted into the working air in the wet side.

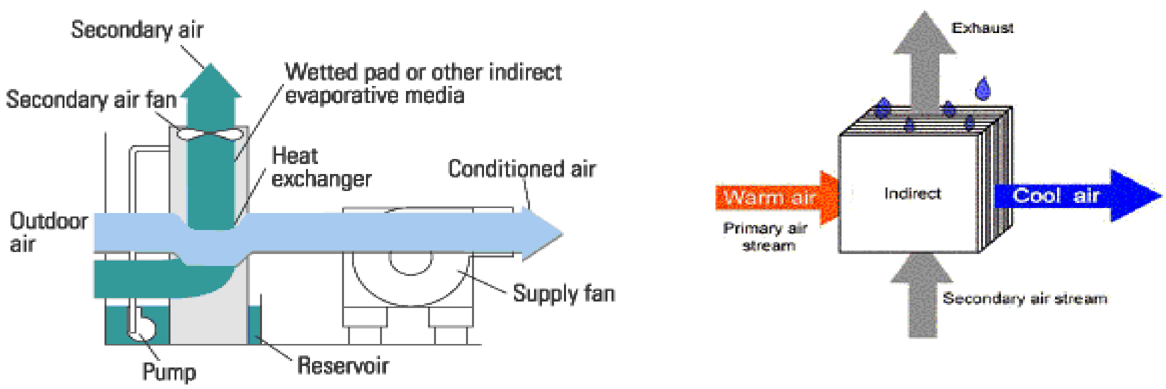


Figure 2.3 Diagram illustrating indirect evaporative cooling (Bhatia, 2012).

If the product air of the IEC system travels in a counter flow manner to the working air at an appropriate air-flow-ratio and across an infinite surface area, the temperature of the product air in the dry side of the plate will reach the wet-bulb temperature of the incoming working air. The temperature of the working air in the wet side of the plate will be lowered from its incoming dry- bulb temperature to the incoming wet-bulb temperature. However, the actual effect is that only 40–80% of the incoming air wet- bulb temperature can be achieved (RSER 16, 2012).

2.2.4.3 Operation of the evaporative cooler

Evaporative cooling involves heat and mass transfer, which occurs when water and the unsaturated air water mixture of the incoming air are in contact. This transfer is a function of the differences in temperatures and vapor pressures between the air and water. Heat and mass transfer is both operative in the evaporative cooler becauseheat transfer from the air to the water evaporates water, and the water evaporating into the air constitutes mass transfer (Johnson, 1988).

Heat inflow can be described as either latent or sensible heat. Whichever term is used depends on the effect. If the effect is only to raise or lower temperature, it is sensible heat. Latent heat, on the other hand, produces a change of state, e.g., freezing, melting, condensing, or vaporizing. In evaporative cooling, sensible heat from the air is transferred to the water, becoming latent heat as the water evaporates. The water vapor becomes part of the air and carries the latent heat with it. The air dry-bulb temperature is decreased because it gives up sensible heat. The air wetbulb temperature is not affected by the absorption of latent heat in the water vapor because the water vapor enters the air at the air wet-bulb temperature.Theoretically, the incoming air and the water in the evaporative cooler may be considered an isolated system. Because no heat is added to or removed from the system, the process of exchanging the sensible heat of the air for latent heat of evaporation from the water is adiabatic. Evaporative cooler performance, therefore, is based on the concept of an adiabatic process (Johnson, 1988).

2.2.5 Sizing the Evaporative Cooling Equipment

Two principal method of sizing evaporative coolers are:Air change sizing method and Sensible heat load removal method (Bhatia, 2012).

2.2.5.1 Air Change Sizing Method

The "Air Change" method is a practical approach to assist in the determination of the size of evaporative cooling equipment. The principle behind this method is to determine two factors: Leaving air temperature from the evaporator cooler and the difference between the inside temperature of the space, when evaporative cooling is notin use andthe outside ambient temperature during its highest condition.Once the above two factors have been determined, refer to table on appendix B to determine theproper number of air changes.

Procedure

Step 1: Determine the Cubic Capacity of the structure or that portion of the structure to be evaporatively cooled;

Formula = Width X Length X Effective Cooling Height* = Capacity in Cubic Feet.

A heat stratification layer will form at the roof level which will not adversely affect the cooling process provided that space is not used. Cold air drops and hot air rises.

Step 2: Calculate the leaving dry bulb temperature.

Formula: LDB = ODB – [SE x (ODB - OWB)],

WhereLDB = leaving dry bulb temperature,

ODB = outdoor dry bulb temperature,

OWB = outdoor wet bulb temperature,

(ODB – OWB) = wet bulb depression,

SE = saturation efficiency of the cooling media.

It is first necessary to know the climate design conditions of Dry Bulb (ODB) and Wet Bulb(ODB) for your location.

Step 3: Determine the number of air changes per hour required to maintain desired indoortemperatures. The air changes can be determined from the column-3 of appendix B. This is an extremelyimportant determination. Too many air changes will result in unnecessary cost while too fewair changes will not achieve the indoor conditions desired. Experience has shown thatsignificant benefit can be achieved with 10-15 AC/Hr for 12 feet height. For a 24-foot-highbuilding, this would mean 5-6 AC/Hr for the entire volume. This will vary by application (Bhatia, 2012).

2.2.5.2 Sensible Heat Removal Sizing Method

Use the sensible heat load equation to determine the air flow rate: SCFM=Indoor sensible heat gain (BTUH)/1.08× (IDB-LDB)×Density ratio. Where IDB = Desired indoor (Design) Dry Bulb and LDB = Leaving Dry Bulb from Cooler (Bhatia, 2012).

2.2.6 Cooling Pads

Cooler pads (sometimes called media) come in several alternatives (Martin and Mary, 1991).A pad material should be porous enough to allow free flow of air. It should be able to absorb water and allow evaporation. It should have maximum amount of wetted surface area for an adequate period of air water contact time to achieve near saturation. The material should be locally available and inexpensive. Moreover, it should allow easy construction into required shape and size (Ganhan*et al.*, 2007).University of Arizona agricultural engineers have long recommended aspenwood fiber pads.Aspenwood pads can be used for an entire cooling season. Although aspenwood pads are efficient in distributing cooled air, they may also produce debris in the water reservoir, increasing cooler maintenance. Some cooler manufacturers recommend a cellulose fiber media or pad for use with their equipment. The media is said to be uniform throughout, to provide consistent cooling performance and to last for several seasons. They are superior to spun aluminum and plastic pads available at hardware or do-it-yourself stores or supermarkets. These are less expensive initially than aspenwood but may need to be changed several times in one cooling season (Martin and Mary, 1991).

2.2.7 Effectiveness and efficiency of cooling pads

The use of water by coolers is generally dependent on their size, air movement and relative humidity of the air (Martin and Mary, 1991). The amount of cooling generated by an evaporative cooler is a function of the amount of evaporation that occurs in the unit(Ganhan*et al.*, 2007).The saturation effectiveness also has an impact on water consumption. Increased saturationeffectiveness is associated with higher water consumption (Saman*et al.*, 2009). Saturation efficiency is defined as the difference between the entering and exit dry-bulb temperatures over the wet-bulb depression (Bhatia, 2012).It is expected that an evaporative cooling system must decrease the air temperature to the desired degree by minimum power consumption and expenses. Thus, an ideal pad media must have the highest evaporative saturation efficiency and the lowest airflow resistance. For this reason, when selecting the optimal pad media for cooling systems of agricultural buildings evaporative efficiency and resistance against airflow of the pad materials must be considered together (Ganhan*et al.*, 2007).Increased dry air movement over the wet cooler pads will increase the amount of evaporation and produce more cool air. At the same time, decreased air movement will decrease the amount of water used for cooling, while the bleed-off rate will remain the same (Martin and Mary, 1991).The results of the tests conducted to evaluate the effects of the pad thickness on the evaporative saturationefficiency of pad materials indicated that efficiency increases slightly with the increase of pad thickness. This result could be due to the fact that with thin pads, the porosity of the pad is enough to allow fast passage of air thus reducing the heat exchange period of evaporation. On the other hand, increasing the pad thickness reduces the porosity of pad and increase the passing time of air which increases the heat exchange period, subsequently improving the evaporation and cooling efficiency (Ganhan*et al.*, 2007).Drip cooler effectiveness depends largely upon pads that had maximum clean wet surface with a minimum air flow resistance. This requires pad materials having surfaces that spread water rapidly by capillary action and through which air passes (Manuwa and Odey, 2012).

2.2.8 Significance of Shape

It was observed in all tests that the hexagonal cross-section cooler was more efficient than the square cross- section cooler (at almost the same maximum and minimum temperatures the cooling efficiency of hexagonal and square cross sections was 93.5 and 84.1 respectively, using jute as cooling pad). This could be attributed to the former having greater projected area than the latter, so that for the same cooler capacity and wind direction, more air would pass through the cooling pads on the hexagonal cross-section cooler than the square cross-section cooler (Manuwa and Odey, 2012).

2.3 Water

Mineral deposits and scale build-up caused by hard water can cause rust and corrosion in metal coolers.Some estimates are that this rust and corrosion can shorten a cooler's life by 50 percent. The sodium added to water by water softening will accumulate on the cooler pads and will become concentrated in the water reservoir. Softened water also may increase the need for pad maintenance and the rate of rusting of metal cooler parts (Martin and Mary, 1991).

2.4 Constructional Materials

Speargrass(*Imperatacylindrica*(L.)Raueschel) is one of the most dominant, competitive, and difficult weeds to control in the humid and sub-humid tropics of Asia, West Africa, and Latin America. In West Africa, it is a serious weed of intensive agriculture particularly in areas prone to recurrent burning in the coastal/derived savanna, also called forest/savanna transition zone (Chikoye*et al.*, 2000). In Ghana, the forest, forest-savanna-transition and coastal savanna zones, which areintensively cropped to cereals, legumes, vegetables, root and tuber crops are prone to frequentburning, contributes to the dominance of the weed. Some uses of speargrass mentioned by the farmers were roofing material by 87.8% of farmers, medicinal (8.7%) and livestock fodder (2.4%). The use of speargrass for soil erosion control was, however, not mentioned by any of the farmers (Bolfrey-Arku*et al.*, 2000).

Fence posts must be strong enough to resist pressures exerted on the wires. Furthermore, posts must have a long life expectancy by resisting decay, rotting or rusting. They must be relatively easy to install and to attach wires to, and they must do all of this at a reasonable cost. The most suitable and most used material for agricultural fence posts is wood; specifically round, chemically pressure treated softwood, such as LodgepolePine.The principal reasons for this preference are that wooden posts are in good supply; they have a high strength to relatively low weight ratio; are economical and provide a long service life. As well, they can be driven into the soil with power equipment and the fence wire can be easily stapled to wooden posts (Fencing FACTSHEET, 1996).

Experience in fence construction is used when selecting wooden post materials and sizes for various fence requirements. Line posts, brace posts, etc. are sized for the load they are expected to resist. Split cedar is also used for fence posts (especially in coastal areas where the wood is common). It may be selected for organic farms as it can be used untreated (Fencing FACTSHEET, 1996).

The biggest disadvantage in using wood as fence posts are the fact that fungi attack and decay wood to the point where the post no longer has the required strength. However, fungi can only grow and cause decay if the correct conditions of moisture, air supply, temperature and most importantly, food supply, exist. Various treatments are available to greatly reduce fungal growth and extend fence post life. Wood maintained at 20 percent moisture or less will not decay nor will wood deep in the ground where oxygen is very low. However, optimum conditions for fungal growth occur in a zone approximately one foot above and below ground level. This is also the area where maximum fence post strength is required (Fencing FACTSHEET, 1996).

Neemis regarded as a promising tree species which can be utilized in various ways to benefit agricultural communities throughout the world. Neem has been growing on the plains near Ghana's capital, Accra, since the 1920s.The trees have naturalized, and their spread has been boosted by birds and bats that feed on the fruits and spit out the seeds while sitting in the branches. Neem is now scattered all over the area, and has become Ghana's major source of firewood (Tinghui*et al.*, 2001).

Always try to find the best post to meet the demands of the situation. Often the least expensive option is to cut your own posts or purchase untreated, wooden posts. They are highly variable in size, shape and durability (University of Tennessee, 2001).

Woven wire fences consist of a number of horizontal lines of smooth wire held apart by vertical wires called stays. The distance or spacing between horizontal line wires may vary from as close as 1 ½ inches (3.75cm) at the bottom for small animals, to as wide as 9 inches (22.5cm) at the top for large animals. In general, the spacing between wires gets wider as the fence gets taller. Woven wire is available in many combinations of wire sizes and spacings, as well as a number of horizontal line wires and fence heights. The height of most woven wire fencing materials ranges from 26 (65cm) to 48 inches (120cm) (University of Tennessee, 2001).

Anumber of special cements are now available to the concrete construction industry. Each type serves a specific function in terms of application, performance and durability. Although each may be used by itself to answer a special construction need, some may be used with other standard or special types to achieve special esthetic or functional objectives. The following descriptions of various special cements deal only with the basic characteristics of the cements andtheir applications.ASTM specifications cover mosttypes of cement used in construction (Special Cements and their uses, 2014).

Masonry cements are available in either grayor white and vary considerably inchemical composition. They are notcovered by ASTM specifications.Most are mixtures of portlandcement,air- entraining additives andfinely ground supplemental materials.Over and above the basic settingand strength requirements, they areformulated primarily for their abilityto impart to masonry mortars workability, water retention andplasticity.When combined with sand and water, masonry cement produces a highly workable mortar. Proportions will vary according to needfrom a low of about I to 2 1/2 to ahigh of about I to 5 by volume (aproportion of I to 3 is common.These mortars have high plasticity,good water retention, minimumvolume change, and no delayed expansion.When mixed with washed concrete sand they are suitable for external rendering and internal plastering.If a setting accelerator is used in cold weather, the quantity required is usually about half that which would be used with ordinary Portland cement and no more than this amount should ever be used. Most masonry cements contain adequate air-entraining agents and, unless mixing is inefficient, no additional agent should ordinarily be required. Plasticizers, likewise, should seldom be added; if they are used it should be determined beforehand that they do not detract from strength (Special Cements and their uses, 2014).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

3.1.1 The study area: Location and size

The Bawku West District lies within the Upper East Region of Ghana. It was carved out of old Bawku District under the new local government system in 1988. It lies roughly between latitudes 10° 30’N and 11° 10’N, and between longitudes 0° 20’E and 0°35’E.The District shares boundaries with Burkina Faso in the North, Bawku Municipality to the East, Talensi/Nabdam District to the West and East Mamprusi District to the South.Two important tributaries of the Volta River namely the White and Red Volta ran contiguous to the Districts’ Eastern and Western boundaries respectively. The District covers an area of approximately 1,070 square kilometers, which constitutes about 12% of the total land area of the Upper East Region (MoFA, 2011).

3.1.2 Topography and Drainage

The relief of the district is generally flat to gently undulating with slopes ranging from 1-5%. These plains are broken in some places by hills or ranges formed from either outcrops of Birimian rocks (greenstones) or granite intrusions. These ranges lie along the border with Burkina-Faso, north of Zebilla, and turn south-west from the Red Volta north of Nangodiin the Talensi/Nabdam district.

The District is drained by both the White and Red Volta and their tributaries. The rivers over- flow their banks during the rainy season (April-October). During the dry season there is always an inflow of water from the Bagre dam which makes it possible for farmers to pump water for irrigation from the White Volta (MoFA, 2011).

3.1.3 Climate and Vegetation

The area experiences a unimodal rainfall regime starting from middle to late April, to late September and sometimes early October, and a long dry period beginning from November to March each year.

The vegetation is Sudan savanna consisting of short drought- and fire-resistant deciduous trees interspersed with open savanna grassland. Grass is very sparse and in most areas the land is bare.Common grasses include *Andropogangayanus* (Northern Gamber Grass) in the less eroded areas and *Hyparheniaspp*, *Aristidaspp*, and *Heteropogon spp*. (Spear grass) in the severely eroded areas. Common trees include *Anogeissusspp, Acacia spp* (Thorn tree) and *Triplochiton spp*. Economic trees include *Parkiafilicoidea* (Dawadawa), *Butyrospermumparkii* (Sheanut), *Andansoniadigitata* (Baobab) and *Ceibapentandra* (Kapok) (MoFA, 2011).

3.1.4 Water supply

The water supply conditions in the district are directly related to the underlying rocks. In the areas occupied by Birimian rocks, the ground is a high so surface flow of streams generally persists throughout the dry season as observed at some places such as Komaka, Kasongo and Kubongo. The rocks weather into clay and this combines with the relatively impermeable bedrock to give conditions favorable for surface water storage.AtKomaka, famers reported year round flow of water from springs at the foot slopes of the greenstone hills separating Ghana from Burkina Faso (MoFA, 2011).

3.1.5 Source of Data

The design, construction and evaluation of a 1.6MT capacity conventional evaporative cooling structure for the storage of mango fruits started from October 2012 to April 2013 in the Bawku West district of the Upper East Region. Primary data was obtained on the field from farmers and mango producer organizations, and in the market from mango retailers.Primary data was also obtainedon the field using a local storage structure, evaporative cooling structure, thermometers, hygrometers, measuring tape, weighing scale, digital cameras, cratesand two mango cultivars (Jaffina and Keitt).Secondary data was obtained from the Kwame Nkrumah University of Science and Technology library, the internet, Ministry of Food and Agriculture, related private firms and the BawkuWestDistrict Assembly.

3.2 Methods

3.2.1 Design

A six-sided sloped roofed hexagonally shaped non-recirculating conventional evaporativecooling structure of size; 1.5 m x 1.5 m and height 2.5m and a capacity of 1.65 MT was designed and constructed for experimentation with sturdy tree poles from locally available trees. Constructed under shade, the wooden frame supported the walls and roof. The walls, about 1.5 m high, which were made of charcoal wasconstructed from a wooden frame covered with wire mesh on both sides separated by about 10 cm from each other with the interior being filled with charcoal. The charcoal walls were on all six sides, filled up to the top 20 cm below the roof, with this space being left open so as to allow field heat in produce to escape and also for air circulation. The cooler has a door to allow for easy access, stocking and removing of produce into and from cooler, and for security purposes. Theroof was made of thatch to provide a cool shade, with a polyethene lining inside to prevent rain water from dripping into the structure. The floor which is a bare ground was raised above ground level to prevent running water from passing through and was compacted usingcement. Pallets were made inside the structure above the floor using wooden slaps. The function of the cooling structure, among others, was to reduce theeffect of sensible heat that could be gained from the ambient environment thereby increasing the shelve life of the stored produce.

3.2.2 Site Selection

Yikudugu, a farming community about 3 Km from Zebilla, the Bawku West District capital, was a suitable site considering its topography (generally flat to gently undulating with slopes)and vegetation (short drought- and fire-resistant deciduous trees interspersed with open savanna grassland) that allows for free air movement for effective cooling.The relatively impermeable bedrock over lined by clay gives conditions favorable for surface water storage. There is also a relatively large dam that rarely dries up during the dry season located at the eastern side of the main road when approaching the community Bawku, and three borehole stand pipes in the community.

Therefore there are many all-year-round springs to ensure a good water supply to render the cooler operational.The relative humidity in the area is very low (10% -

35%) during the dry season making the rate of evaporation very high which resulted in better cooling.

Relatively large quantities of both local and grafted mango varieties are eitherproduced or imported in the Bawku West District and there is a relatively good feeder road network within and into the District making the project site accessible to producers.The cooler waslocated under shade so that fruits were not exposed to direct sun before going into the cooler and so they reached a lowertemperature much sooner. This also resulted in lower water requirements for the operation of thecooler (i.e. the charcoal walls were wetted less frequently or did not dry out quickly).

3.2.3 Main Frame

The construction of the evaporative cooler was conducted in stages, starting with the structural frame. The ground was first cleared of grasses and rubbles, and levelled before digging and putting in the poles. The frame was made from sturdy nim poles of approximately 10 cm diameter. Neem poles were used as they are locally available. Six poles were used, one at each corner of the hexagonal room. A seventh pole was used to provide support for adoor of about 70 cm wide and of the same height as the structural poles. The poles were fixeddirectly into the ground using holes 40 cm deep. The ends of the poles going into the holes were treated with a preservative (neem leaf preparation) to prevent termites attack should they be present on the site. The soil around each pole waswell compacted with a concrete mixture so that the pole is firmly anchored. This was to ensure that the structure will be able to withstand strong winds and storms as is the case during the harmattan (North-East trade wind) and the raining season respectively. The poles were painted with a white oil paint to protect the wood against water, to prevent the wood from absorbing more heat from its surrounding (white colours absorb less heat as they reflect most of it) and also to make the cooler attractive.

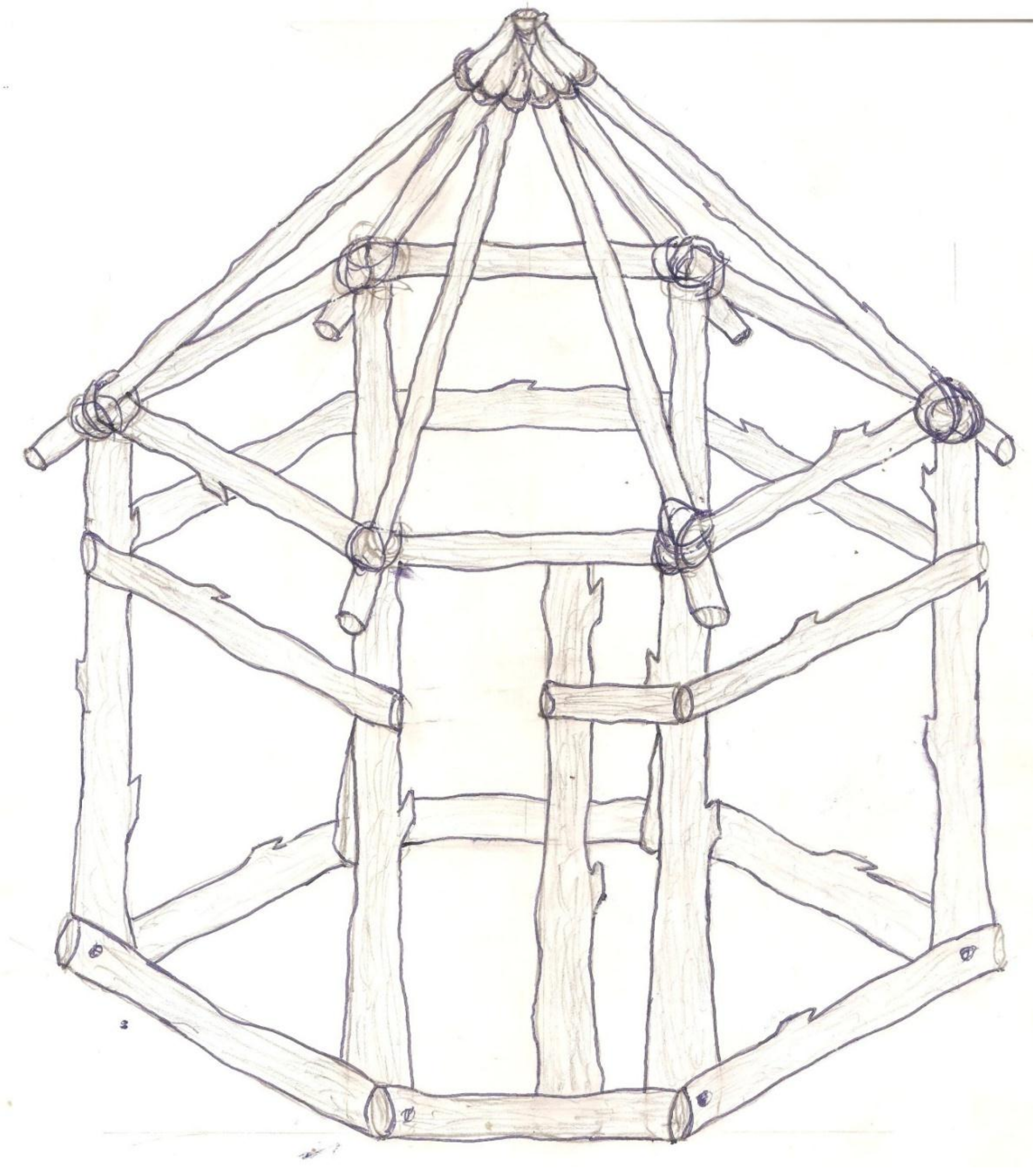


Figure 3.1: A structural sketch of the main frame of the evaporative cooler

3.2.4 Walls

The walls were constructed using charcoal, sawn timber and wire netting. The poles of the structural frame were used as vertical support to the walls. Wooden strips (in pairs) made from sawn timber, with dimensions of 25 mm x 50 mm, on either side of these poles, about 10cm apart, were attached horizontally, from one structural pole to the other, at regular intervals going up the poles to a height of 1.5 m, creating a frame for the walls. These wooden strips facilitated the fixing of the wiremesh since this (the wire mesh) was nailed tightly to the wood which were at the bottom, middle and top of the wall. The distance between the wooden strips up the poles was 0.75 m,which made attaching the fence easier. To prevent the inside strips of timber from crossing each other at the point of attachment with the poles, beveled joints were cut out of the timber at the point where they crossed and they were then fitted together to make a curved joint. The width of the wall was maintained along the two parallel wooden strips by fixing a 10 cm wide block between them at the halfway point. This was to strengthen the frame and reduce bulging. This frame was then covered with a wire mesh, attached by pulling tightly before nailing (this was to ensure that the wall kept its shape when they were filled with charcoal), from the bottom and on all sides except the top was kept open for filling in with charcoal. The walls (including the wooden strips) were painted with a white oil paint for the same reason as is the case with the structural frame (vertical poles).To prevent the walls from bulging when they were filled with charcoal, copper wire strips were used to tie the wire nets from the two sides of the vertical poles at regular intervals. The wall was then filled lightly with charcoal to ensure good air circulation from the bottom up to the top.

3.2.5 The roof

A trapezoidal roof was constructed using thatch made from spear grass. A plastic sheet was spread underneath the grass thatch over six wooden rafters of about 5 cm in diameter. This will protect the interior of the cooler from rains. The rafters werecut from fine neem branches and were attached, from the base of the roof, to the six structural poles where they overlapped to about 20 cm, and to a short round piece of wood of about 20 cm long and 10 cm in diameter at the top center of the roof. These rafters were fastened at their point of attachments with nails.The thatch was also fastened to the rafters with twines made from okro stems. The roof was pecked at an angle of about 30˚ from the apex which is steep enough to allow free down flow of water with no problem of water seeping through into the cooler when it is raining. The roof had an overlap of about 20 cmto prevent water from entering the cooler through the open space above the charcoal walls. An overhead water reservoir support was constructed away from but at the height of the overlap with sawn timber (5 cm thick). This structure was rectangular shaped (1.5 m × 0.5 m) and attached to the main cooler at the two vertical poles at the back of the cooler and braced to the cooler by two other pieces of sawn timber of the same thickness.

3.2.6 The door

The door was constructed with five pieces of sawn timber of about 5 cm × 2.5 cm. These pieces of wood formed the main frame of the door withtwo (approximately 1.5 m high) acting as the vertical support and two, which was as long as the width of the door (0.7 m), being the horizontal support. These pieces of wood were attached to each other by half beveled joints and fastened with nails to form a rectangle. The fifth piece of wood (0.7 m) was attached to the door half way up the vertical pieces of sawn timber by beveled joint and also fastened with nail to serve as a support to the door frame. The door was completed with the attachment of elephant grass (which is a poor conductor of heat) to the door frame by means of soft wires to cover the surface of the door. The door was then attached to the cooler on the seventh vertical structural pole planted to support thedoor by means of hinges. The door opened outward to maximize space inside the cooler when the door was opened. A security lock was also provided to prevent unlawful entry into the cooler.

3.2.7 The floor

The floor was a cement-compacted raised platform, hexagonal in shape. Drains of about 5 cm deep and 10 cm wide from the walls were constructed along the walls with cement mortar to allow for easy draining of excess water, during watering of charcoal walls, away from the cooler.These channels were gently sloped backward to a water reservoir of size, 0.6 m × 0.6 m and 0.4 m deep, constructed to hold runoff water.

3.2.8 The pallets

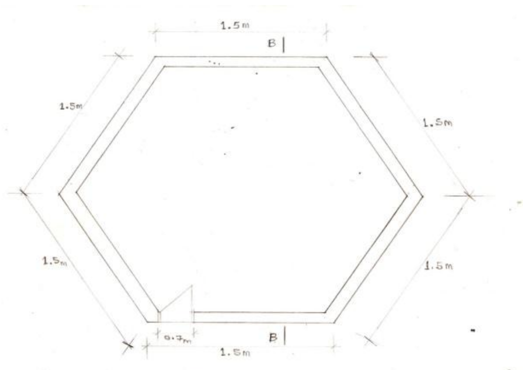
Wooden pallets of 10.0 cm wide, 2.0 cm thick (length ranged from 1.4 m to 2.8 m depending on its position in the evaporative cooler) wereconstructed with sawn timber about 5 cm above the floor. About fifteen pallets were placed in the cooler with about 10 cm space between them. These pallets were supported in the middle, especially the longer once, to be able to support a large number of crates of mangos of all varieties that were stored.

3.2.9 Water reservoir

A reservoir was provided in the form of an overhead tank of about 50litres. The reservoir was held at about 0.5 m above the charcoal wall by two 10 cm diameter sturdy nim poles of about 1.5 m above the ground and the two nim structural poles behind the cooler, with a seat made from 2.5 cm × 5.0 cm thick sawn pieces of timber of length 1.0 m and width 0.5 m.A tap was connected to the bottom middle of the water reservoir to control the flow of water out of the reservoir.

3.2.10 Header

A header was constructed on top of five of the charcoal walls with iron sheets each of dimension 1.5 m long and 20 cm wide. The header was U-shaped with perforations of about 5 mm in diameter and spaced at regular intervals of about 5 cm along the middle of the U-shaped bottomto supply water in uniform sprays along and downward the wall. The tap at the bottom middle of the water reservoir flowed into a distributor (also made of the same material and U-shaped as the header) that sends water in two directions along the charcoal wall.



Scale: 1cm:20 units

Figure 3.2 Site plan

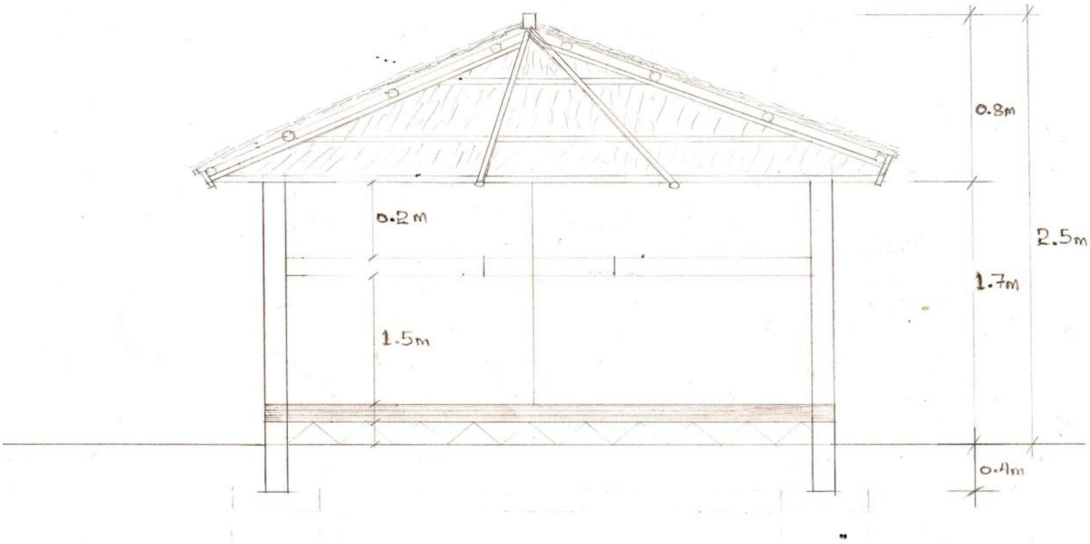


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Figure 3.3: Section B - B

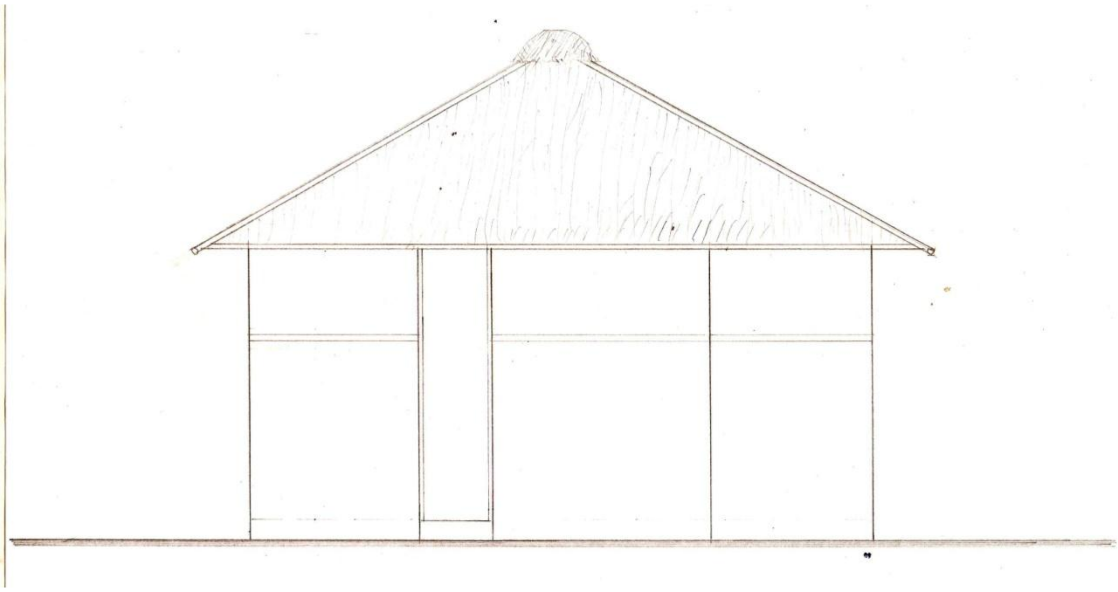

Figure 3.4: Front view

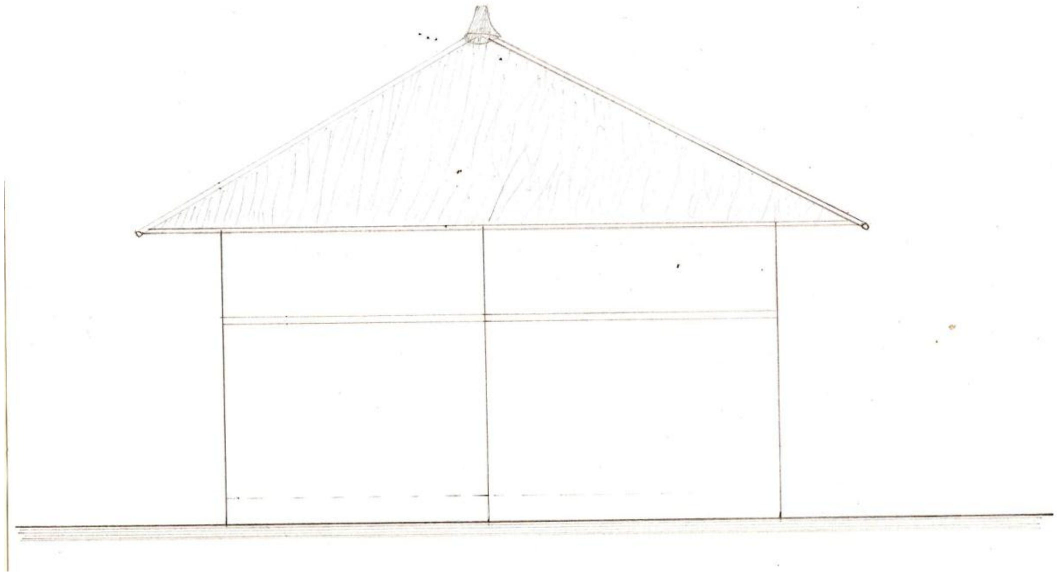

Figure 3.5: Side view

Table 3.1;Constructional Materials

	PART	MATERIAL	LENGTH	QUANTITY
1	Main Frame	Round sturdy nim poles about 10 cm base diameters.	2.1m	7
		Round sturdy nim poles about 10 cm base diameters.	2.4m	4
		Round sturdy nim poles about 5 cm base diameters.	1.5m	6
		Round sturdy nim poles about 5 cm base diameters.	1.0m	3
		Round sturdy nim poles about 5 cm base diameters.	0.5m	3
2	Wall	Sawn timber of about 2.5cm × 5cm thickness.	1.5m	30
		Sawn timber of about 2.5cm × 5cm thickness.	20cm	20
		Sawn timber of about 2.5cm × 5cm thickness.	80cm	6
		Charcoal of granular size of about 4cm × 4cm × 3cm.		270kg
		Wire mesh with mesh size of about 0.1cm × 0.1cm and height 1.5m.	9m	2
3	Roof	Round sturdy nim poles about 5 cm base diameters.	1.7m	6
		Woven dry spear grass.	10m	2
		Polyethelene sheet of about 2m × 1.5m		2
4	Door	Sawn timber of about 2.5cm × 5cm thickness.	0.7m	3
		Sawn timber of about 2.5cm × 5cm thickness.	1.5m	2
5	Floor	Cement of about 50kg bag.		2
6	Water tank	25 litres vegetable oil container.		1
7	Header	0.8 wide iron sheet of about 0.1cm thickness	1.5m	2
8	Others	Nails	2.6cm	0.5kg
		Nails	5.2cm	0.5kg
		Nails	7.8cm	0.5kg

Table 3.2: Cost of Constructing a Noncirculating Evaporative Cooler

MATERIAL	DESCRIPTION	QUATITY	UNIT COST (GH¢)	TOTAL COST(GH¢)
Round sturdy neem poles about 10cm base diameter	2.1m	7	2	14
Round sturdy neem poles about 10cm base diameter	2.4m	4	2	8
Round sturdy neem poles about 5cm base diameter	1.5m	6	1	6
Round sturdy neem poles about 5cm base diameter	1.0m	3	1	3
Round sturdy neem poles about 5cm base diameter	0.5m	3	0.5	1.5
Sawn timber of about 2.5cm x 5.0cm	1.5m	30	1	30
	20cm	20	0.5	10
	80cm	6	1	6
Charcoal of granular size of about 4cm x 4cm x3cm	45kg	6	12	72
Wire mesh with mesh size of about 0.1cm x 0.1cm and height 1.5m	9m	2	27	54
Round sturdy neem poles about 5cm base diameter	1.7m	6	1	6
Woven dry spear grass	10m	2	5	10
Polyethelene sheet about 2cm x 1.5m		2	2	4
Sawn timber of about 2.5cm x 5.0cm	0.7m	3	1	3
Sawn timber of about 2.5cm x 5.0cm	*1.5m*	*2*	*1*	*2*
Cement	50kg	2	22	44
25 liters vegetable oil container		1	5	5
0.8m wide Iron sheet of about 1mm thickness	1.5m	2	10	20
Nails	2.6cm(0.5kg)	1	1.5	1.5
	5.2cm(0.5kg)	1	2	2
	7.8cm(0.5kg)	1	2.5	2.5
Other cost	Labour	3	20	60
TOTAL				**364.5**

3.3.0 Operation of the evaporative cooler

3.3.1 Water requirement test

Water was applied from the top of the charcoal wall through the header. Charcoal was wetted until there was a runoff to wash dust and soot. It was then observed for the frequency of watering.

3.3.2 Temperature and humidity test

During the testing on the first day, water from the overhead reservoir was applied through the distributer to the header on top of the charcoal wall to allow water to move down ward to the lower part of the wall. Two thermometers each(dry bulb and wet bulb) were mounted outside and inside the evaporative cooler and in the storage room to take the ambient temperature and the thermodynamic conditions of the evaporative cooler and the storage room, and readings were after 20 minutes. The door was closed and readings were taken every 2 hours.Water was subsequently applied to the charcoal wall every 2 hours to keep the wall wet all the time. Data was collected and recorded on the sheet on table 4.1.

3.3.3 Mango fruit response test

Good quality mango fruits were selected from the available varieties (keitt and Jaffina). Fruits selected were matured and unripe. The fruits were washed and observed for visible signs of rot, shrivellingor mechanical damage under the sun light. The fruits were pre-cooled to the 15°C before packed into crates. The same quantity of fruits were packed into two separate equal number of crates and packed into the evaporative cooler and the control storage room and placed on pallets, one on top of the other (each storage having the same quantity of fruits and crates).

Fruits were observed for 21 days and daily data was taken on the conditions of fruits and recorded on the sheet on tables 4.4 and 4.5.

3.4 Instrumentation

The daily ambient and internal temperatures were collected using dry and wet bulb thermometers and the humidity inside the cooler and inside storage room was read from digital hygrometers. The project was executed under the moderation of two supervisors.

3.5 Data Analysis

The Evaporative Cooler was evaluated for efficiency and effectiveness using existing storage methods as control, and data collected was analyzed using Gen stat 12.0.

CHAPTER 4

4.0 RESULTS

The results of the field experiment are presented on tables and charts under the different areas studied. Water requirement test (table 4.1), Saturation or cooling efficiency test Temperature and Humidity test (table 4.2 and figure 4.2), and Temperature response test for fruits (tables 4.4 and 4.5, and figures 4.4 and 4.5) are the areas covered in the results of the experiment.

4.1 Evaluation of the evaporative cooler

4.1.1 Test number 1: Water requirement test of the evaporative cooler

Table 4.1 shows results from the water requirement test of the evaporative cooler. The results indicate that the average water requirement of the cooler is 8.79 liters per hour. It also shows that 82% (40.5 liters) is evaporated.

Table 4.1: Water requirement test of the evaporative cooler

Time of application	Quantity of water applied to wall(litre)	Quantity of Runoff collected(litre)	Quantity of water evaporated (litre)	%of runoff water	% of water evaporated	hours
6:00am	50	10	40	20	80	0
12:10pm	48	7.5	40.5	15	80.4	6.1
6:00pm	50	9	41	18	82	5.9
6:00am	50	8	42	16	84	0
12:10pm	48	9	39	18.8	81.5	6.1
6: 00pm	50	10	40	20	80	5.9
Average	**49.2**	**8.7**	**40.5**	**17.875**	**82**	**5.6**

Source: Field experiment

4.1.2Test number 2: Cooling or Saturation efficiency test

Table 4.2 is the result of the cooling or saturation test carried out to determine the cooling efficiency of the evaporative cooler for two days. The results indicated that the average day time dry bulb temperature of the ambient air is 31°C and that of the working air is 23.8°C with a wet bulb depression of 8.3. With a temperature drop of 7.6°C, the cooling efficiency, which is a ratio of the temperature drop and wet bulb depression, is 0.91.

Table 4.2: Cooling and saturation efficiency

Time (2 hourly)	**Ambient air temperature (°C)**			**Working air temperature (°C)**		
	Dry bulb (Tdb)	**Wet bulb (Twb)**	**Wet bulb depression**	**Dry bulb (Tdb)**	**Wet bulb (Twb)**	**T°C drop**
6am	24.6	17.8	6.2	18.4	16.2	5.6
8am	25.6	19.6	6.0	19.7	15.5	5.9
10am	30.3	23.8	6.5	23.7	19.2	6.6
12pm	38.8	30	8.8	28.6	24.5	10.2
2pm	41.1	29	12.1	31.2	25	9.9
4pm	33.2	24	9.2	26	21	7.2
6pm	27	18	9	19	15.2	8
Average	**31.4**	**24.6**	**8.3**	**23.8**	**20.2**	**7.6**

Source: Field experiment April 2013

Figure 4.1 is a line chart illustrating the temperature drop between the working air and the product air dry bulb temperatures.

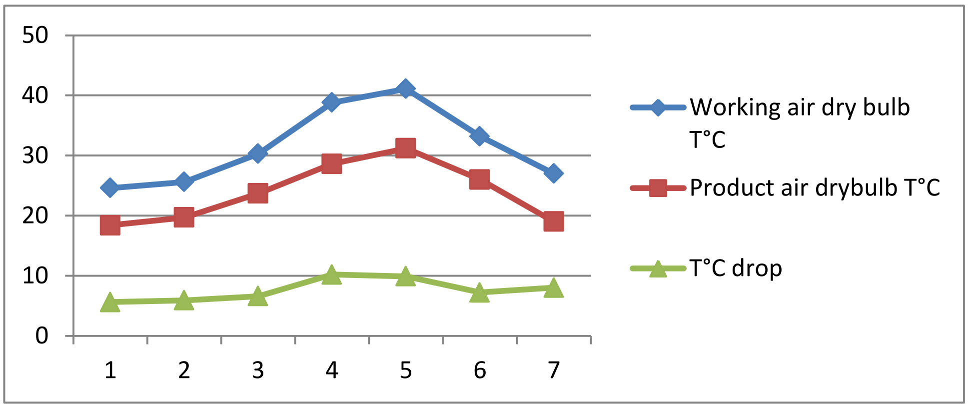

Figure 4.1. Temperature drop pattern

Source: Field experiment 2013

4.1.3 Test Number 3: Temperature and Humidity test

Table 4.3 is the results from the temperature and humidity test conducted on the evaporative cooler. The data indicate that the temperature inside the cooler was 3.7°C lower than the temperature in the rooms used as storage for mango fruits. It also shows that there was an increase in relative humidity by 9.6%.

Table 4.3: Temperature and Humidity test

DATE	Time	Room Temperature (°C)			Temperature inside cooler (°C)			Relative humidity (%)	
26/27-04-2013		**Dry bulb**	**Wet bulb**	**Wet bulb depression**	**Dry bulb**	**Wet bulb**	**Wet bulb depression**	**Room**	**Inside cooler**
	6am	22.2	17.6	4.6	18.4	16.2	2.2	65	85
	8am	23.7	18.7	5.0	19.7	15.5	4.2	61	68
	10am	27	21.6	5.4	23.7	19.2	4.5	59	64
	12pm	32	27.3	4.7	28.6	24.5	4.1	58	62
	2pm	34	25.4	8.6	31.2	25	6.2	48	60
	4pm	30	21	9.0	26	21	5	44	63
	6pm	24	19.7	4.3	19	15.2	3.8	62	65
	Average	**27.5**	**21.6**	**5.9**	**23.8**	**20.2**	**4.2**	**56.7**	**66.3**

Source: Field experiment April 2013

Figure 4.2 is a line chart that shows the aerodynamics inside the room and the cooler

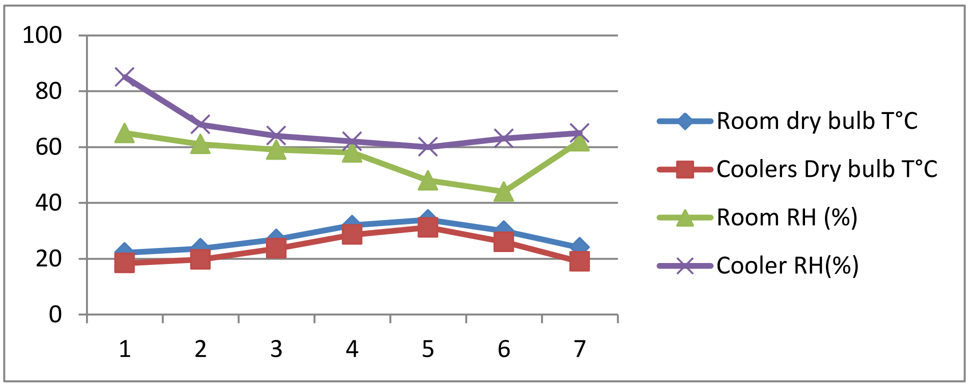

Figure 4.2.The aerodynamics of room and evaporative cooler

4.1.5 Test number 4A:Temperature Response test for 600Jaffna Mango Fruits harvested matured green

Figure4.4 shows the results of the temperature response of 600 Jaffna mango fruits (300 stored under room conditions and 300 stored in the cooler) stored over a number of days. Out of 300 fruits stored in the room, 209 got ripened for consumption in 11 days as against 260 out of 300 stored in the cooler in17 days. It also indicates that within the same period 88 of the fruits stored in the room got rotten as against 40 fruit stored in the cooler.

Table 4.4: Temperature Response test for 600Jaffna Mango fruits

Day	Skin colour (Number yellowing)		Number of Shriveled fruits		Number of rotten fruits	
	Room	**Cooler**	**Room**	**Cooler**	**Room**	**Cooler**
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	8	0	0	0	0	0
5	8	6	5	0	4	0
6	17	8	6	0	7	0
7	18	5	8	0	9	0
8	22	6	0	0	14	0
9	32	5	0	0	11	3
10	58	13	0	0	10	2
11	46	14	0	0	23	11
12	0	24	0	0	13	7
13	0	22	0	0	0	8
14	0	31	0	0	0	4
15	0	48	0	0	0	2
16	0	42	0	0	0	2
17	0	36	0	0	0	1
18	0	0	0	0	0	0
19	0	0	0	0	0	0
20	0	0	0	0	0	0
21	0	0	0	0	0	0
TOTAL	**209**	**260**	**19**	**0**	**88**	**40**
***** Increase in number of ripe fruits**			**51**			

Source: Field experiment April 2013

Figure 4.3 is a line chart that shows the temperature response of 600 Jaffna mangoes.

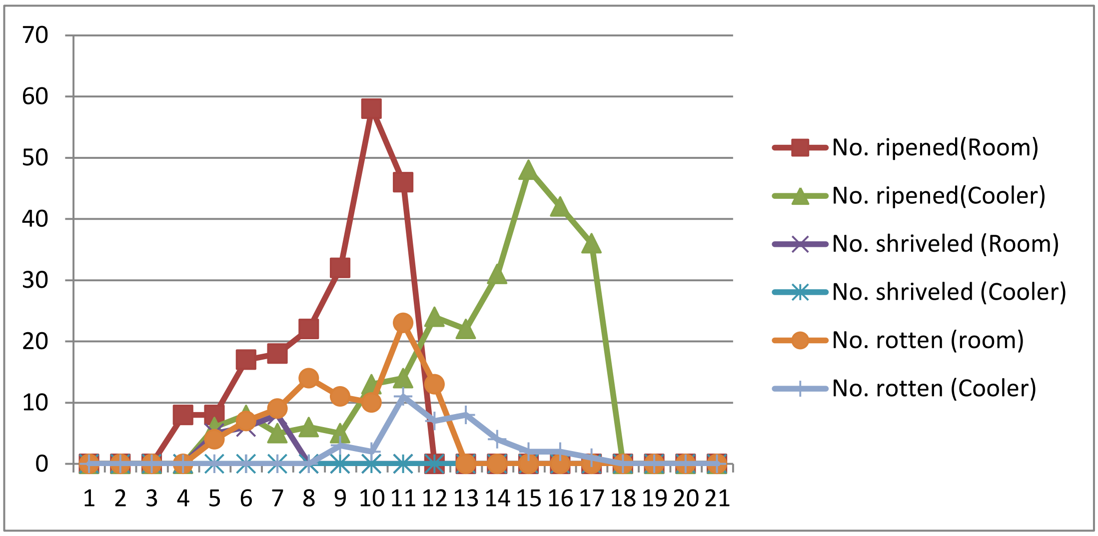

Figure 4.3.Temperature Response test for 600Jaffna Mango fruits

4.1.5 Test number 4B: Temperature Response test for 600 Keitt Mango Fruitsharvested matured green

Table 4.5 below show the results of the temperature response of 600 Keitt mango fruits (300 stored under room conditions and 300 stored in the cooler) stored over a 21 day period. Out of 300 fruits stored in the room, 173 got ripened for consumption in 8 days as against 219 out of 300 stored in the cooler in13 days. It also indicates that within the same period 101 of the fruits stored in the room got rotten as against 81 fruit stored in the cooler.

Table 4.5: Temperature Response test for 600 (Keitt) Mango Fruits

Day	Skin colour (Number yellowing)		Number of Shriveled fruits		Number of rotten fruits	
	Room	**Cooler**	**Room**	**Cooler**	**Room**	**Cooler**
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	28	0	0	0	4	0
4	34	11	0	0	16	0
5	38	9	4	0	25	2
6	32	19	3	0	21	7
7	26	26	9	0	27	16
8	15	33	0	0	18	15
9	0	31	0	0	0	19
10	0	29	0	0	0	17
11	0	27	0	0	0	2
12	0	22	0	0	0	3
13	0	12	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	0	0	0	0	0	0
17	0	0	0	0	0	0
18	0	0	0	0	0	0
19	0	0	0	0	0	0
20	0	0	0	0	0	0
21	0	0	0	0	0	0
TOTAL	**173**	**219**	**16**	**0**	**111**	**81**
***** Increase in number of ripe fruits**			**46**			

Source: Field experiment April 2013

Figure 4.4 is a line chart that shows the temperature response of 600 Keitt mangoes.

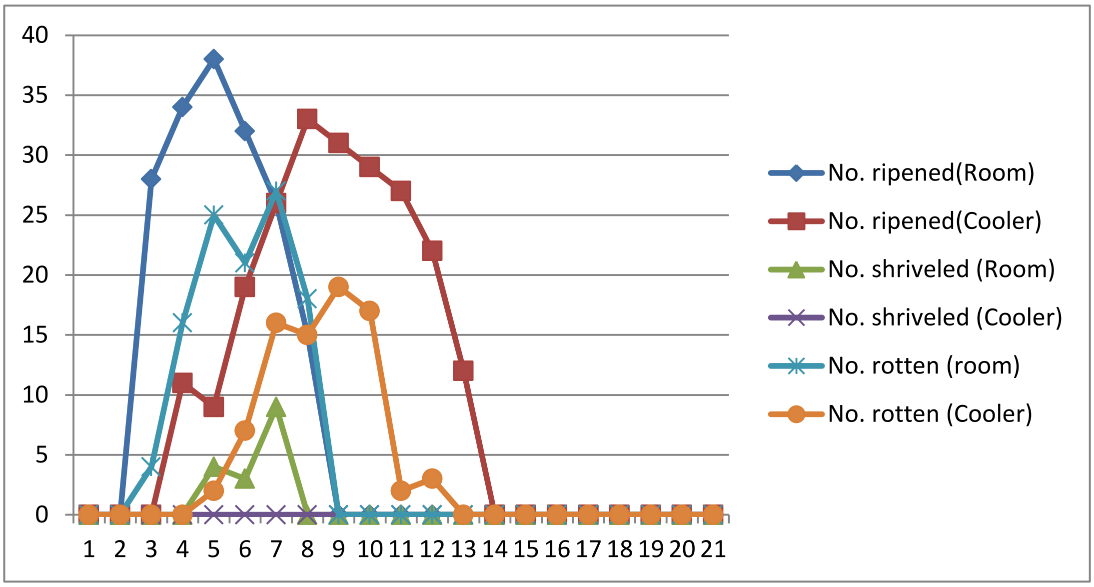

Figure 4.4.Temperature Response test for 600Keitt Mango fruits

Figure 4.5 is a line chart that compares the temperature response of Keitt and Jaffna mangoes. It indicates that 38 Keitt fruit ripened on the fifth day in the room storage as against 8 during the same period and 9 got ripened in the evaporative cooler as against 6.

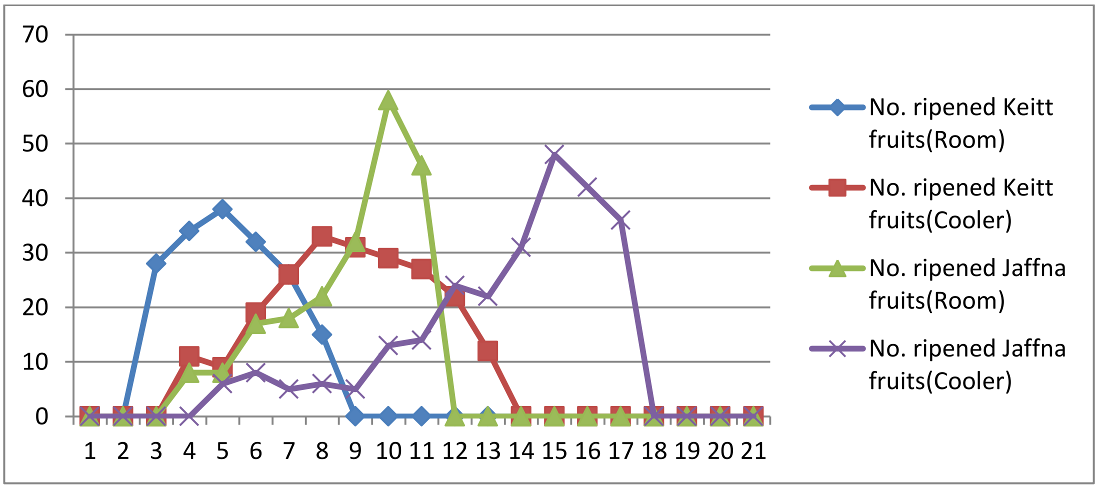

Figure 4.5. Comparing the temperature Responses of Keitt and Jaffna Mango fruits

CHAPTER 5

5.0 DISCUSSION

The results from the water requirement test of the evaporative cooler showed that an average of 8.79 litres of water was applied to the charcoal wall every hour to make the cooler operational. This shows that 148 litres of water was consumed daily for effective functioning of the cooler, indicating a high water consumption rate which is consistent with the statement by Mawuna and Odey, (2012) that charcoal has a poor water holding capacity (0.5).

The experiment indicated that even though the cooler consumes much water daily, it is able to evaporate much of the water applied (82%) for effective cooling. According toMartin and Mary, (1991)the cooling process works on the principle of evaporation of moisture. Charcoal granules are porous (cannot hold water for long) (Mawuna and Odey ,2012) but have larger individual surface areaand low air flow resistance for evaporation of moisture. This makes drip cooling effective as the phenomenon is largely dependent on cooling pads that have maximum clean wet surface with a minimum air flow resistance (Mawuna and Odey ,2012).

The water supply system in the Bawku West District can support this project as in some communities (Komaka), farmers reported year round flow of water from springs at the foot slope of the green hill separating Ghana from Burkina-Faso (MOFA, 2011).

The data further indicated that there was a decrease in the quantity of the water applied to the charcoal wall after six (6) hours of the first application and during that period there was anincrease in ambient temperature of about 14.2℃ (24.6°C to

38.8°C). This was mainly due to the fact that the charcoal wall was saturated with water after the first application and the temperature increase during the period was gradual resulting inlow evaporation (0.4%). However, after the second application (between 12:00pm to 6:00pm), the quantity of water increased by 2 litres (from 48 litres to 50 litres). During the period, there was a small increase in ambient temperature (2.3 °C). This increase was drastic and its falling from 41.1°Cto 27 °C was slow giving rise to a long period of evaporation, hence a water evaporation increase of 1.6% (80.4% to 82%).

The aerodynamics of the ambient air and the air inside the cooler (working air) were also recorded during the cooling or Saturation efficiency test. The day time dry bulb and wet bulb temperatures were taken precisely. The thermometers were read at two (2) hourly intervals and reading recorded from 6:00am to 6:00pm each day for two days. The results showed that the average daily day time dry bulb temperature of the ambient air during the experimental period is 31.4 °C, and that of the working air is 23.8 °C. This resulted in a temperature drop of about 7.6 °C. It also indicates that the average wet bulb temperature of the ambient air is 24.6 °C. Since the wet bulb depression of the ambient air is the difference between its dry bulb and wet bulb temperatures and the cooling or saturation efficiency is the ratio of the temperature drop and the wet bulb depression (Bhatia 2012), the evaporation cooler has a cooling or saturation efficiency of 0.91 (91% when expressed as percentage).

Sama*et al.* (2009) stated that the saturation efficiency of a cooler has an impact on water consumption. Increased Saturation efficiency is associated with higher water consumption. Therefore a Saturation efficiency of 91% explains the higher water consumption rate of the cooler observed during the water requirement test discussed above.

Reference to appendix B indicated that with a mean leaving air temperature of 23.8°C (66°F) and a cooler height of 2.5m, the air change per hour is about 10 – 15 AC/h. This has contributed to a large temperature drop resulting in a large cooling or saturation efficiency According to Bhatia(2012), experience has shown that significant benefit can be achieved with an air change per hour of 10 – 15 AC/h.

The evaporative cooler was compared with a standard room for the storage of mango during the temperature and humidity test. The room has a volume of 36.3m^3 (length 3.6m, width 3.6m and height2.8m). It is built with mud and roofed with corrugated iron sheets. It has a door opening of 0.8m × 2m and two windows of about 1m above the ground with 0.7m × 1m opening on two walls. The room is cement floored and windows are covered with mosquito nets. The room has a storage capacity of 6.2MT of mango fruits.

The result of the temperature and humidity test indicated that the temperature inside the evaporative cooler was 3.7 °C lower than that in the storage room and humidity inside the evaporative cooler was 9.6% higher than the humidity in the storage room.

The results indicated a 3.7 °C drop in air temperature inside the evaporative cooler compared with the air temperature inside the storage room. Though the average temperature of 23.8 °C inside the cooler is not optimum for the storage of mango (10 °C – 14 °C)Yahia(2005), it will minimize premature ripening and fruit damage which is the aim of the post harvest handling of mango (Gomez-Lim, 1997) and chillinginjuring due to low temperatures as mango has low tolerance to cool temperature s (< 10℃) (Gomez-Lim 1997). Most cultivars (Keitt and Haden) show chilling injury at temperatures below 10 °C especially if fruits have just reached maturity (Farzana, 2005).

Average humidities of 66.3% and 56.7% were recorded for the evaporative cooler and storage room respectively. This indicates that the relative humidity inside the cooler is 9.6% higher than the relative humidity inside the storage room. This means that mango fruits stored in the evaporative cooler will be maintained at a higher relative humidity than fruits stored in the storage room. According to Yahia (2005), lower relative humidity will promote water loss, shriveling, uneven ripening and quality deterioration.

With the humidity higher in the evaporative cooler than the room storage, a longer shelve life will be attained in the cooler than the storage room.

Two mango cultivars, Keitt and Jaffna, which are locally available, were used for the temperature and humidity response test. Six hundred (600) fruits from each cultivar were selected for storage in the storage room and evaporative cooler; Three hundred (300) fruits from each selected cultivar were stored in the storage room and the same in the evaporative cooler. These fruits were selected mature green.

The results indicated that the Jaffna mango fruits started ripening on the fourth day for fruits stored in the storage room and the fifth day for fruits stored in the storage cooler. Sign of rot was observed in fruits stored in the storage room on the fifth day and fruits stored in the evaporative cooler on the ninth day. Sign of moisture loss was also observed on the fifth day in fruits stored in the storage room.

A total of two hundred and nine (209) good quality ripened fruit were obtained at the end of eleventh day from the total number of stored in the storage room and two hundred and sixty (260) were obtained at the end of the seventeenth day from fruits stored in the evaporative cooler. Nineteen (19) out of the total number of fruits stored in the storage room showed signs of moisture loss as against zero (0) fruits stored in the evaporative cooler during the storage period. During the storage period, eighty-eighty (88) of the fruits stored in the storage room showed signs of rot, as against forty (40) fruits stored in the evaporative cooler.

The results also showed that, the Keitt mango fruits started ripening on the third day of storage for fruits stored in the storage room and on the fourth day for fruits stored in the evaporative cooler. Signs of rot were observed in the fruits stored in the storage room on the third day and on the fifth day in fruits stored in the evaporative cooler. Signs of moisture loss were observed only in fruits stored in the storage room on the fifth day of storage.

A total of one hundred and seventy three (173) good quality ripened fruits were obtained out of the total number of fruits stored in the storage room at the end of a storage period of eight (8) days, as against two hundred and nineteen (219) fruits out of the total number stored in the evaporative cooler at the end of a storage period of fifteen days. During the same period, nineteen (19) fruits out of the total number of fruits stored in the storage room showed signs of moisture loss with one hundred and eleven (111) fruits exhibiting signs of rot. For the same period of storage, eighty-one (81) fruits stored in the evaporative cooler showed signs of rot.

CHAPTER 6

6.0 CONCLUSIONS AND RECOMMENDATIONS

Mango is one of the most widely consumed fruit in the Bawku West District in. Its consumption will continue to expand through ages. As the trade in mango expands, and postharvest fungicides become less available, improved postharvest handling has led to the development of new storage and distribution systems for mango. The conventional evaporative cooler is cheap to construct and materials are locally available. It does not require complex skill and has less labour requirement. Even though the charcoal wall is porous and has a poor water holding capacity, it offers low resistance to air flow and individual granules have large surface area to hold water for evaporation.The evaporative cooler was able to reduce temperature by 3.7^{0}C and increased relative humidity by 9.6% compared to the traditional storage room.

Under these conditions, the percentage of good and consumable Jaffina and Keitt mango fruits stored in the evaporative cooler was 86.7% in 17 days and 73% in 13 days respectively, compared to 67.9% in 11 days and 57% in 8 days respectively for fruits stored in the traditional storage room.Loses obtained was high in the traditional storage room for the two mango cultivars than in the evaporative cooler. Therefore the storage life of mango was longer in the evaporative cooler compared to the traditional storage room.

Indeedmany technological procedures are used commercially as supplements to temperature management. None of these procedures alone or in their various combinations, can substitute for maintenance of optimum temperature and relative humidity, but they can help extend the shelf life of harvested produce beyond what is possible using refrigeration alone.It is therefore recommended that the experiment should be repeated in other mango producing areas with locally available materials to verify my conclusions.

It is also recommended that these evaporative coolers should be used to store mangoes at retail centers.

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APPENDIX A1

MEAN MONTHLY MAXIMUM AND MINIMUMTEMPERATURE IN THE BAWKU WEST DISTRICT

YEAR	2010		2011		2012	
MONTH	Max T(°c)	Min T (°c)	Max T (°c)	Min T (°c)	Max T (°c)	Min T (°c)
January	38.7	17.3	36.8	13.1	36.2	16.6
February	41.1	21.9	39.9	16.1	38.9	16.8
March	41.5	26.8	41.9	21	40.5	23.9
April	41.2	27.4	41.5	21.7	38.5	23.6
May	38.7	24.9	38.1	23.5	35.4	23.4
June	34.4	23.8	35.4	23.5	33.9	22.7
July	31.2	22.9	33	23.2	31.8	22.5
August	31.8	22.6	31.2	22.6	30.7	22.6
September	32	22.7	32.4	23.1	31.4	22.5
October	34.2	22.7	_	_	34.6	22.9
November	37.7	19.5	39.3	19.4	37.7	21.1
December	38.4	14	37.1	15.6	37.7	18.7

SOURCE: GHANA METEOROLOGICAL SERVICES DEPARTMENT - BOLGATANGA

APPENDIX A2

MEAN MONTHLY RELATIVE HUMIDITY IN THE BAWKU WEST DISTRICT

YEAR	2010		2011		2012	
MONTH	RH - 0600	RH - 1500	RH - 0600	RH - 1500	RH 0600	RH 1500
January	47	18	48	23	50	26
February	51	25	45	24	50	28
March	48	25	69	30	45	25
April	68	36	70	33	77	44
May	84	48	81	47	89	57
June	93	67	90	59	89	65
July	91	75	93	67	91	75
August	91	77	93	75	93	78
September	92	76	94	73	94	77
October	91	69			95	73
November	87	37	69	24	87	37
December	66	22	49	20	62	23

SOURCE: GHANA METEOLOGICAL SERVICES DEPARTMENT - BOLGATANGA

APPENDIX B

SIZING THE EVAPORATIVE COOLING EQUIPMENT

Leaving air temperature	Temperature over ambient [NOTE1]	Air changes/Hr[NOTE2]
Above 36°C	20 degrees (C)	30 to 60
34°C to 36°C	15 to 20	20 to 40
32°C to 34°C	10 to 15	15 to 30
30°C to 32°C	5 to 10	12 to 20
under 30 degrees (C)	less than 10	10 to 15

Note1 - Average indoor temperature over the outdoor temperature when evaporative coolingis not in use. For example, say in an industrial building due to occupancy, lighting andmachinery heat load the indoor temperature may rise to 20°F over ambient temperaturewithout any ventilation/evaporative cooling in place.

Note 2 - The air change column indicates a range of frequency and is used in determining air volume requirements (Bhatia, 2012).

Plate 1: Roofing the evaporative cooler

Plate 2: Structure of the Evaporative Cooler

Plate 3: Constructing the structure

Plate 4: Constructing the walls

Plate 5: Mango being washed for storage

Plate 6: Mango sorted after storage