DEVELOPMENT OF COOL STORAGE SYSTEM USING LOCALLY AVAILABLE MATERIALS FOR QUALITY PRESERVATION OF DRIED VEGETABLES

BY

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DECLARATION

I declare that the work in this thesis entitled **“DEVELOPMENT OF COOL STORAGE SYSTEM USING LOCALLY AVAILABLE MATERIALS FOR QUALITY PRESERVATION OF DRIED VEGETABLES”** has been carried out by me in the Department of Agricultural and Bio-Resource Engineering. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another higher degree at this or any other institution.

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DEDICATION

This work is dedicated to the Department of Agricultural and Bio-resources Engineering Ahmadu Bello University, Zaria –Nigeria.

CERTIFICATION

This thesis titled: **DEVELOPMENT OF COOL STORAGE SYSTEM USING LOCALLY AVAILABLE MATERIALS FOR QUALITY PRESERVATION OF DRIED VEGETABLES** by the author, ABUBAKAR Mohammed meets the regulations governing the award of doctor of philosophy (Agricultural Engineering) of Ahmadu Bello University and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

Food and Agricultural Organization of United Nations projected that Nigeria on the average loses $9billion annually to postharvest loss and waste of food. This losses and wastages occur as a result of in-adequacy of affordable and sustainable processing and storage mechanization technology. Among the food products, fruits and vegetables were found to be the most vulnerable .A cool storage system was designed and constructed with aim of mitigating dried vegetables losses and wastage. Surveys on dried vegetables and agricultural cold storages were conducted in the North Western region of Nigeria. Two cool rooms of 500kg dried vegetable capacity each were built using Laterite soils and Thatch grasses, soil classification and Atterberg limits tests were conducted using standard methods. A standard British mould (230x110x100mm) was used in moulding laterite soil blocks after 6% cement stabilization; the blocks were cured both in the shed and the sun for 14months in which its strengths were measured. Physical properties of the Thatch materials were determined, thermal conductivity of both Thatch and the stabilized blocks were also measured. Natural and artificial cooling methods were designed as a cooling medium for the rooms. Temperature and humidity mapping was carried out on the constructed rooms as no load test. Three dried vegetables; Baobab leaves, Okra and Tomato were dried using traditional method and a solar dryer then packaged in food grade polypropylene sheet and loaded into the rooms for load test after a statistical design, similar samples were kept in ordinary room as control. Room1 was set at air conditioner temperature of 20^{o}C while Room2 was set at a temperature of 25^{o}C, five quality indicating parameters: color, water activity, rehydration ratio, solid content and moisture contents were traced and tracked for four months starting from May using standard laboratory procedures. The survey results indicated that only fresh fish were stored in the region’s cold rooms and baobab leaves, okra and tomato are the most produced and stored dried vegetables in the region. The no load test showed that the inside Room1 temperature remains at 25^{o}C while the outside room temperature ranges between 18^{o}C to 41^{o}C, similarly Room2 inside temperature stood at 23^{o}C at the same condition of outside temperatures. That is at all outside temperature the inside temperature remains constant. The inside relative humidity of the rooms varies as that of the outside. By DMRT ranking, tomato and okra did not show significant color difference (5%level) for both storage temperatures and drying methods within the storage period but significant differences exist when compared with the controls. Baobab leaves colour differences were significant for all the storage samples (5% levels). The moisture content ranges between 6.5% and 9.0 %within the storage period of three months and then shot up to 13.9% in the month of August for Tomato and Okra. There was no significant difference in Fungal and Bacterial load on Tomato and Baobab but it existed in Okra (5% level) for the two storages. Water activity, rehydration ratio and solid content indicated stability at 0.05level of significance for all stored products except their controls. Within the storage period there was no significant difference in the quality indicating parameters measured for all the crops stored at 20^{o}C and 25^{o}C in the designed rooms at their packaging condition. During temperature mapping at natural cooling condition the rooms temperature remains constant (25^{o}C) for all outside temperatures, therefore the products can be stored without the need of artificial cooling (air conditioner). The research cost of storage per kilogramme of products was ₦20.56.

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LIST OF ABBREVIATIONS, SYMBOLS AND UNITS

Abbreviations

AC	Air Conditioner
AOAC	Association of Official Analytical Chemist
ASHRAE	American Society for Heating, Refrigeration and Air-conditioning Engineering
BI	Browning Index
BUK	Bayero University Kano
BS	British Standards
CFD	Computational Fluid Dynamics
CIL	International Colour Laboratory
CSEB	Compressed Soil Earth Block
CVS	Computer Vision System
DAC	Division of Agricultural Colleges
DB	Distribution Box
ERH	Equilibrium Relative Humidity
FAO	Food and Agricultural Organization of the United Nations
HoD	Head of Department
KFR	Karl Fischez Reagent
LPG	Liquefied Natural Gas
NEB	Non Enzymic Browning
ORP	Oxidation Reduction Potential
PG	Post Graduate
PH	Hydrogen Potential
PhD	Doctor of Philosophy
RR	Rehydration Ratio
SAS	Statistical Analysis System
USD	United State Dollar

Symbols

a_w	Water activity
a	Redness / Greenness
b	Yellowness / Blueness
^oC	Degree centigrade
C_p	Specific heat capacity
D	Diffusion
δ	Stress
E_a	Activation energy
ΔE	Change in colour
H_2	Hydrogen
K	Rate of reaction
L	Lightness / Blackness
LL	Liquid limit
N_2	Nitrogen
ƛ	Latent heat of vapourization
PL	Plastic limit
R	Ideal gas constant
ρ	Bulk density
Td	Dew poit temperature
Tdb	Dry bulb temperature
t	time
T	Tomato
TD	Tomato dried using dryer
TF	Tomato dried by farmers (traditional)
TD20	Tomato dried using dryer and stored at 20^oC
TD25	Tomato dried using dryer and stored at 25^oC

TDC	Tomato dried using dryer at controlled storage
KB	Okra
KBD	Okra dried using dryer
KBF	Okra dried by farmers (traditional)
KBD20	Okra dried using dryer and stored at 20^oC
KBD25	Okra dried using dryer and stored at 25^oC
KBDC	Okra dried using dryer at controlled storage
KK	Baobab
KKD	Baobab dried using dryer
KKF	Baobab dried by farmers (traditional)
KKD20	Baobab dried using dryer and stored at 20^oC
KKD25	Baobab dried using dryer and stored at 25^oC
KKDC	Baobab dried using dryer at controlled storage

Units

Quantity	**English Units**	**SI Unit**	**Conversion Factor Equalities**
Length	inch (in. –)	meter (m)	1 in. = 0.0254 m = 25.4 mm
foot	(ft .)	meter (m)	1 ft = 0.3048 m = 304.8 mm
mile	(mi U.S. statute)	kilometer (km)	1 mile = 1.609 km = 1609 m
Volume	gallon (gal U.S.)	meter3 (m3)	1gal = 0.003785 m3 = 3.785 liters
Force	(weight) pound (lb)	Newton (N)	1 lb = 4.448 N
Torque	pound-foot (lb ft)	Newton-meter (N m)	1 lb ft = 1.356 N m
Work, Energy	foot-pound (ft lb)	Joule (J)	1 ft lb = 1.356 J
Power	foot-pound/second	watt (W)	1 ft lb/s = 1.356 W
Horsepower	(hp)	kilowatt (kW)	1 hp = 0.746 kW
Stress,	pounds/in.2 (psi)	Pascale (Pa)	1 psi = 6895 Pa
Pressure	thousand pounds/in.2.	megapascal (MPa)	1 ksi = 6.895 MPa
Mass	(British) slug	kilogram (kg)	1 slug = 14.59 kg
Mass (English)	lbm	kilogram (kg)	1 lbm = 0.454 kg = 454 grams
Temperature	Degree Celsius	Kelvin	Celsius = Kelvin -273.15

CHAPTER ONE

INTRODUCTION

1.1 Background

Vegetables are important protective food for the maintenance of health and prevention of diseases. The production of vegetables has been recognized as the most affordable and accessible sources of micronutrients to millions of Nigerians. Vegetables value addition is increasingly regarded as a catalyst for rural development and as a means of increasing and generating foreign exchange in Nigeria (Kumar et al. 2010). Both leafy and non-leafy vegetables are produced, within which 20-45% of the production are lost annually along the post-harvest chain, despite the national consumption demand has not been met (FAO, 2016). Due to their perishability and out of season nature, sun or solar drying is employed by farmers and merchants for their preservation .Boabab leaves, Okra, and Tomato (in that order) are said to be the most produced and consumed dried vegetables in the North Western Region of Nigeria (Stanley,2017).These products can be spotted in our markets including super markets in the towns and cities within the region, more especially in Kano city(Plate1), vegetables are distributed within the other regions of Nigeria, also reported to be consumed across West African sub region (Ngbede *et al.*, 2014). Boabab leaves are harvested from Boabab tree which is a wild forest tree; its production is not yet documented (Heuze, 2016).Nigeria is the second largest producer of okra in the world with annual productions of up to 1.04 million metric tonnes (Kumar et al.,2010) and ranked thirteen in tomato production with annual production of 1.8 million metric tons (Leketty,2013).Many undesirable quality changes occur in the dried vegetable products during storage (Maskan, 2000, 2001). One of that is the color of products which is an important quality index concerning consumer acceptance (Dermesonlouoglou et al., 2007; De Sousa et al., 2008).

A common problem in dried vegetables is browning, and browned products are not attractive and are not desired by the consumers and can result to total value loss (Demirbüker et al., 2004; Cemeroğlu and Acar, 1986). Lycopene is the main colouring agent for the red colour of the tomatoes (D'Sousa et al., 2008; Lavelli and Scarafoni, 2011). Lycopene oxidation is reported to be the most important reason for the colour loss during storage of tomatoes (Demirbüker, 2001). Nguyen and Schwartz (1999) indicated that lycopene is susceptible to chemical changes when exposed to light and heat because of the presence of a long chain of conjugated carbon–carbon double bonds. Oxygen plays an important role on non-enzymatic or enzymatic browning of the vegetables products.

Deterioration mechanisms in dried foods that affect its quality are usually assumed to be dependent on these parameters: time, temperature, oxygen,light and moisture. These parameters constitute a storage condition that sometimes could be more hash to storage of fruits and vegetables in the tropical Africa. Indeed, fruits and vegetables are generally handled and stored in cool chain. Cooling significantly slows down the rate of deterioration, thereby increasing the storage life of the produce; therefore, the existing dried vegetables storage in market shops/shades practiced by Nigerian vegetable farmers and merchants can not address the hazard of the above-mentioned parameters (Plate2). Cold storage is essential for vegetable farmers to preserve produce quality and extend the revenue period. A cool store is a structure that operates at a controlled temperature above freezing point. This work is centered towards the storage of the three mentioned crops above taking cognizance of tomato to be the only climacteric crop within.

Plate1.1: A display of dried Tomato and Pepper dried in Jifatu Super Market in Kano

Plate 1. 2: Market stall method of storing Tomato, Okra and Pepper

December, 2019 (N8.9/kg)

January,2019 up (N700/kg) (Dried)

January,2019up

August2019 (N50/kg)

Plate 1.3: Minimal processing Pattern of Tomatoes

1.2 Problem Statement

Nigerian vegetable supply chain produces about 3.0 million metric tons of Tomato and Okra annually (FAO, 2016). During full production season gluts are said to be experienced which tends to lower the prices of both crops. There is no functional processing facility in the country that mop out the excess supply (Merchet, 2001). As such, farmers resorted to preserve the excess through open sun/solar drying. The Baobab leaves are wildly harvested from the forest tree and are culturally consumed in powdery form. The leaves are harvested during its full season and sun dried. At the end of the drying, the dried leaves of these trees are often packaged in used grains bags and stored in home rooms and market stalls for lean and out of season markets where prices are high. Products will be in store for the heat period of month of March-May and rain period of May- August. The lean period sales of these products begin by mid-May and the out of season sales begins by mid of June and end by August. The price trend during the sales indicated a price rise during lean sales to the early out of season sales, but prices fall as the rain period increases as a result of quality deterioration. By September the products deterioration reaches its peak and lead to off shelf condition. Deterioration mechanisms in dried foods that affect its quality are usually assumed to be dependent on these parameters: time of storage, temperature, oxygen, light and moisture. Therefore, the value addition model used by these farmers cannot adequately mitigate the wastages of these vegetables (Fig.1.3). Dried Baobab leaves powder and dried okra has been spotted in Europe, America and Middle East by some Nigerians that visited those areas. In Europe alone, the dried vegetables market volume has reached 11.5 billion euro (Derossi et.al, 2009). Nigerian dried vegetables value addition model cannot compete with India, China, Kenya, Chad, in international markets. However, an improved storage system that can control the deteriorative parameters is necessary.

1.3 Aim and Objectives

Aim: The aim of the study is to mitigate the losses and wastages of dried vegetables products in the North Western Nigeria

Objectives: The objectives to achieve the aim are as follows;

1. To conduct a baseline survey on dried vegetables and agricultural cold storage facilities in North Western Zone of Nigeria.
2. To select appropriate walling and insulation materials suitable for construction of cool storage.
3. To design and construct an appropriate cool storage system for dried vegetables.
4. To conduct performance evaluation of the cool storage system

1.4 Justification for the Study

Developing a sustainable storage system that can effectively preserves quality of dried vegetables at optimum energy consumption will benefit vegetables farmers, merchants and the nation, through:

(i) Increase in the income of vegetable farmers and merchants

(ii) Increase availability of vegetables to consumers

(iii) Reduce the post-harvest losses of vegetables

(iv) Create employment through storage service providing

(v) Provides quality raw materials to pharmaceutical and poultry industries

(vi) Ensure environmental sustainability (preventing greenhouse gases from vegetable waste)

1.5 Scope of the Study

The dried vegetables considered in this study are the first three most used vegetables as identified by objective 1. The storage structure shall be tested before loading the vegetable products and while loaded.

CHAPTER TWO

LITERATURE REVIEW

2.1 Food Preservation

Preservation is a means of protecting a product, usually against microbiological deterioration. It is important to understand the differences between biotic deterioration, which refers to changes in a food product brought about either by a biological function (e.g., ripening of fruit, respiration of vegetables) or attack by microorganisms (e.g., molds, bacteria, and yeasts) and abiotic deterioration, which is brought about by physical or chemical agents (e.g., atmospheric O_2, moisture, light, odours, and temperature). Both biotic and abiotic deterioration can lead to food spoilage.

2.1.1 Food quality and safety

The term “food quality” has a variety of meanings to professionals in the food industry, but the ultimate arbiters of food quality must be the consumers. This notion is embodied in the frequently cited definition of food quality as “the combination of attributes or characteristics of a product that have significance in determining the degree of acceptability of the product to a user.” Another definition of food quality is “the acceptance of the perceived characteristics of a product by consumers who are regular users of the product category or those who comprise the market segment.” The phrase “perceived characteristics” includes the perception of the food’s safety, convenience, cost, value, and so on, and not just its sensory attributes (Cardello, 1998).

For the majority of foods and beverages, quality decreases over time. Therefore it follows that there will be a definite length of time before the product becomes unacceptable. This time from production to unacceptability is referred to as shelf life (Anonymous.1993). Quality loss during storage may be regarded as the result of a form of processing at relatively low temperatures that goes on for rather a long time. Knowledge of the kinds of changes that influence food quality is the first step in developing food packaging that will minimize undesirable changes in quality and maximize the development and maintenance of desirable properties. Once the nature of the reactions is understood, knowledge of the factors that control the rates of these reactions is necessary in order to minimize the changes occurring in foods during storage, that is, while packaged.

The nature of the deteriorative reactions in foods and the factors that control the rates of these reactions will be briefly outlined. Deteriorative reactions can be enzymic, chemical, physical (typically as a result of moisture gain or loss), and biological (both microbiological and microbiological). Biochemical, chemical, physical, and biological changes occur in foods during processing and storage, and these combine to affect food quality. The most important quality-related changes are (van Boekel, 2008) as follows:

i) Chemical reactions, mainly due to either oxidation or non-enzymic browning reactions.

ii) Microbial reactions: microorganisms can grow in foods. In the case of fermentation this is desired; otherwise, microbial growth will lead to spoilage and, in the case of pathogens, to unsafe food.

iii) Biochemical reactions: many foods contain endogenous enzymes that can potentially catalyze reactions leading to quality loss (enzymic browning, lipolysis, proteolysis, and more).

In the case of fermentation, enzymes can be exploited to improve quality.

iv) Physical reactions: many foods are heterogeneous and contain particles. These particles are unstable, and phenomena such as coalescence, aggregation, and sedimentation usually lead to quality loss. Also, changes in texture can be considered physical reactions, although the underlying mechanism may be of a chemical nature.

2.1.2 Deteriorative reactions in food

Intrinsic Parameters

Intrinsic parameters are an inherent part of the food and include water activity (*a*w), pH, oxidation reduction potential (*E*h), O_2 content, and product formulation, including the presence of any preservatives or antioxidants.

Water Activity

The parameter a_w is defined as the ratio of the water vapor pressure of a food to the vapor pressure of pure water at the same temperature. Mathematically: (Rockland, 1987)

$$a_w = p/p_o \tag{2.1}$$

where p is the vapor pressure of water exerted by the food and p_o is the saturated vapor pressure of pure water at the same temperature. This concept is related to equilibrium relative humidity (ERH) in that (Rockland, 1987)

$$\mathrm{ERH} = 100 \times a\mathrm{w}. \tag{2.2}$$

However, whereas *a*w is an intrinsic property of the food, ERH is a property of the atmosphere in equilibrium with the food. The *a*w of most fresh foods is above 0.99. Every microorganism has a limiting *a*w value below which it will not grow, form spores, or produce toxic metabolites (Rockland, 1987) .

Water can influence chemical reactivity in different ways. It may act as a reactant (e.g., in the case of sucrose hydrolysis), or as a solvent, where it may exert a dilution effect on the substrates, thus decreasing the reaction rate. Water may also change the mobility of the reactants by affecting the viscosity of the food systems and form hydrogen bonds or complexes with the reacting species. Thus, a very important practical aspect of *a*w is controlling undesirable chemical and enzymic reactions that reduce the shelf life of foods. It is a well-known generality that rates of changes in food properties can be minimized or accelerated over widely different values of *a*w. Small changes in *a*w can result in large changes in reaction rates. When a food is placed in an environment at a constant temperature and relative humidity (RH), it will eventually come to equilibrium with that environment, at steady state is referred to as the equilibrium moisture content. When this moisture content (Expressed as mass of water per unit mass of dry matter) is plotted against the corresponding RH constant temperature describes moisture sorption characteristics, a moisture sorption isotherm plots are very useful in assessing the stability of foods and selecting effective packaging. As *a*w is temperature dependent, it follows that moisture sorption isotherms must also exhibit temperature dependence. Thus, at constant moisture content (which is the situation existing in a food packaged (Robertson, 2006).

Oxidation-Reduction Potential

The oxidation-reduction potential (also referred to as the redox potential and abbreviated *E*h or ORP) is a physicochemical parameter that determines the oxidizing or reducing properties of the medium, and it depends on the composition of the food, pH, temperature, and, to a large extent, the concentration of dissolved O_2 (DO). *E*h plays an important role in the cellular physiology of microorganisms, such as growth capacity, enzyme expression, and thermal resistance. Alwazeer *et al*., (2003) demonstrated that reducing the *E*h of orange juice using gas (N_2 and H_2) immediately after heat treatment maximized microbial destruction during pasteurization, prevented the development of microorganisms, and stabilized color and ascorbic acid during storage at 15°C. The relationship between ORP values and DO levels in milk is not well understood. Several modifications that occur in milk during its processing and storage are driven by different oxidation-reduction reactions. Electrolysis treatments have been applied to milk to produce milk powder with better flavor quality. ORP and DO levels in enriched milk a re mainly responsible for the oxidation of unsaturated fatty acids and the loss of viability of probiotic strains such as bifidobacteria. Decreasing the *E*h in milk could allow an improvement in the quality of these products. Recent studies on electro reduction of milk by membrane electrolysis have shown that this electrochemical process decreased the *E*h of milk without changing the organoleptic and nutritive values (Schreyer et al., 2008).

Extrinsic Parameters

Extrinsic factors that control the rates of deteriorative reactions include temperature, RH, gas atmosphere, and light; packaging, to varying degrees, influence the impact of these factors on the rates of deteriorative reactions, depending on the specific packaging material.

Temperature

Temperature is a key factor in determining the rates of deteriorative reactions, and in certain situations the packaging material can affect the temperature of the food. This is particularly so with packaging materials that have insulating properties, and these types of packages are typically used for chilled and frozen foods. For packages that are stored in refrigerated display cabinets, most of the cooling takes place by conduction and convection. Simultaneously, there is a heat input by radiation from the fluorescent lamps used for lighting. Under these conditions, aluminum foil offers real advantages because of its high reflectivity and high conductivity.

Several models have been developed to represent the effect of temperature on the rates of deteriorative reactions.

Linear Model-This simple expression relating the rate of reactions and temperature has been used for many years: (Lindsay,2008)

$$k = k\mathrm{o}\ \mathrm{e}b(T-T\mathrm{o}) \qquad (2.3)$$

where

ko = rate at temperature To (°C) , initial

k = rate at temperature T (°C) , final

b = a constant characteristic of the reaction

e = 2.7183.

Arrhenius Relationship-The most common and generally valid relationship for the effect of temperature on the rates of deteriorative reactions is that of Arrhenius. The relationship in the integrated form is (Lindsay,2008)

$$k = k\mathrm{o}\ \mathrm{e}{-}E\mathrm{a}/\mathrm{R}T \tag{2.4}$$

where

k = rate constant for deteriorative reaction

ko = constant, independent of temperature (also known as the Arrhenius, pre-exponential, collision,
or frequency factor)

Ea = activation energy (J mol–1)

R = ideal gas constant (8.314 J K–1 mol–1)

T = absolute temperature (K)

The integrated relationship contains the inherent assumption that the activation energy and the pre-exponential factor do not change with temperature. Although this assumption is generally true, it is not universally so, and predictions based on this model sometimes fail when applied over a temperature span of greater than ~40°C. Furthermore, when the reaction mechanism changes with temperature, the activation energy may vary substantially. The value of Ea is a measure of the temperature sensitivity of the reaction, that is, how much faster the reaction will proceed if the temperature is raised. The activation energy depends on factors such as aw, moisture content, solids concentration, and pH.

ii)Temperature Quotient

Another term used to describe the response of biological systems to temperature change is the Q value, a quotient indicating how much more rapidly the reaction proceeds at temperature T_2 than at a lower temperature T_1. If Q reflects the change in rate for a 10°C rise in temperature, it is then called Q10. Mathematically: (Boekel, 2008)

$$Q10 \quad = KT10/KT \tag{2.5}$$

It can be shown that the rate of a deteriorative reaction at two temperatures is related to the shelf life ϴ at those two temperatures; that is: (Boekel, 2008)

$$KT\ \Theta\ (T) = \mathrm{K}T + 10\ \Theta\ (T{+}10) \tag{2.6}$$

where

ϴ (T) = shelf life at temperature T°C

(ϴ T+10) = shelf life at temperature (T + 10)°C

Therefore,

$$Q10 = \Theta(\mathrm{T})/\ \Theta\ (\mathrm{T}+ 10) \tag{2.7}$$

If the temperature difference is Δ rather than 10°C, the following equation can be used:

$$Q\ T = \Theta(\mathrm{T1})/\ \Theta\ (\mathrm{T2}) \tag{2.8}$$

iii) Relative Humidity

The RH of the ambient environment is important and can influence the *a*w of the food unless the package provides an excellent barrier to water vapor. Many flexible plastic packaging materials provide good moisture barriers, but none is completely impermeable, thus limiting the shelf life of low *a*w foods (Baner,2008).

Light

Many deteriorative changes in the nutritional quality of foods are initiated or accelerated by light. Light is, essentially, an electromagnetic vibration in the wavelength range between 4000 and 7000 A; the wavelength of ultraviolet (UV) light ranges between 2000 and 4000 A. The catalytic effects of light are most pronounced in the lower wavelengths of the visible spectrum and in the UV spectrum. The intensity of light and the length of exposure are significant factors in the production of discoloration and flavor defects in packaged foods. Modification of plastic materials can be achieved by incorporation of dyes or application of coatings that absorb light at specific wavelengths. Recently nano-sized particles of titanium dioxide have been incorporated into plastic films to absorb UVA and UVB rays. Glass is frequently modified by inclusion of color-producing agents or by application of coatings. In this way a wide range of light transmission characteristics can be achieved in packages made of the same basic material.

There have been many studies demonstrating the effect of packaging materials with different light-screening properties on the rates of deteriorative reactions in foods(Boekel,2008). Among the most commonly studied foods has been fluid milk, the extent of off-flavour development being related to the exposure interval, strength of light, and amount of milk surface exposed.

Enzymic Reactions

From a food packaging point of view, knowledge of enzyme action is essential to a fuller understanding of the implications of different forms of packaging. The importance of enzymes to the food processor is often determined by the conditions prevailing within and outside the food.

Control of these conditions is necessary to control enzymic activity during food processing and storage. The major factors useful in controlling enzyme activity are temperature, *a*w, pH, chemicals that can inhibit enzyme action, alteration of substrates, alteration of products, and preprocessing control. Three of these factors are particularly relevant in a packaging context. The first is temperature: the ability of a package to maintain a low product temperature and thus retard enzyme action will often increase product shelf life. The second important factor is *a*w, because the rate of enzyme activity is dependent on the amount of water available; low levels of water can severely restrict enzymic activities and even alter the pattern of activity. Finally, alteration of substrate (in particular, the ingress of O_2 into a package) is important in many O_2-dependent reactions that are catalyzed by enzymes, for example, enzymic browning due to oxidation of phenols in fruits and vegetables.

Chemical Reactions

Many of the chemical reactions that occur in foods can lead to deterioration in food quality (both nutritional and sensory) or the impairment of food safety. Such reaction classes can involve different reactants or substrates, depending on the specific c food and the particular conditions for processing or storage. The rates of these chemical reactions are dependent on a variety of factors amenable to control by packaging, including light, O_2 concentration, temperature, and aw. Therefore, the package can, in certain circumstances, play a major role in controlling these factors, and thus indirectly the rate of the deteriorative chemical reactions. The two major chemical changes that occur during the processing and storage of foods and lead to a deterioration in sensory quality are lipid oxidation and nonenzymic browning (NEB). Chemical reactions are also responsible for changes in the color and favor of foods during processing and storage.

Lipid Oxidation

Autoxidation is the reaction of molecular O_2 by a free radical mechanism with hydrocarbons and other compounds. The reaction of free radicals with O_2 is extremely rapid, and many mechanisms for initiation of free radical reactions have been described. The crucial role that autoxidation plays in the development of undesirable flavors and aromas in foods is well documented, and autoxidation is a major cause of food deterioration. Factors that influence the rate and course of oxidation of lipids are well known and include light, local O_2 concentration, high temperature, the presence of catalysts (generally transition metals such as iron and copper, but also heme pigments in muscle foods), and aw. Control of these factors can significantly reduce the extent of lipid oxidation in foods.

Non-enzymic Browning

Non-enzymic browning (NEB) is one of the major deteriorative chemical reactions that occur during storage of dried and concentrated foods. The NEB, or Maillard, reaction can be divided into three stages: (1) early Maillard reactions involving a simple condensation between an aldehyde (usually a reducing sugar) and an amine (usually a protein or amino acid) without browning; (2) advanced Maillard reactions that lead to the formation of volatile or soluble substances; and (3) final Maillard reactions leading to insoluble brown polymers.

Colour Changes

Acceptability of colour in a given food is influenced by many factors, including cultural, geographical, and sociological aspects of the population. However, regardless of these many factors, certain food groups are acceptable only if they fall within a certain colour range. The color of many foods is due to the presence of natural pigments such as chlorophylls, anthocyanins, carotenoids, flavonoids, and myoglobin.

Flavour Changes

In fruits and vegetables, enzymically generated compounds derived from long-chain fatty acids play an extremely important role in the formation of characteristic flavours. In addition, these types of reactions can lead to important off-flavours. Enzyme-induced oxidative breakdown of unsaturated fatty acids occurs extensively in plant tissues, and this yields characteristic aromas associated with some ripening fruits and disrupted tissues (Lindsay, 2008).Fats and oils are notorious for their role in the development of off-flavours through autoxidation. Aldehydes and ketones are the main volatiles from autoxidation, and these compounds can cause painty, fatty, metallic, papery, and candle like flavours in foods when their concentrations are sufficiently high. However, many of the desirable flavours of cooked and processed foods derive from modest concentrations of these compounds. The permeability of packaging materials is of importance in retaining desirable volatile components within packages and in preventing undesirable components entering the package from the ambient atmosphere.

Nutritional Changes

In addition to the chemical changes described earlier, which may have a deleterious effect on the sensory properties of foods, there are other chemical changes that can affect the nutritive value of foods. The four major factors that influence nutrient degradation and can be controlled to varying extents by packaging are light, O_2 concentration, temperature, and aw. However, because of the diverse nature of the various nutrients as well as the chemical heterogeneity within each class of compounds and the complex interactions of these variables, generalizations about nutrient degradation in foods are unhelpful.

Physical Changes

The physical properties of foods can be defined as those properties that lend themselves to description and quantification by physical rather than chemical means and include geometrical, thermal, optical, mechanical, rheological, electrical, and hydrodynamic properties. Geometrical properties encompass the parameters of size, shape, volume, density, and surface area as related to homogeneous ood units, as well as geometrical texture characteristics. Although many of these physical properties are important and must be considered in the design and operation of a successful packaging system, in the present context the focus is on undesirable physical changes in packaged foods. The major undesirable change in food powders is the sorption of moisture as a consequence of an inadequate barrier provided by the package, resulting in caking. This can occur as a result either of poor selection of packaging material in the first place or of failure of the package integrity during storage. Caking or spontaneous agglomeration of food powders (especially those containing soluble components or fats) occurs when they are exposed to moist atmospheres or elevated storage temperatures. The phenomenon can result in anything from small soft aggregates that break easily to rock-hard lumps of variable size to solidification of the whole powder. For foods containing solid carbohydrates, the greatest effect in physical properties results from sorption of water; such changes can occur in boiled sweets (leading to stickiness or graining) and milk powders (leading to caking and lumpiness).

Microbiological Changes

Microorganisms can make both desirable and undesirable changes to the quality of foods, depending on whether they are introduced as an essential part of the food preservation process (e.g., as inocula in food fermentations) or arise adventitiously and subsequently grow to produce food spoilage. In the latter case, they reach readily observable proportions only when they are present in the food in large numbers. As the initial population or microbial load is usually small, observable levels are reached only after extensive multiplication of the microorganisms in the food. The two major groups of microorganisms found in foods are bacteria and fungi, the latter consisting of yeasts and molds. Bacteria are generally the fastest growing, so in conditions favorable to both, bacteria will usually outgrow fungi. The phases through which the two groups pass are broadly similar: a period of adjustment or adaptation (known as the lag phase) is followed by accelerating growth until a steady, rapid rate (known as the logarithmic phase, because growth is exponential) is achieved. After a time the growth rate slows until growth and death are balanced and the population remains constant (known as the stationary phase). Eventually, death exceeds growth and the organisms enter the phase of decline.

The species of microorganisms that cause the spoilage of particular foods are influenced by two factors: the nature of the foods and their surroundings. These factors are referred to as intrinsic and extrinsic parameters and were discussed earlier. Every microorganism has a limiting *a*w value below which it will not grow, form spores, or produce toxic metabolites. Water activity can influence each of the four main growth cycle phases by its effect on the germination time, the length of the lag phase and the growth rate phase, the size of the stationary population, and the subsequent death rate. Generally, reducing the *a*w of a given food increases the lag period and decreases the growth rate during the logarithmic phase, the maximum of which becomes lower.

Whether a microorganism survives or dies in a low aw environment is influenced by intrinsic factors that are also responsible for its growth at higher aw. These factors include water-binding properties, nutritive potential, pH, *E*h, and the presence of antimicrobial compounds.

Microbial

Growth and survival are not entirely ascribed to reduce *a*w but are also attributable to the nature of the solute (Rockland,1987). Key extrinsic factors relating to *a*w that influence microbial deterioration in foods include temperature, O_2, and chemical treatments. These factors can combine in a complex way to encourage or discourage microbial growth.

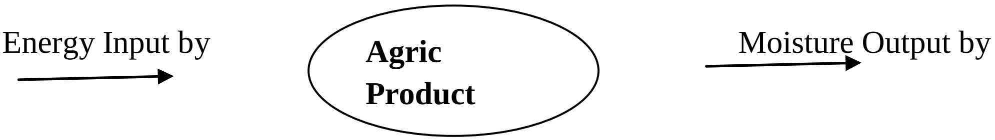
Microbiological changes due to the growth of microorganisms are desirable in fermentation but are mostly undesirable in other environments, because microbial growth may lead to spoilage and even health-threatening situations when pathogens come into play. The ability to predict growth of bacteria in foods is very important in predicting shelf life. A frequently used growth model is the modified Gompertz model, the temperature of storage is particularly important, and several food preservation techniques (e.g., chilling) rely on reducing the temperature of the food to extend its shelf life. Although there is a very wide range of temperatures over which the growth of microorganisms has been reported (–34°C to 90°C), specific microorganisms have relatively narrow temperature ranges over which growth is possible. Molds are able to grow over a wider range of temperature than bacteria, with many being capable of growth at refrigerator temperatures. The presence and concentration of gases in the environment has a considerable influence on the growth of microorganisms. Most food pathogens do not grow at refrigerator temperatures, and $CO_2$is not highly effective at non-refrigeration temperatures. Therefore, most MAP food is usually held under refrigeration. Temperature abuse of the product (i.e., holding at non-refrigerated temperatures) could allow the growth of organisms (including pathogens) that were inhibited by CO_2 during storage at lower temperatures. For these reasons, it is difficult to evaluate MAP safety solely on the growth of certain pathogens at abusive temperatures.

2.2 Drying of Agricultural Products

Drying is removal of a liquid from a solid/semi-solid/liquid to produce solid product by thermal energy input causing phase change (Sometimes converts solid moisture into vapor by sublimation eg. Freeze drying with application of heat.).Needed for the purpose of preservation, storage, reduction in cost of transportation, value addition, etc. Most common and diverse operation with over 100 types of dryers in use and competes with distillation as the most energy-intensive operation(Mujundar,2011).

2.2.1 Basics about drying

Simultaneous heat and mass transfer:



Conduction
Convection
Radiation
Microwave and Radio Frequency Fields
Combined mode

Liquid diffusion
Vapor diffusion
Capillary flow (Permeability)
Knudsen diffusion (Mean free path < pore dia.)
Surface diffusion
Poiseuille flow
Combination of above

Drying a complex process

As a result of drying agricultural products is bound to pass through several change processes as shown in the chart below.

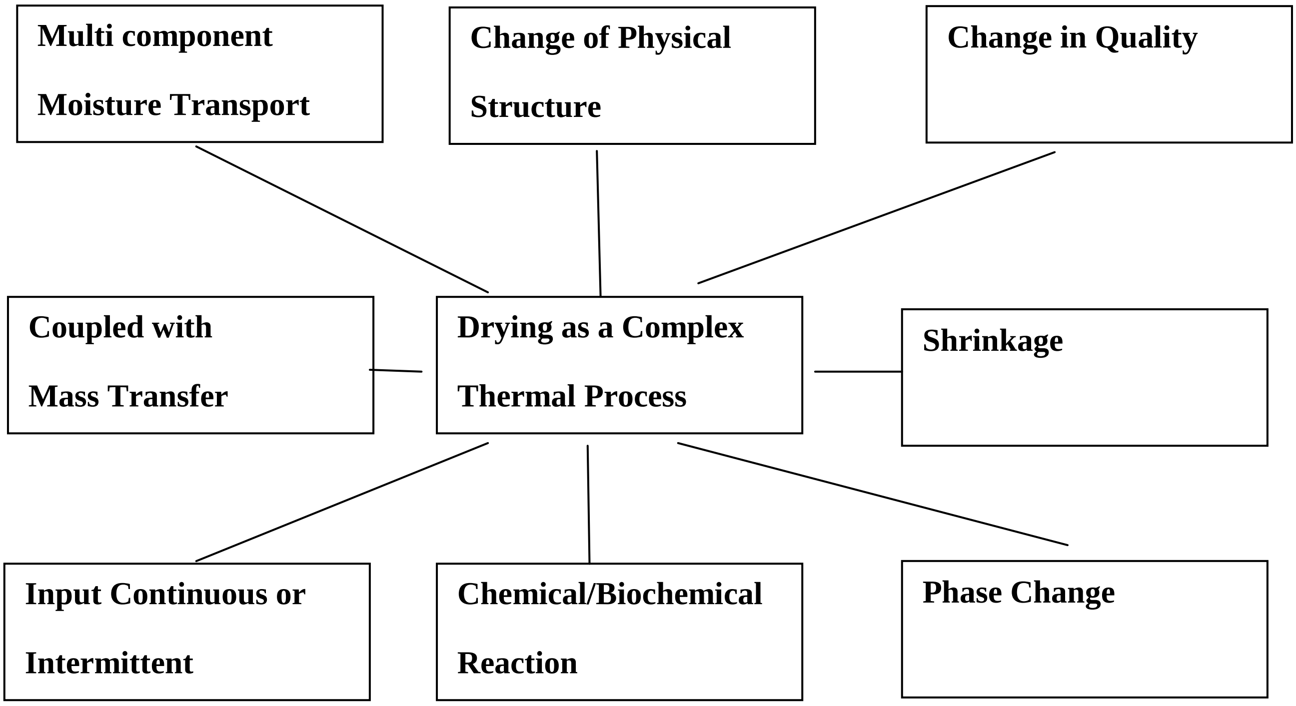
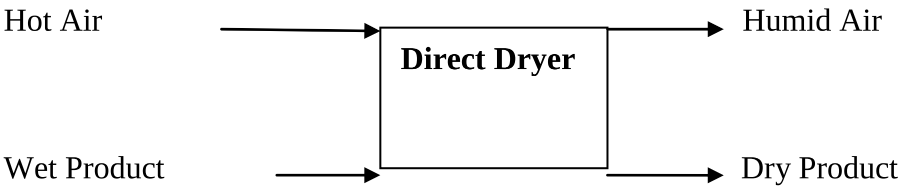


Figure2.1 Change processes during drying

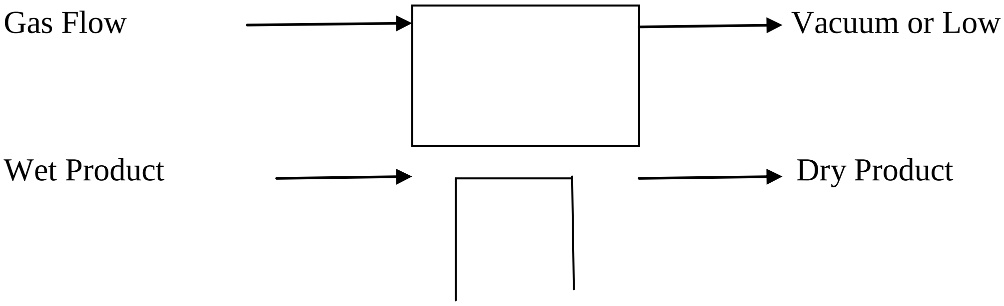
Drying based on heat input

Direct



Drying medium directly contacts material to be dried and evaporated moisture is carried out leaving the dried product.

Indirect (contact or conduction)



Heat supplied by heat exchanger (through metal wall).

2.2.2 Common terminology used in drying

Table 2. 1 Drying Technology

Terms/Symbol	Meaning
Adiabatic saturation temperature, Tad	Equilibrium gas temperature reached by unsaturated gas and vaporizing liquid under adiabatic conditions. Only for air/water system, it is equal to the wet bulb temperature
Bound moisture	Liquid physically and/or chemically bound to solid matrix so as to exert a vapor pressure lower than that of pure liquid at the same temperature
Constant rate drying period,	Under constant drying conditions, drying period when evaporation rate per unit drying area is constant (when surface moisture is removed
Dew point, Td	Temperature at which a given unsaturated air-vapor mixture becomes saturated

Dry bulb temperature, Tdb	Temperature measured by a (dry) thermometer immersed in vapor-gas mixture.
Equilibrium moisture content, Xe	At a given temperature and pressure, the moisture content of moist solid in equilibrium with the gas-vapor mixture (zero for non-hygroscopic materials)
Critical moisture content, Xc	Moisture content at which the drying rate first begins to drop (under constant drying conditions)
Falling rate period NF	Drying period under constant drying conditions during which the rate false continuously with time
Free moisture,	Moisture content in excess of the equilibrium moisture content (hence free to be removed) at given air humidity and temperature.
Drying bed	A column of agric. product in a dryer, it poses surface area and a depth(defines thin layer or deep bed drying)

Source : Mujundar, 2011

2.2.3 Drying theory

Drying involves simultaneous application of heat and mass transfer from and to the drying material respectively. During the drying process, the drying air supplies the necessary sensible and latent heat of evaporation to the moisture and also carries the water vapor from the surface. In drying, it is usually desired to estimate the size of dryer; the various operating conditions of humidity and temperature of drying air; and time required for the drying operation. These parameters and many others which influence the drying rate are interrelated by using empirical relationships. However, empirical relationships for most agricultural materials are not available and have to be obtained experimentally. To experimentally determine the rate of drying (drying kinetics) for a given material (e.g. fruits), a sample is placed on a tray, which is placed on a balance in a cabinet through which drying air is flowing. The loss of weight during drying is recorded and the data can be presented in form of curves as shown in Figure 1. A study of these curves show that in a drying circle can be considered to consist of a number of stages (Mujundar, 2011).

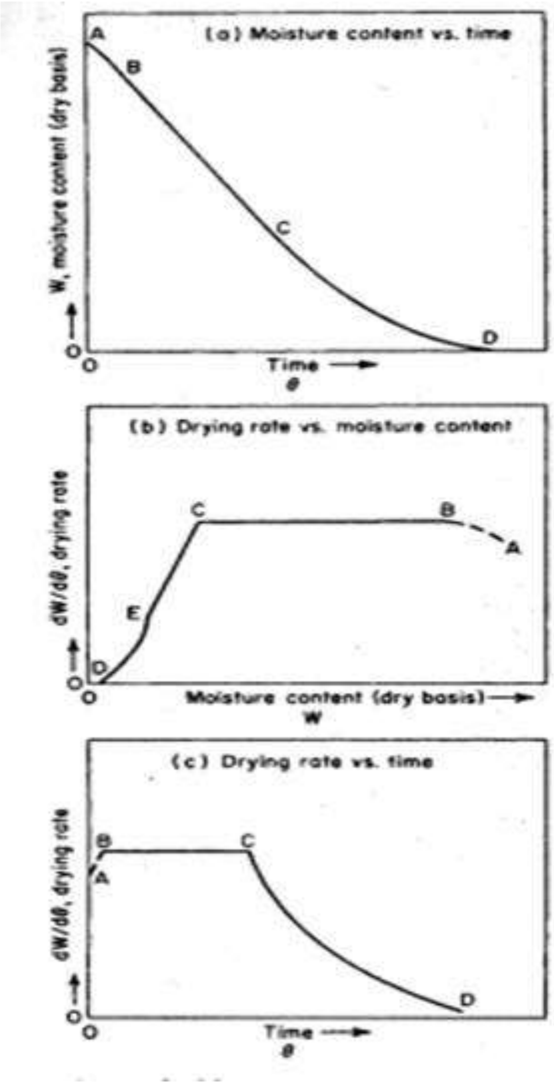


Figure 2.2: Periods of drying

Stage A – B: This section represents a “settling - down” or “warming – up” period during which the solid material is heated by conduction so that the surface temperature comes in equilibrium with the drying air conditions. This continues until the surface temperature is equal to the wet-bulb temperature of the drying air. This section is usually negligible in the overall drying cycle, but in some cases it is significant.

Stage B – C: This section represents the “constant – rate” period during which the surface of the material remains saturated with liquid water because the movement of water within the material to surface is the same as the rate of evaporation. Drying takes place by movement of water vapor from saturated surface through a stagnant air film into the main a stream of drying air. The rate of drying is dependent on the rate of heat transfer to the drying material and is equal to the rate of mass transfer, thus the temperature of the drying material remains constant. This continues until the “critical moisture content” is reached, point C, then the drying rate begins to fall.

Stage C – D: This section represents the “falling rate” period during which the drying rate slowly decreases until is approaches zero at the “equilibrium moisture content” (i.e. when the material comes to equilibrium with the drying air). Often, there are two parts of the falling rate, the first and second falling rate periods C – D and D – E respectively. In the first section, the surface is drying out and is known as unsaturated drying. The second section in which the plane of evaporation moves into the drying material and the drying rate falls further. This second falling period is also known as the saturated dying. Based on thin layer, drying time is computed as:-

Warming – up Period:

In this period, heat is transferred to the material by conduction to warm up the material. Thus the governing equation for symmetric heating an infinite slab without heat generation is given by(Mujumdar,2011):

$$\rho c_p \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial x^2} \qquad (2.9)$$

Boundary conditions: at $x = 0$, $\frac{\partial T}{\partial x} = 0$; at $x = L$, $T(L, t) = T_s$

Initial conditions: at $t = 0$, $T(x, 0) = T_i$

Where:

ρ = bulk density of dried material (kg/m^3)

c_p = specific heat (J/kg.K)

T = temperature (^{o}C)

k = thermal heat conductivity of material (W/m.K)

L = thickness of material (m)

Applying the initial and boundary conditions to the governing equation and using the separation of variables, the solution to equation (1) becomes:

$$\frac{T-T_s}{T_i-T_s}=\sum_{n=0}^{\infty}\frac{4(-1)^n}{(2n+1)\pi}\cos\frac{(2n+1)\pi x}{2L}e^{-\alpha\left(\frac{(2n+1)\pi}{2L}\right)^2 t} \qquad (2.10)$$

Where $\alpha = k/\rho c_p$ is thermal diffusivity.

For long time dying, the exact solution of equation (2) is approximated by taking n = 0, thus solution becomes:

$$\frac{T-T_s}{T_i-T_s}=\frac{4}{\pi}\cos\frac{\pi x}{2L}e^{-\alpha\left(\frac{\pi}{2L}\right)^2 t} \qquad (2.11)$$

Thus the drying time during the warm is given by:

$$t=\frac{4L^2}{\alpha\pi^2}\ln\left\{\left(\frac{T-Ts}{T_i-T_s}\right)\left(\frac{\pi}{4}\right)\right\} \qquad (2.11.\ a)$$

$$t=\frac{4L^2\rho c}{k\pi^2}\ln\left\{\left(\frac{T-Ts}{T_i-T_s}\right)\left(\frac{\pi}{4}\right)\right\} \qquad (2.11.\ b)$$

However, the warming phase is usually neglected.

T = drying air temperature

Ti = room temperature of the drying environment

Ts = product surface temperature(for saturation drying equals wet bulb temp of drying air)

Constant – rate Period:

During this period, the rate of mass flow equal to the rate of heat transfer. The mass flow rate is given by:

$$\frac{\partial M}{\partial t} = K_s A(H_s - H_a) \tag{2.12}$$

Where:

$\frac{\partial M}{\partial t}$ = mass flow rate (drying rate) (kg/m^2.s)

K_s = mass transfer coefficient

A = surface area available for drying (m^2)

H_s = humidity at surface (kg moisture/kg air)

H_a = humidity of air (kg moisture/kg air)

The rate of heat transfer is given by:

$$\frac{\partial Q}{\partial t} = \frac{hA}{\lambda}(T_a - T_s) \tag{2.13}$$

Where:

$\frac{\partial Q}{\partial t}$ = rate of heat transfer (W)

h = heat transfer coefficient (W/m^2.K)

Ta = average dry-bulb temperature of drying air (^{o}C)

Ts = average wet-bulb temperature of drying air (^{o}C)

λ = latent heat of vaporization (kJ/kg)

Since during the constant rate drying, the heat and mass transfer are at equilibrium, we equating equation (4) and (5),

$$\frac{\partial M}{\partial t} = \frac{hA}{\lambda}(T_a - T_s) = K_s A(H_s - H_a) \tag{2.14}$$

The rate of moisture removed from the material with no change in volume during drying can given by:

$$\frac{\partial M}{\partial t} = \frac{h}{\rho L \lambda}\left(T_a - T_s\right) \tag{2.15}$$

Where:

L = thickness (m)

Integrating Equation (7) we obtain the drying time during the constant-rate phase as:

$$t = \frac{\rho L \lambda}{h}\left(\frac{M_o - M_c}{T_a - T_s}\right) \tag{2.15 a}$$

Falling – rate Period

In section, applying Fick's second law for unsteady state diffusion:

$$\frac{\partial M}{\partial t} = D\frac{\partial^2 M}{\partial x^2} \tag{2.16}$$

Where:

D = liquid diffusivity (m^2/hr.)

M = moisture ratio (kg waster/kg solid)

Initial conditions, $t = 0$, the moisture is uniformly distributed and is equal to the critical moisture content M_c

Boundary conditions, at $t > 0$, moisture is equal to equilibrium moisture M_e

Applying the initial and boundary conditions to the governing equation and using the separation of variables, the solution to equation (8) becomes:

$$\frac{M - M_e}{M_o - M_e} = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left(-\frac{(2n+1)^2\pi^2}{4}\frac{DT}{x^2}\right) \tag{2.17}$$

For long drying times, Equation (9) becomes:

$$\frac{M - M_e}{M_o - M_e} = \frac{8}{\pi^2}\exp\left(-\frac{(2n+1)^2\pi^2}{4}\frac{DT}{x^2}\right) \tag{2.17 a}$$

Differentiating Equation (9.a), we obtain the drying rate as:

$$-\frac{dM}{dt}=\frac{\pi^2 D}{4L^2}\left(M-M_c\right) \tag{2.17 b}$$

Thus the drying time during falling phase for which the moisture in the material is controlled by diffusion is obtained by integrating Equation (9.b) and is given by:

$$t=\frac{\pi^2 D}{4L^2}\ln\left(\frac{M_c-M_e}{M_f-M_e}\right) \tag{2.18}$$

An approximation drying time during the falling for which moisture movement in the material is controlled by capillary flow is given by:

$$t=\frac{\rho L\lambda\left(M_c-M_e\right)}{h\left(T-T_s\right)}\ln\left(\frac{M_c-M_e}{M_f-M_e}\right) \tag{2.19}$$

Where;

ρ = density of material (kg//m3)

Mc = critical moisture content

Me = equilibrium moisture content

Mf = final moisture content

2.2.4 Drying equipment (Types)

Table 2. 2 Dryer type based on Trade name

Main dryer classification criteria Criterion	Types
Mode of operation	Batch Continuous*
Heat input-type	Convection*, conduction, radiation, electromagnetic fields, combination of heat transfer modes Intermittent or continuous* Adiabatic or non-adiabatic
State of material in dryer	Stationary Moving, agitated, dispersed
Operating pressure	Vacuum* Atmospheric
Drying medium (convection)	Air* Superheated steam Flue gases
Drying temperature	Below boiling temperature* Above boiling temperature Below freezing point
Relative motion between drying medium and drying solids	Co-current Counter-current Mixed flow
Number of stages	Single* Multi-stage
Residence time	Short (< 1 minute) Medium (1 – 60 minutes) Long (> 60 minutes)

Source: Mujumdar, 2011

The following steps provide a procedure to determine if drying is needed as well as whether or not to use heated air.

1. Measure the initial moisture content of grain or product to be dried.
2. Using a sling psychrometer or thermometer, determine the wet and dry bulb temperatures of the air.
3. Using these temperatures, determine the relative humidity (RH) from the psychrometric chart.
4. Round the relative humidity and dry bulb temperature values to the nearest point.
5. Determine the equilibrium moisture content (EMC) corresponding to air temperature and the RH from the EMC model/equation or tables.
6. Determine the volume of air per minute (usually in cubic feet per minute or cfm) being moved by the fan from the fan performance chart corresponding to the static pressure. Refer to fan manufacturer's specifications and performance curves.
7. Check if the air volume exceeds the minimum airflow requirements of your grain's initial MC to accomplish drying.
8. If the EMC is found to be below the safe storage MC, then no heat will be needed – run fans with unheated air. If the EMC is found to be greater than the safe storage MC, heat will be needed to dry the grain to a safe storage moisture level.
9. Add 5 degrees of heat to the dry bulb temperature reading, and use psychrometric chart to determine the new RH. Note that the new dry bulb temperature is now 5 degrees greater than it was originally – the wet bulb temperature also increases slightly. (See the psychrometric chart in Figure 2.)
10. Determine the equilibrium moisture content of the grain for these new conditions. If the EMC is equal or slightly less than safe storage moisture content, then proceed

with drying at this temperature. If the EMC is higher than for safe storage MC, determine the amount of additional heat needed.

11. Care should be used when temperatures exceed 100°F, particularly for rice, soybean and any grain saved for seeds (planting).

2.2.5 Commercial food drying equipment

Application of the diverse types of process dryers to food dehydration should take into serious consideration the unique requirements of processing of foods and biological products. The strict product requirements for food dryers (organoleptic, nutritional, and functional) should be met at the lowest possible cost. Practical aspects of food dehydration and food dryers are presented by Greensmith (1998). Design and performance of food dryers are discussed by Barbosa-Canovas and Vega-Mercado (1996), Crapiste and Rotstein (1997), and Baker (1997). The technology of dehydration of various food products, with emphasis on fruits and vegetables, is discussed by Woodroof and Luh (1986, 1988), and Salunkhe et al. (1991). Preparation and pretreatment of raw food materials, especially fruits and vegetables, involving washing, peeling, slicing, blanching, and chemical treatment (e.g., sulfur dioxide, salts, sugar) is an integral part of the dehydration flow sheet (e.g., Figure 2.3), and is discussed by Greensmith (1998), Woodroof and Luh (1986), and Lub and Woodroof (1988). The various types of drying operations and equipment, used in commercial food processing, are shown in Table 8-3. Selected operating characteristics were taken from the literature (Walas, 1988; Perry and Green, 1997; Crapiste and Rotstein, 1997). The following description of the modem mechanical drying equipment is preceded by a brief overview of the ancient method of sun drying, which is still practiced today for drying certain fruits and other agricultural products, and some fish. The energy consumption depends on the type of dryer, varying from 3 to 6 *MJ/kg* water evaporated. Much higher energy consumption is required in vacuum and freeze-dryers.3

Table 2. 3 Characteristics of Food Drying Operations and Equipment

Dryer type	*Product form*[123]	*Product*	*Evap. capacity*	*Residence*
Sun drying	Pieces	Ambient	—	10-20 days
Bin or silo	Pieces, grains	30-50	—	1-3 days
Tray	Pieces	40-60	0.2-2	3-10 h
Tunnel	Pieces	50-80	5-15	0.5-3 h
Conveyor belt	Pieces	50-80	5-15	0.5-3 h
Rotary	Grains, granules	60-100	30-100	0.2-1 h
Drum	Sheet	80-110	5-30	10-30S
Fluid bed	Grains, granules	60-100	30-90	2-20 min
Pneumatic flash	Grains, granules	60-120	10-100[b]	2-20 s
Spray	Powder	60-130	1-30[4]	10-60s
Vacuum/freeze	Pieces	-10-20	1-7	5-24 h

a. Sun Dryers

Large quantities of grapes (raisins), apricots, figs, prunes, and dates are dried by direct exposure to sunlight in relatively hot and dry climates. Other sun-dried food materials include coffee beans, cereal grains, and fish. Sun-dried fruits contain about 15-20% moisture, which is near the equilibrium moisture content at ambient air conditions, and they can be stored in bulk, without the danger of microbial spoilage. Typical operations for sun drying of grapes, figs, and apricots are as follows. Seedless (Sultana) grapes are usually pretreated by dipping in alkali solutions, containing vegetable oil or ethyl oleate, which increases the drying rate by increasing the moisture permeability of the grape skin. Corinth (currant) raisins are not pretreated, since they have thin skins. The grape bunches are spread in trays and dried by exposure to direct sunlight. Wooden or paper trays may be used, placed on the ground, between the vines. The grapes may also be dried by hanging the bunches from a string, while they are covered with a transparent plastic cloth, which protects the product from adverse weather conditions. Some currant raisins are dried in the shade, resulting in higher quality. The sun drying time varies from 10 to 20 days, depending on the solar radiation. The sun-dried raisins are separated from the stems by mechanical equipment, and stored in bulk before further processing and packaging. The ripe apricots are usually cut into halves before sun drying on trays, placed on the ground. Figs may be sun dried on the trees, after ripening. The dried figs are left to fall to the ground, and they may need further sun drying to reach the desired moisture content (15-20%). Some large figs are sliced into halves to reduce the sun drying time. Dried fruits, especially figs and apricots, may require fumigation treatment with sulfur dioxide or other permitted insecticide during storage and before packaging.

b. Solar Dryers

Solar drying is actually a form of convective drying, in which the air is heated by solar energy in a solar collector. Usually, flat-plate collectors are used with either natural or forced circulation of the air. Solar energy and, in general, renewable energy sources are important and economical, particularly during energy crises, when the cost of fuel energy increases sharply. Figure 2.3 shows a simple solar dryer with a flat-plate solar collector connected to a batch tray dryer. The air movement is by natural convection, but addition of an electrical fan will increase considerably the collector efficiency and the drying rate of the product. Several types of solar collectors and drying systems have been proposed for drying various food and agricultural products, like fruits, vegetables, and grains. The common flat-plate collector consists of a black plate, which absorbs the incident solar radiation, a transparent cover, and insulation material.

The incident solar energy (insolation) varies with the geographical location and the season of the year. A typical insolation for a hot climate would be 0.6 kW/m^2 with an average sun shine time of 7 h /day. This energy corresponds to about 0.6 X 3600 = 2.16 MJ/h or 15

MJ/m^2 day (Imre, 1995). The evaporation of water at 40°C requires theoretically 2.4 MJlkg and practically about 3 MJlkg. Therefore, the mean evaporation rate of water will be about 2.16/3 = 0.72 kg/m2 h (intermittent operation 7 h/day).

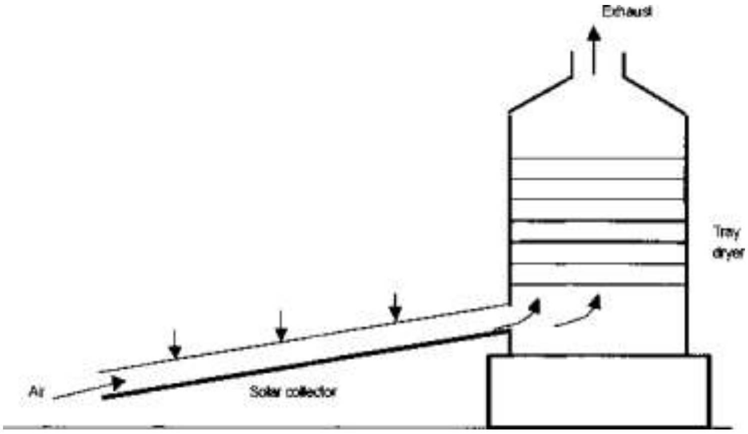


Figure 2.3 Simple solar dryer

The relatively low intensity of incident solar radiation is a serious problem for drying applications, where large amounts of thermal energy are required for the evaporation of water from the food material. Large surfaces of solar collectors are needed for drying significant amounts of food materials. For example, evaporation of 1000 kg/h of water (capacity of a typical mechanical convective dryer) would require about 100/0.72 = 1400 m2 of collector surface for a hot climate (intermittent operation 7 h/day). A larger surface would be required in a temperate zone. Solar tunnel drying compares well with conventional convective drying, except for the lower capacity (kg water evaporated per hour) of the solar system (Fuller, 1994). Solar drying is considered effective for relatively small drying operations of fruits, like grapes and apricots, under the climatic conditions of e.g., southern Australia. Solar energy collected in this area for a continuous 30-h operation (including night) was estimated at 20 MJ/m^2, corresponding to about 6 W/m^2 (continuous operation) or 0.6kW/m2 (intermittent, 7 h/day operation). The problem of intermittent solar radiation (day-night) is usually met with the use of some form of auxiliary energy, like fuel or electricity. Thermal storage of solar energy can also be applied, using rock beds or water to absorb extra solar energy for night or cloudy weather use (Maroulis and Saravacos, 1986;

Raouzeos and Saravacos, 1986). Some other solar collectors, proposed for solar drying, are: (1) a low-cost tunnel collector 1 X 20 m connected to a tunnel dryer for drying a batch of 1000 kg grapes (Lutz and uhlbauer, 1986); (2) a solar collector with V-grooves, attaining temperatures 50-70°C at 0.7 kW/m2 insolation, used for drying chili in Malaysia; and (3) an evacuated tubular solar collector (glass tubes 12.6 cm diameter and 2.13 m length), capable of heating the air to 90-11 O°C (Yan and Hu,1994).Solar collectors, integrated in the roof or the wall of a farm building, can provide heated air for drying grain in a bin or silo (Henrikson and Gustafson, 1986). A conventional bin dryer is shown in Fig. 8-9. Silo drying of grain usually reduces moisture content from about 20% to 18%. Solar collectors for drying chili were described by Ruslan *et al*. (2000).

c. Bin, Silo, and Tower Dryers

Bin and silo dryers are used widely in the drying of agricultural products,notably grain (e.g., wheat, shelled com, rice, soybeans) from an average harvestmoisture of 25% to a storage moisture of about 15%. In addition to drying, mechanical aeration of the stored grain is needed to prevent local overheating and spoilage (Raghavan, 1995). The aeration flow rate depends on the moisture content of the grain, varying usually from 45 to 90 m3/h m3 of grain. The moisture content of cereal grains in silos increases about 3% during the winter. Silo fans require about 2 kW power for 1000 tons of bulk grain igure 8-9 is a diagram of a batch bin or silo dryer, which consists basically of a fixed bed of product (e.g., grain), through the bottom of which heated air is

Figure 2.4 Batch bin (silo) dryer forced by a mechanical fan. The maximum safe temperature of the air depends on the stored food material, ranging from 43°C (rice) to 60°C (wheat). Efficient grain dryers require high air flow rates, e.g., 450 m3/h m3 of grain.In addition to the fixed batch dryers, recirculating batch, recirculating continuous, and portable grain dryers are also used (Raghavan, 1995). The drying capacity of the grain dryers is about 2-4 *tons/h* for the batch, 3-9 *tons/h* for the portable, and above 15 tons/h for the continuous flow units. Bin dryers are also used in finish drying of some vegetable materials, when the product is difficult to dry (low moisture diffusivity) in the primary dryer, without raising the temperature. Dehumidified air at near ambient temperature may be needed in finish drying of hygroscopic materials. The tower dryer (Figure 2.5) is a variation of the bin/silo dryer. Such dryers are used in reducing the moisture content of cereal grains after harvesting and before storage in silos. The tower dryers are usually metallic structures, composed of several similar units, each having dimensions 3.5 X 2.0 X 18.0 m. The product after cleaning, is transported by bucket elevators to the top of the dryer, at a rate controlled by the emptying mechanism at the bottom of the unit . Hot air, in cross flow, is drying the grain, which flows downward. The downstream movement, and thus the moisture of the grain, can be controlled by varying the cross section of the upper and lower parts of the dryer. The capacity of the tower dryer may be from 5 to more than 100 tonslh of fresh grain. The initial moisture content of the grain depends on the product, the harvesting area, and the climatic conditions of the harvesting season. For long-term storage, the moisture content must be reduced to below 16%. The temperature of the heating air is usually 70-100°C. In heating grain that is utilized in baking processes, the drying temperature must not exceed 80°C to avoid heat damage of the useful enzymes. More than two large fans are used to blow the dying air, each requiring 5-11 kW power and blowing 20000 to 30 000 m31h. The specific energy consumption of tower dryers is about 5 MJ/kg water evaporated, and the total energy consumption of a tower dryer is 4-33 GJIh.

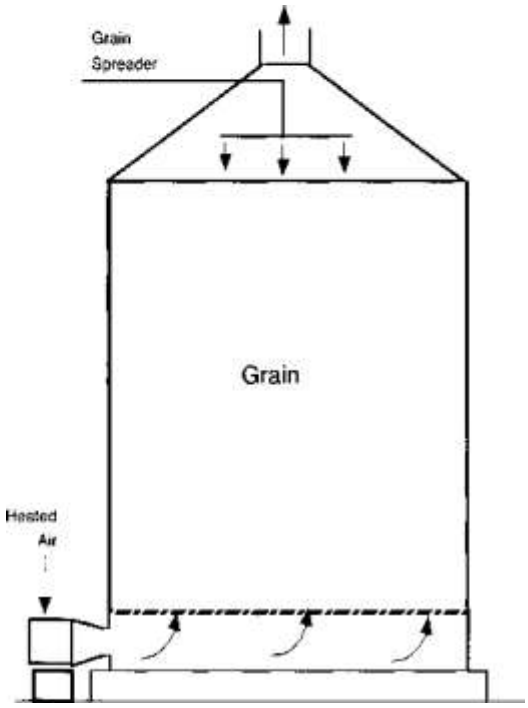


Figure 2.4 Batch bin (silo) dryer

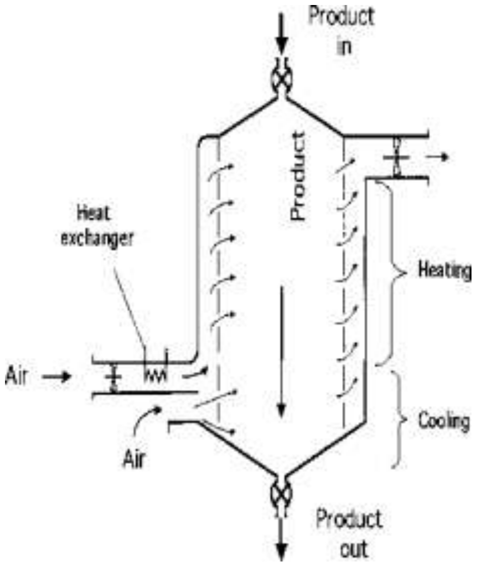


Figure 2.5 Diagram of a continuous tower dryer

d. Tray/Cabinet Dryers

Tray or cabinet dryers are the simplest convective dryers, and they are used for drying relatively small batches of food materials in the form of pieces, such as sliced fruits and vegetables. They consist of a stack of trays, placed in a cabinet, and are equipped with a heat exchanger and a mechanical fan to circulate the heated air through the trays (Figure 2.6). The heat exchanger is usually operated with steam, and part of the air is re-circulated to recover part of the heat of the exhaust air or air/flue gases. The trays may be placed on a mobile truck, moving on rails, for easy loading and unloading of the dryer. Large cabinet dryers can handle more than one truck of trays, making possible a semi-continuous operation. A truck may contain about 30 trays with dimensions of 80 X 80 X 5 cm. The amount of product loaded on a truck, containing 30 trays of dimensions 80 X 80 X 5 cm, each loaded with 5 kg, will be 30 X 5 = 150 kg (Greensmith, 1998).

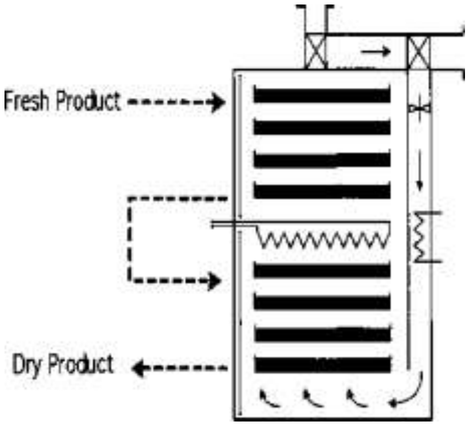


Figure 2.6 Cabinet (tray) dryer.

e. Tunnel Dryers

The tunnel (truck) dryers are essentially an extension of the tray/cabinet dryers, with several trucks moving slowly in a long tunnel, while coming in contact with hot air in parallel, counter, or combined flow (Fig. 8-12). The drying air is moved by mechanical fans and heated by heat exchangers, operating with steam at a pressure of about 7 bars. Partial recirculation of the air is practiced (about 50% ofthe total air), as in other convective dryers. The dryer is loaded successively with new trucks, while an equal number of trucks of the dried product are removed from the other end. Each truck (trolley) is loaded with about 50 trays. A typical drying time for vegetables is about 6 h(Greensmith, 1998).

Tunnel dryers can be constructed from low-cost materials, and are simple to operate. They are suitable for economical dehydration of fruits and vegetables, near the production farms. Since the production of most fruits and vegetables is seasonal, the dryers should be used for various products to increase their operating time.

f. Conveyor Belt Dryers

Figure2.5 is a diagram of a typical single-belt dryer, used widely in the dehydration of food materials. The belt (band) of a typical medium-scale operation is 30-40 m long and 2.5-3 m wide (Greensmith, 1988). High air velocities are used (3-6 *mls)* for fast drying. The capacity (product throughput) of commercial belt dryers varies with the product in the range of 1000 to 3000 kg/h. Heat for drying is supplied either by direct combustion of "clean" fuels (natural gas or LPG) or by indirect heat exchange from steam or oil flue gases. The heated air passes through the product and the perforated belt upward or downward with properly installed fans. The loading of the trays depends on the bulkiness or compactness of the material.

Higher loading is used with porous than nonporous materials. Typical depth of belt loading for vegetable materials is 5-12 cm. Two or more passes (stages) may be needed for some drying operations. Changing the operation from stage to stage exposes new surfaces of the product to the drying medium, resulting in faster and more uniform drying (Fig. 8-14). For economic reasons, belt drying of some vegetables is stopped at about 12-15% moisture, and the drying is completed to about 5% in a bin dryer (Figure 2.7). Small or mobile bin dryers may be used. Figure 8-14 shows diagrammatically a three-belt conveyor dryer, suitable for fruit and vegetable dehydration. Each belt is 1-3 m wide and 10--30 m long. The drying capacity is about 2-15 kg/m2 h and the specific steam consumption 1.8-2.0 kg/kg water. Total electrical power is up to 100 kW, temperature range 70--100°C, and air velocities 0.5-1.5 *mls.*

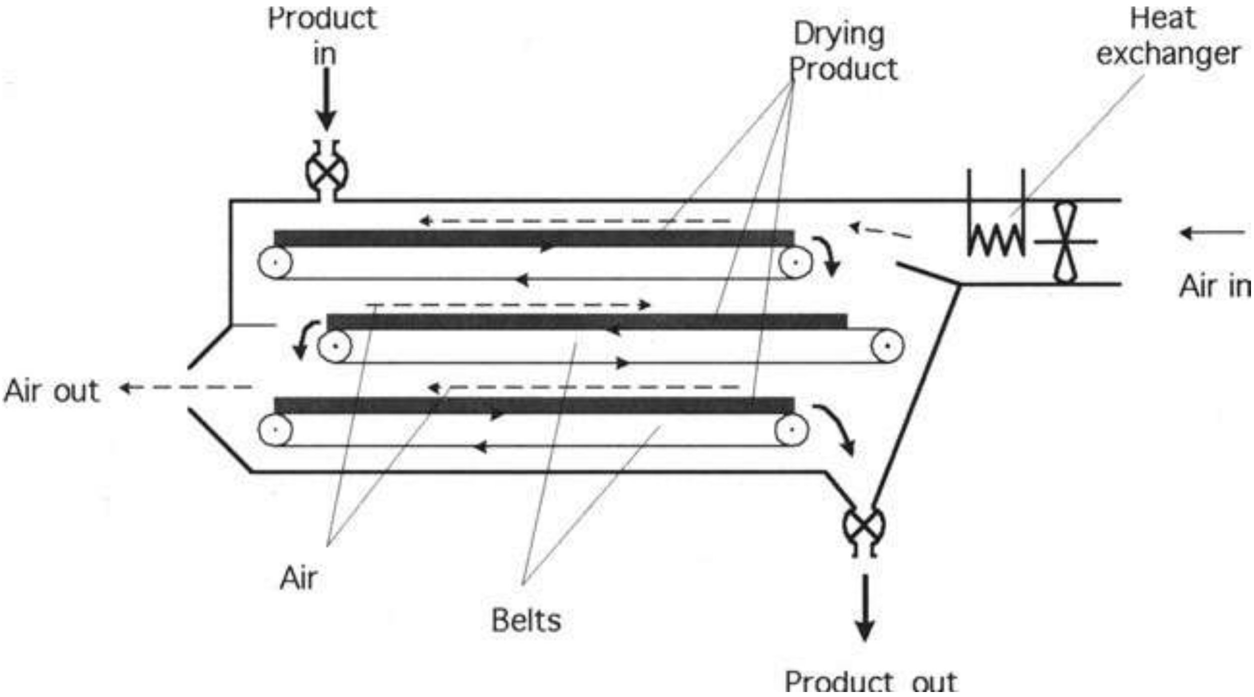


Figure 2.7 Diagram of a three-belt dryer

g. Rotary Dryers

The rotary dryers consist of an inclined long drum (cylinder), rotating slowly through which the material (particles or grains) flows with a tumbling (cascading) action (flights) in co-current or countercurrent flow with the heating air/gases (Figure 2.8). The dryer shell is inclined about 5° to the horizontal, and is rotating by a gear mechanism at a peripheral velocity of 0.2-0.5 *mls.* A cyclone dust collector may be needed at the exit of the exhaust gases. The rotary dryer is characterized by high air/gas temperatures, high evaporation rates, and relatively short residence time. The dimensions of normal rotary dryers range from 1.5 to 3 m diameter and 6 to 20 m length. The evaporating capacity is about 50 kg/m2 h per heating surface or about 60 kg/m3 h per dryer volume (Walas, 1988). The air/gas velocity ranges between 0.5 and 2.5 *mls.* Heating of the rotary dryers is either by steam tubes, installed along the inside of the cylindrical shell, or by combustion gases from natural gas, LPG, or oil.

Rotary dryers usually operate at high temperatures and, therefore, have high evaporative capacity. They are used mostly in drying food by-products and wastes (peels and pomace), where high temperatures are permissible and economics is important. Application of rotary dryers to food products is limited to particulate materials, such as granulated sugar and some grains. Large food particles cannot be handled in this type of dryer, due to the relatively short residence time, the danger of overheating, and the mechanical damage (abrasion) of the products. Such materials are dried more effectively in conveyor belt dryers. Direct and indirect (steam) heated rotary dryers are used economically for commercial drying of

fish meal (Fresland et aI., 2000), and solid food wastes, e.g., citrus peel and pulp. Rotary dryers are used widely in the chemical process industries, and their mechanical and operational characteristics are discussed by Bhatia (1983), Walas (1988), and Perry and Green (1997). Automatic control of rotary dryers can improve significantly the economics of operation (Ventzas, 1998)

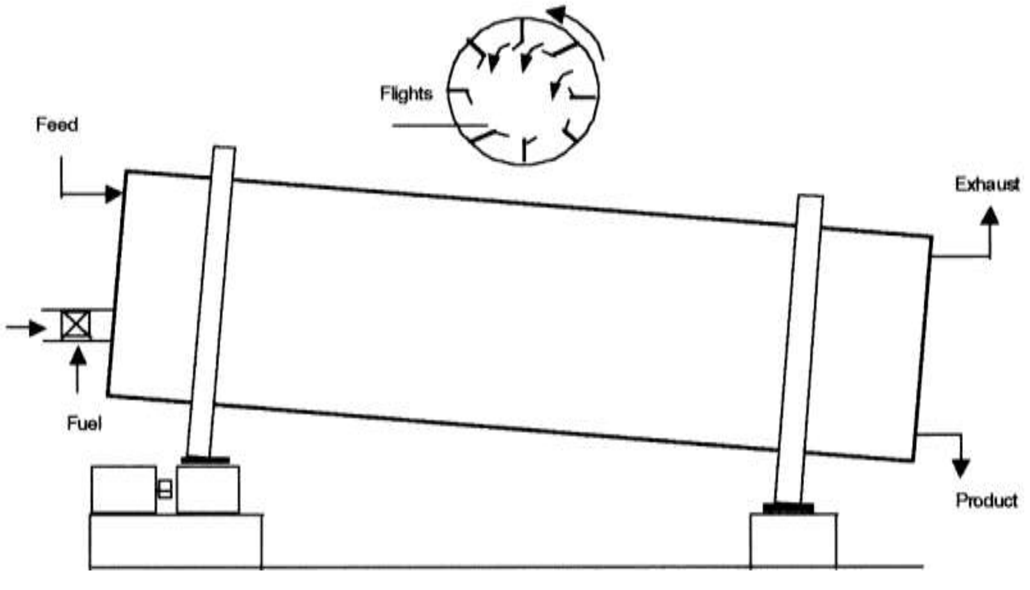


Figure 2.8 Diagram of direct (fuel) heated rotary dryer

h. Fluid Bed Dryers

Fluid bed dryers are fast drying equipment, which is based on the very high heat and mass transfer rate between the heating medium (hot air) and the fluidized granular material. They are efficient and economical units for drying food materials in granular form, like grains, peas, and other food particles. The basic elements of a fluid bed dryer are a bed of the material supported on a perforated plenum, through which hot air is assed, fluidizing and drying the material. A cyclone collector and other dust-collecting equipment are installed before the centrifugal exhaust fan (Figure. 8-16). Basic requirement for this operation is the air-fluidization of a bed of the particulate material (Hovrnand, 1995), which is affected by the size, shape, and density of the particles. Average particle size for efficient operation is 20 f.1m to 10 mm. A narrow particle size distribution is desirable, since it reduces entrainment of the smaller particles. Rapid mixing of the solids leads to nearly isothermal operation throughout the bed, and better process control. Residence time can be chosen on the order of minutes, in contrast to the pneumatic short-time operation (Vanecek et aI., 1966). Fluid bed dryers are used for the efficient primary and secondary drying of paddy rice in the moisture ranges of 45 to 22 and 26 to 22%, respectively (Soponronnarit et aI., 1996).

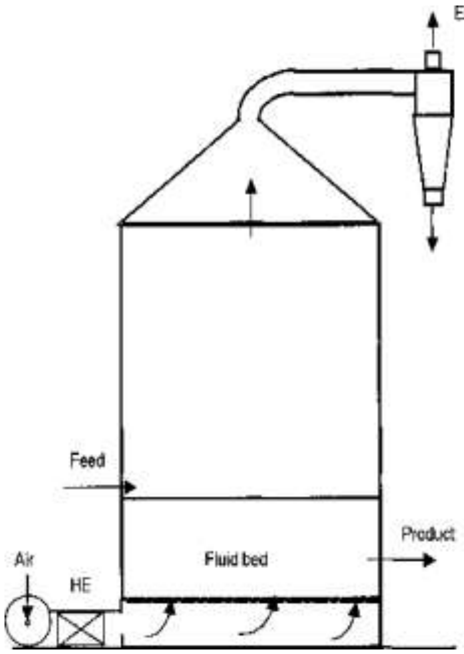


Figure 2.9 Diagram of fluid bed dryer.

L Spray Dryers

Spray dryers are used for drying liquid foods and food suspensions, which can be dispersed in the form of droplets in a stream of hot air. Figures 8-25 and 8-26 show the main components of co-current and countercurrent spray drying systems, which consist of a spraying device, a large cylindrical drying chamber, a particle collection system (cyclone and bag filters) for the dried product, and the required heating and air moving equipment (Masters, 1991; Filkova and Mujumdar, 1995). The size and capacity of the spray dryers vary widely, with diameters up to 10 m and heights up to 30 m. Concentrated food liquids, such as milk, coffee, and juices, are dispersed as droplets, using three types of atomizers, i.e., pressure nozzles, centrifugal (wheel), and two-fluid (pneumatic). The type of atomizer depends on the properties of the food liquid (concentration, viscosity) and the droplet size distribution desired (5 to 500 J,Lm). Pressure nozzles, operating at 50-100 bars, produce nearly uniform size (narrow size distribution) of droplets; their capacity is limited to about 1000 kg/h liquid, and, therefore, multiple nozzles are needed in large spray dryers. The centrifugal wheel operates at very high speeds, 5000 to 25 000 rpm, with peripheral velocities of 100-200 *mis*, it has a higher capacity than the pressure nozzle, and it gives a wider range of droplet sizes. The average droplet size, produced by the centrifugal wheel, is larger than the sizes produced by the pressure atomizers, an advantage in producing large, easily dissolved dried particles. The pneumatic nozzle operates at air pressure of 3 bars, requiring- 0.5-0.6 m3/kg liquid, and it is used mostly in small installations and pilot plants

(Filkova and Mujumdar, 1995) .Hot air, usually mixed with "clean" combustion gases at high temperature (150-300°C), is used as the drying medium in co-current or countercurrent flow with the liquid droplets, which are sprayed from the top of the drying chamber The droplets dry rapidly, due to high heat and mass transfer rates in the system, producing food particles, which are collected either at the bottom or in the cyclone collector system, before the air is exhausted to the atmosphere. The temperature of the exit air is 70-100°C. The product is kept at a relatively low temperature (50-70°C), due to the evaporative cooling in the dryer. The residence time in spray dryers is short, e.g., 5-30 s, during which the material must be dried to the desired moisture content, without under- or over- dried particles. Some spray drying systems include a post drying section, such as a fluid bed dryer, in which the residence time is controlled to obtain the desired moisture content of the particles. The fluid bed can also act as an agglomeration unit to increase the size of the particles and improve their solubility and other functional properties. The heat consumption in spray dryers, due to high temperatures, is relatively high, about 6 MJ/kg water, and energy-saving systems are used (e.g., preheating of air) to improve the thermal efficiency. Recirculation of the dry particles in the dryer is used to agglomerate the fine particles of the product (see Chapter 4). The food agglomerates are finish-dried in a fluidized bed, installed in the bottom of the drying chamber. Small quantities of liquid ingredients can be added to the product during recirculation. Recent advances in spray drying of liquid foods are reviewed by Masters (1998) and Mermelstein (2001). Most of spray drying applications are related to the dairy industry (milk and whey products). Pressure spray atomizers are preferred because of the narrow size distribution of droplets. Uneven size distribution results in overheating of the smaller particles. However, the centrifugal wheel atomizer may be preferred in some food applications, since it results in larger particles, which are dissolved more readily. Separation of small dried particles from the exhaust air/gases is achieved in cyclone separators, followed by bag filters. Bag filters of hygienic design are more effective than mechanical cyclone collectors in removing fine particles from the exhaust gases and preventing air pollution . An improved design of the spray drying chamber is based on the flow of the hot air from the top in the middle of the chamber, followed by the upward flow close to the walls, with exit at the top. In this system, the walls are kept at a relatively lower temperature, preventing the sticking and overheating of the drying droplets. Safe operation of the drying chamber is required against spontaneous combustion and explosion, which may occur from overheated flammable and explosive powders, accumulating in the corners and crevices within the drying chamber. A fire suppression system, relief valves, and electrical insulation should be installed in the dryer. Energy savings in spray drying can be achieved either by mixing the exhaust gases with fresh air, or by indirect heating of the fresh air by the hot exhaust gases, using a heat exchanger. The second system can save about 7% more energy than direct mixing of the two air streams, but it requires significant investment in an air/gas heat exchanger

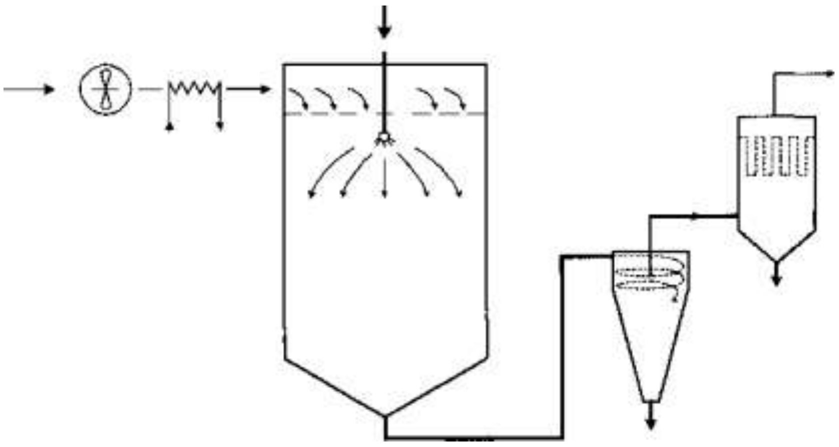


Figure 2.10 Diagram of a co-current spray dryer.

Energy and Cost Considerations of Drying

The cost of energy represents the major part of the operating cost of the industrial dryers. A typical cost breakdown for convective dryers is as follows (Bhatia,1983): energy 62%, capital cost 13%, labor 10%, overhead 10%, and maintenance5% Industrial drying consumes about 12% ofthe total energy used in manufacturing, e.g., 128 X 109 MJ/year in the United Kingdom and 166 X 109 MJ/year in France (Strumillo et aI., 1995). The major part of this large energy is used for drying food and agricultural materials. The energy consumption in drying is used mainly for the evaporation of free water, desorption of sorbed water, or sublimation of ice in freeze-drying. Theoretically, evaporation of free water requires 2.26 MJlkg at 100°C or 2.36 MJlkg at 60°C. The heat of sublimation of ice at O°C is 2.84 MJlkg, and higher energies are required for desorption of water, bound on food biopolymers. In addition, energy is required for sensible heating of the food material, the dryer, and the exhaust air, and for mechanical movement of the process air (operation of fans). Thus, the total energy consumption varies in the range of 3--4 MJlkg water in continuous convective dryers. It is higher in batch dryers (3-6 MJlkg water), and may reach 10 MJlkg water in vacuum and freeze dryers. It is obvious that economy in drying is related to the efficient use of energy and the development of new systems and equipment, which will operate more efficiently and reduce the energy losses. In addition to the economic reasons, energy saving will reduce pollution (chemical and thermal) of the environment, and preserve the fuel reserves. Utilization of renewable energy resources, like solar, wind, and geothermal energy, can reduce the excessive use of fossil energy for industrial drying.

Heat Sources for Drying

The heat required for drying is provided mostly by direct heating (firing) with fuels (gas or oil) and saturated steam. In some rather small-size applications, heat is supplied in the form of hot water, IR radiation, or MW energy. Combustion of fuel (natural gas, LPG, or fuel oil) is the simplest and most economical energy source for drying applications. Saturated steam and hot water are more expensive than direct fuel combustion, because heat exchangers and condensers are needed, but they are preferred in some cases, when contamination of the food material with combustion gases may not be acceptable Natural gas, used for direct firing of the dryer, is suitable for agricultural and food drying (Kudra, 1998). High temperatures are obtained, which increase substantially the drying rate and shorten the drying time. The natural gas contains about 98% methane and ethane, and its heating value is 37.2 MJ/m3• The heating value of propane is 50.4 MJ/kg, and that of fuel oil is 41.7 MJ/kg. The major limiting factor of using direct heating by natural gas and LPG fuels in drying is the presence of significant amounts of water vapor in the flue gases, produced by combustion of the hydrocarbons. Stoichiometric calculations indicate that flue (combustion) gases would contain 19% by volume of water vapor, but in practice lower concentrations are obtained, due to the use of excess air. As a result, the capacity of the heating air/gases to remove water in the dryer is reduced, and a low moisture content may not be reached easily for some food materials, which may require finish-drying with low humidity air in e.g. bin dryers.

Cost Considerations

Reliable cost data for industrial dryers can be provided by manufacturers and suppliers of process equipment. To aid the price quotation, data for the particular application should be provided in an appropriate specification form..Preliminary cost estimation can be made on the basis of drying capacity (kg water/h), using empirical correlations, tables, and the Marshall and Swift Index (M&SI) of the journal *Chemical Engineering* (Chapter 1). The exponent («) of the cost/capacity equation (1.3) for convective dryers varies in the range of 0.50 to 0.70 (Sztabert and Kudra, 1995). For preliminary cost estimates, the following equation gives the capital cost of drying equipment (C_E in USD, 1995):

$$C_E = A\,Q^n \qquad (2.20)$$

where Q is the capacity, defined either by the transfer area (m^2) or the effective volume (m^3) of the dryer. The coefficient A and the exponent n are characteristic of each type of dryer. Typical values of these parameters for industrial dryers are (Sztabert and Kudra, 1995): belt conveyor dryer (stainless steel), basis Q = belt surface area, $A = 21$, and $n = 0.59$; direct (fuel gases) rotary dryer (carbon steel), basis Q = dryer volume, $A = 17$, and $n = 0.69$.

The total (installed) cost of drying plant (C_T), which includes the costs of dryer, piping, motors, fans, instrumentation, buildings, and engineering, can be estimated from the equipment cost (C_E), using the empirical relation (van't Land, 1991; Sztabert and Kudra, 1995)

$$C_T = a\, C_E \tag{2.21}$$

The coefficient a is taken equal to 2.25 for carbon steel and 2.75 for stainless steel. Typical prices of drying equipment, converted to year 2000 by the M&SI, are (van't Land, 1991; Sztabert and Kudra, 1995):

Rotary dryer, carbon steel, steam tube heating, 1.83 m diameter and 18.30 m length, 290 m^2 transfer area, and 14.9 kW power motor: USD 450 000.

Spray dryer, co-current open cycle, 5 m diameter, operating at 370°C (air inlet)/105 °C (air outlet) temperatures, 1090 kg/h water evaporative capacity: USD 380 000.

Costs of new, used, and salvage drying equipment are listed by Bhatia (1983). The cost of used dryers is roughly 50% of the cost of the new equipment, depending on the condition and the age of the various units. The salvage value of dryers is about 5% of the initial cost.

Comparative cost data for concentration and drying food processes were presented by Sapakie and Renshaw (1984). The relative cost of dryers is convective 1, drum 1, spray 1, vacuum 3, and freeze 6. It should be noted that the basis of cost comparisons should be the total evaporative capacity of the unit (kg/h), and not the specific cost per transfer surface (m^2) or transfer volume (m^3). For example, the specific cost of drum dryers per square meter is very high, compared to the specific cost of tray dryers, but their specific evaporative capacity (kg/m^2h) is much higher, and the two dryers are approximately equivalent in cost, in terms of overall capacity (kg/h).

The cost of energy for drying applications is usually expressed as cost per gigajoule or cost per kilogram of water evaporated, assuming the appropriate energy requirement in mega joules per kilogram of water evaporated, e.g., 3-5 MJ/kg (1 GJ = 1000 MJ). The cost of natural gas, LPG, and fuel oil depends on the location, and it may increase significantly during international oil (petroleum) crises.

2.3 Packaging Characteristics of Agricultural Products

Even the best processing method is practically useless if the right package or equipment is not available. For example, the aseptic process was familiar several years ago, but the widespread application of the method was achieved by the introduction of the aseptic Form-FiB-Seal (FFS) packaging system. The same holds also for several products packed in modified atmosphere, or for gas containing foods and for the sterilization of food in plastic pouches. The main objectives of food packaging are to meet the technical, safety, technological, economical and ecological requirements. Figure 2.11 identifies the factors that must be taken into account when choosing food packages (Robertson, 1993).

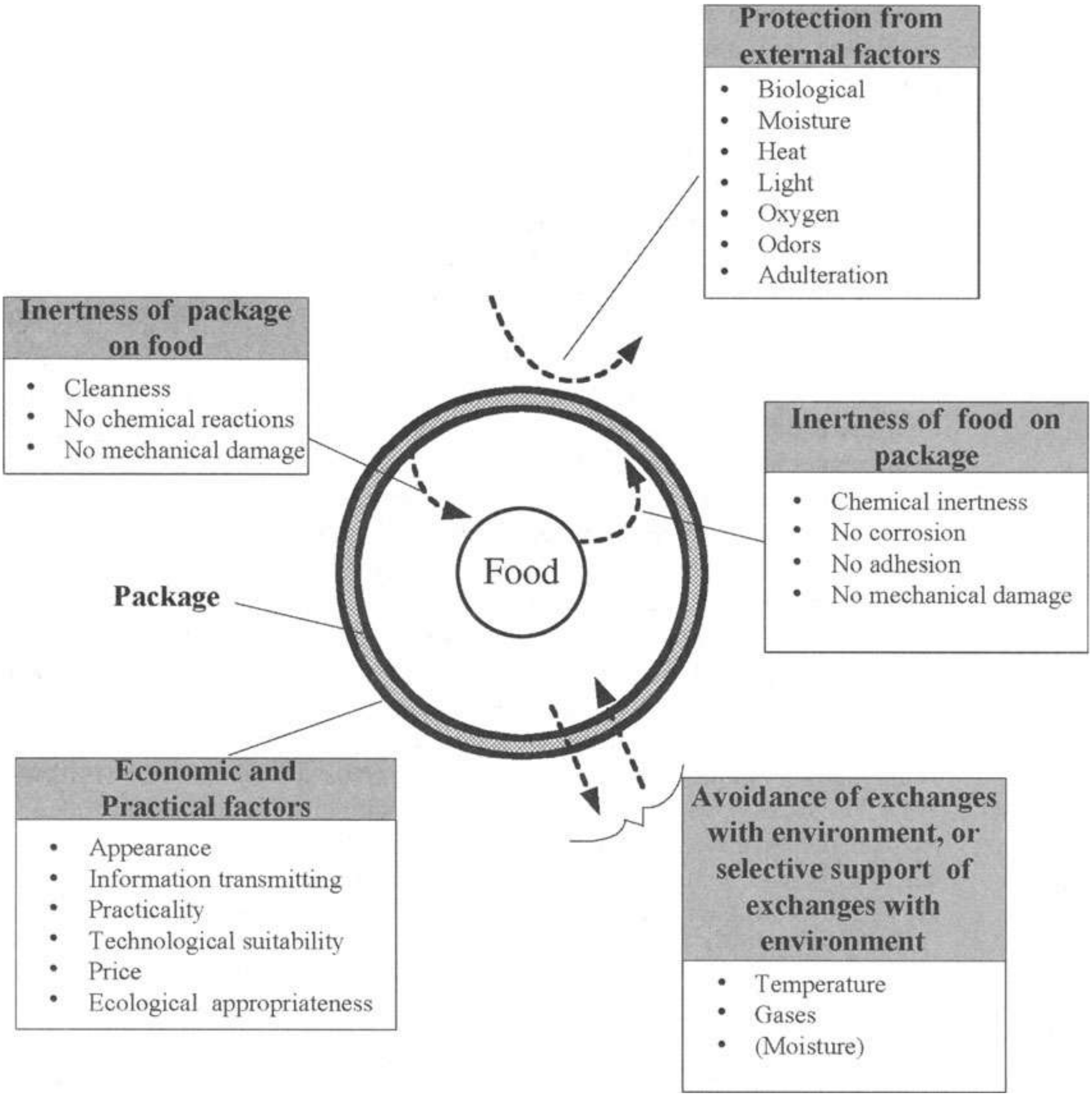


Figure 2.11 Factors influencing the choice of food packages

a. Technical Considerations

Food packaging must include the following considerations: (l) protection of the food from mechanical stress; (2) creation of conditions that protect the food from the physical environment; and (3) protection of food and the packaging material from chemical reactions. Most foods are delicate products and therefore require protection against stress conditions, which can occur during transportation (dynamic stress) or during storage (static stress).

Furthermore, the packaging material must be strong enough to withstand mechanical stress due to processing methods (e.g., pressure differences during the sterilization process in an autoclave or in seaming of cans). Factors influencing the firmness of packages include the main material used (e.g., glass, metal), the quality of the material, the weight/quantity of the material (e.g., the thickness of plastic film), the design of the packaging material (e.g., laminated plastic film, corrugated kraft paper), and the design/construction of the package (e.g., the wall thickness of cans was reduced from 0.3 to 0.1 mm, after the introduction of the drawn iron process, Robertson, 1993).

The environmental conditions, such as temperature, humidity, light, oxygen, odors, and insects, have a strong influence on the food. In many cases, these factors are harmful, or reduce the value of foods. High temperature is usually not desired during storage; it accelerates chemical and biological reactions, resulting in the faster degradation or spoilage of food. Humidity is often desired, if the proper low temperature is also applied, but there are products, such as the dried foods, that must be stored at low air humidity. Oxygen and light have negative effects on oils and fats and on some vitamins. They can also induce undesired chemical reactions. Odors influence· the organoleptic properties of food, and insects, besides damaging the food, can also be a source of microbiological contamination. The package must not be affected chemically by the food, nor the food by the package. The composition of food (e.g., fat content) and several methods of food preservation (e.g., acidification, salting, heating) may cause problems with respect to several metallic and plastic containers. Therefore, metal containers must be provided with the proper varnish (enamel), and plastic packages that contain harmful placticizers must not be used.

b. Safety Considerations

Food packaging must consider the following safety aspects: (1) protection of fresh products from deterioration; (2) protection of fresh and processed products from contamination; and

(3) protection of food products from adulteration. As a general rule, the food must be safe, meaning that fresh or preserved! Processed food must be completely harmless to the consumer. Properly packaged fresh and preserved foods must be protected from quick degradation or. Contamination, e.g., due to dirt or environmental pollution. In most cases, packaging helps food to maintain its initial condition during storage, as far as possible. Special case is aseptic packaging, whereby pasteurized or sterilized food retains the initial safety condition, due to proper packaging. Packaging also guarantees no adulteration after processing of food.

c. Technological Considerations

Technological considerations of food packaging include the following: (1) feasibility of the processes; (2) improving the quality of food; and (3) compatibility of packaging with existing processing equipment.

Several preservation methods (e.g., sterilization in cans) can be applied only if the food is packaged. Packaging is furthermore especially important when it is part of a certain food preparation, as in the case of tea bags and sausages. However, there are cases where packaging restricts the application of food processing methods. Aluminum or other metallic packages are not suitable for microwave processing. Therefore, the thermal, mechanical, and other physical properties of food are very important in choosing the right package in relation to the processing method applied. Packaging may also contribute to the preservation or to the improvement of food. Several foods, such as various wines and cheeses, ripen better under controlled conditions, provided by packages. Packaging can also be essential in protecting food from losing water (weight) and aroma substances. Packaging is also important in facilitating processes, such as the dosing, standardization, and control of food, and it enables the transportation, handling, and, in many cases, storage of food products.

d. Economic Considerations

The following economic considerations are important in food packaging: (1) cost of packages; (2) attractiveness; (3) transmission of information; and (4) marketing. Most foods are not luxury products and cannot bear the cost of very expensive packages. Therefore, one of the main criteria in choosing the right package is its price. The role of packaging is very important also in trade. Attractive packaging supports the sales and is one of the best advertisers of its contents. Attractive packaging, along with technical and technological characteristics of packages, facilitating food consumption, such as easy-open containers, one-way packages, and packages combining several items (e.g., in ready meals), are factors contributing very much to the promotion of the food. Packaging is also very important in transmitting messages to the consumers. For example, these can be nutritional or technical messages, they can refer to the preparation or safeness of food, or they can be simply advertisement. The package can also facilitate marketing by giving information about the cost of food and the date and place of manufacture, as well as stating any guarantees of the manufacturer.

e. Ecological Considerations

Ecological considerations of food packaging include recycling and disintegrations of packages.

Since consumers have become more and more aware about environmental priorities, the packaging material must either be recyclable or disintegrated. New methods in packaging technology extend the use of more ecological materials, such as paper and glass. In the case of glass, weight reduction and the increase of the container strength have improved their economic efficiency and competitiveness over other materials. When reused, glass bottles can normally be refilled up to 10-15 times.

2.4 Cold Storage of Agricultural Products

Although the primary function of any cooling facility is to remove field heat, an important secondary function is to provide cold storage space. Cooling capacity and storage capacity are separate characteristics, but together they determine the size of the facility. Cooling capacity and, to a lesser degree, storage capacity depend upon the size of the facility and the capacity of its refrigeration system. Therefore, it is important to determine the amount of produce you are likely to cool and store. A refrigeration system can be thought of as a pump that moves heat from one place to another. Refrigeration capacity, a measure of the rate at which a system will transfer heat energy, is normally expressed in tons. A ton of refrigeration capacity is the ability to transfer the amount of heat required to melt 1 ton of ice in a 24-hour period (288,000 Btu). Said another way, a refrigeration system of 1-ton capacity is theoretically capable of freezing 1 ton of water in 24 hours. That is, it can transfer 288,000 Btu in 24 hours or 12,000 Btu per hour. The correct size for a refrigeration unit is determined by three factors, the first of which is the weight of produce to be cooled. Since most produce is sold by volume (by crates, boxes, or bushels) you may have to determine its weight per unit of volume. Obviously, the more produce to be cooled, the larger the refrigeration unit must be. The second factor is the minimum time required from start to finish of cooling. Ideally, cooling should take place fast enough to prevent serious degradation of the produce but no faster. Cooling produce faster than necessary is unduly expensive because the refrigeration system must be larger and the demand cost for electrical energy is greater. To cool a load of produce in 2 hours instead of 4 may require twice the refrigeration capacity, and the cost of electricity may be three times as high. The third factor is the nature of the refrigerated space: its size, how well it is insulated, and how it is to be operated. Because as much as one-half of the refrigeration capacity in a typical facility is used to overcome heat gained through the floor, walls, ceiling, and doors, it is important to minimize these gains. Selecting a refrigeration unit of the proper size will be discussed in a later section.

2.4.1 Storage capacity.

The decision to cool produce immediately or to store it for a time often depends not only on the type of produce and market conditions but also on the availability of space in the storage facility. The type of produce you grow will determine, in part, how much storage space you need. Obviously, highly perishable produce requires less storage space than less perishable items simply because it cannot be held for long periods without losing quality. If the construction budget will allow, it is advisable to construct enough storage space for at least one day s maximum harvest of the most perishable commodities and even more for the less perishable items. It is much easier to build adequate storage space initially than to add space later. Cost per square foot decreases and energy efficiency increases with the size of the facility. Adequate storage space should not be overlooked, since one of the major benefits of a postharvest cooling facility is the marketing flexibility it allows by providing short- term storage. On the other hand, excess (unused) storage space is a waste of energy and money.To determine the amount of refrigerated space to build, use the following formula:

$$V = 2.5 \text{ X } (C + S) \tag{2.22}$$

Where:

V = volume of the refrigerated space in cubic feet

C = maximum number of bushels to be cooled at any one time

S = maximum number of bushels to be stored at any one time

After you have determined V, divide it by the ceiling height in feet to obtain cooling room floor area in square feet. Keep in mind that the ceiling height should be no more than 18 inches greater than the maximum stacking height of the produce you intend to cool. For produce packaged in bulk, volume must be converted to bushels before applying the above equation.

2.4.2 Agricultural produce packages

The fresh produce industry uses a bewildering array of packaging containers, such as fiberboard cartons, bulk boxes, baskets, wire bound cartons, and trays (Figure 1). The types of package you select should always conform to the standard type used by the wholesale market. Produce marketed in nonstandard containers often does not sell easily.

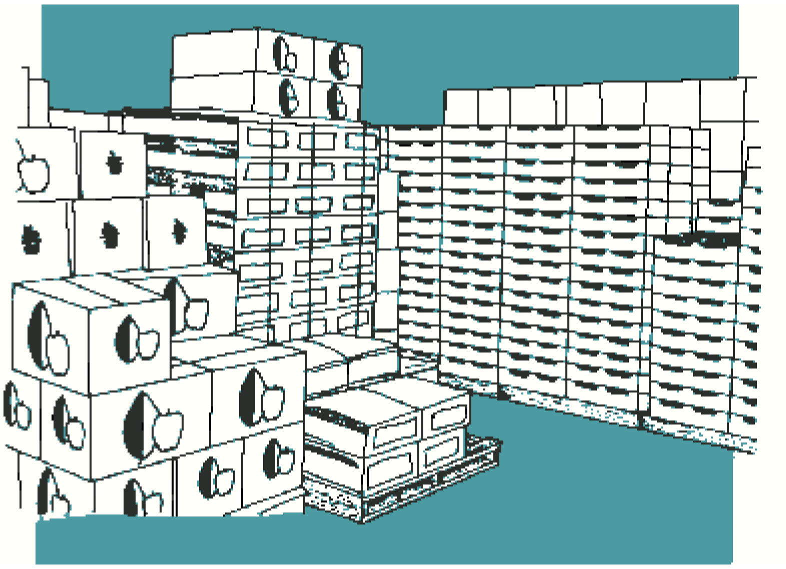


Figure 2.12 Common produce packages.

Be sure to allow enough space in your floor plan for aisles and walkways. They must provide ready access to all the produce stored in the room. For small to medium cooling rooms, devoting 25 percent of the total floor space to aisles and walkways is not excessive. Since produce containers should never be allowed to touch interior or exterior walls, reserve at least an additional 6 inches of space for good air circulation. There are also limits as to how high produce containers may be stacked. The maximum height varies with the commodity and type of package but should not exceed a safe level nor damage the produce. To allow for good air circulation, produce should never be stacked closer than 18 inches to the ceiling. Whether or not you anticipate the use of forced-air cooling, allow sufficient space for active cooling. That is, allow space to install forced-air fans or to spread the produce out for rapid cooling. If the produce volume is sufficient to justify the use of a lift truck and hence palletized loads, their dimensions should be considered in the design of the facility. Doors and aisles should be no less than 1 1/2 times the width of the lift trucks. Ramps leading to floors above grade should be inclined at a slope of no more than 1 to 5. It is also convenient to include a raised dock for loading trucks and trailers.

2.4.3 Location and layout of cold room

The location chosen for the cooling facility should reflect its primary function. If you plan to conduct retail sales of fresh produce from the facility, it should be located with easy access to public roads. A retail sales operation located away from the road, particularly behind dwellings or other buildings, discourages many customers. Adequate parking for customers and employees, if any, must be provided. If the cooling facility is used in connection with a pick-your-own operation, it is best to locate it near restrooms and retail sales areas. If, however, the primary function of the cooling facility is to cool and assemble wholesale lots, ease of public access is less important. In this case, the best location may be adjacent to the packing or grading room. In addition to housing grading and packing equipment, the space could be used to store empty containers and other equipment and supplies when it is not needed for cooling. All cooling and packing facilities should have convenient access to fields or orchards to reduce the time from harvest to the start of cooling .Regardless of how it is used, the facility will need access to electrical power and water. For larger cooling rooms requiring more than about 10 tons of refrigeration in a single unit, access to three-phase power will be necessary. The location of existing utility lines should be carefully considered, as connection costs can be prohibitive in some rural areas. Consult your local power company for details. In addition, it is a good idea to anticipate any future growth when locating and designing your facility. Before you begin construction, familiarize yourself with any applicable laws, regulations, and codes pertaining to construction and electrical systems, worker health and safety, and the handling and storage of food products.

2.4.4 Design and construction

The construction of a produce cooling and storage facility is an investment in quality maintenance. Therefore, the materials and workmanship of the facility itself should be of the best possible quality. Many different construction materials are suitable for such a project. The difficulty is deciding which ones are the most appropriate and cost effective for your application. Many problems can be avoided by paying particular attention during the construction phase to the items discussed in the following sections.

2.4.4.1 Foundation and floor

Almost all postharvest cooling facilities built nowadays are constructed on an insulated concrete slab with a reinforced, load-bearing perimeter foundation wall. The slab should be built sufficiently above grade to ensure good drainage away from the building, particularly around doors. The floor should also be equipped with a suitable inside drain to dispose of wastewater from cleaning and condensation. The floor of a refrigerated room must support heavy loads and withstand hard use in a wet environment but still provide an acceptable measure of insulation. The slab floor should be at least 4 inches of wire-mesh-reinforced concrete over 2 inches of waterproof plastic foam insulation board such as DOW Styrofoam or equivalent. Five or even 6 inches of concrete may be necessary for situations where loads are expected to be unusually heavy. The need for floor insulation is often poorly understood and therefore neglected to cut cost. This is false economy, however, since the insulation will pay for itself in a few seasons of use. If the room is to be used for long-term subfreezing storage, it is essential that the floor be well insulated with at least 4 inches of foam insulation board (having a rating of R-20 or greater) to prevent ground heave. Any framing lumber in contact with the concrete floor must be pressure treated to prevent decay, especially the sill plates and lower door frames, which may be in long-term contact with water. Although no produce would normally come into contact with it, the lumber must be treated with an approved nontoxic material. Information on the toxicity of treated lumber should be obtained from the building materials supplier. Additional information is available in Extension publication AG-99-1, *Pressure-Treated Southern Pine: Some Questions and Answers*. During construction, the interface between the underside of the sill plate and the floor must be sealed to prevent the movement of water. This is easily done by completely coating the underside of the sill plate with a heavy layer of suitable sealant before securing it to the foundation pad with anchor bolts. The sill plate must be adequately secured to the floor to prevent the building from moving off the foundation in a high wind.

2.4.4.2 Insulation of Cold Room Walls

Thermal energy always flows from warm objects to cold ones. All materials, even good conductors like metals, offer some resistance to the flow of heat. Insulation, however, is any material that offers high resistance to the flow of energy. Hundreds of different materials have been used at one time or another for thermal insulation. Since selecting the proper insulation is one of the most important building decisions you will make, it is important that the material be not only cost effective but also correct for the job. The characteristics of insulation materials differ considerably. Suitability for a particular application, not cost, should be the deciding factor in choosing a material. Some of the important characteristics that should be considered are the product s R-value, its cost, and the effects of moisture on it.

R-Value. A measure of an insulation s resistance to the movement of heat is its R-value. The R (for resistance) number, is always associated with a thickness; the higher the R-value, the higher the resistance and the better the insulating properties of the material. The R-value can be given in terms of a 1-inch-thick layer or in terms of the total thickness of the material. The total resistance to the flow of heat through any insulated wall is simply the sum of the resistances of the individual components. That is, in addition to the thermal resistance of the insulation, the inside and outside sheathing, layers of paint, and even the thin layer of air next to the surface contribute to the wall s overall thermal resistance. Although they are highly weather resistant and require little upkeep, metal sheathing materials are very poor insulators. When specifying building materials, be sure to select those with the best combination of economic value and thermal resistance. The R-values of common building materials are listed in Table 3.

Table 2. 4 Insulation R-Values for Common Building Materials

	R-Value	
Material	1 inch thick	Full thickness of material
Batt and Blanket Insulation		
Glass wool, mineral wool, or fiberglass		3.50
Fill-Type Insulation		
Cellulose		3.50
Glass or mineral wool		2.50-3.00
Vermiculite		2.20
Wood shavings or sawdust		2.22
Rigid Insulation		
Plain expanded extruded polystyrene		5.00
Expanded rubber		4.55
Expanded polystyrene molded beads		3.57
Aged expanded polyurethane		6.25
Glass fiber		4.00
Polyisocyranuate		8.00
Wood or cane fiber board		2.50
Foamed-in-Place Insulation		
Sprayed expanded urethane		6.25
Urea-formaldehyde		4.20-5.50
Building Materials		

Solid concrete	0.08	
8-inch concrete block, open core	1.11	
8-inch lightweight concrete block, open core	2.00	
8-inch concrete block with vermiculite in core	5.03	
Lumber, fir or pine	1.25	
Metal siding	<0.01	
3/8-inch plywood	1.25	0.47
1/2-inch plywood	1.25	0.62
Masonite particleboard	1.06	
25/32-inch insulated sheathing	2.06	
1/2-inch Sheetrock	0.45	
1/2-inch wood lapsiding	0.81	

2.4.5 Cost of insulation materials

The cost of insulation varies considerably with the type, whether expressed in dollars per square foot per inch of thickness or dollars per square foot per unit of thermal resistance (R). For example, even though the R-value per inch of polyisocyranuate (Table 2.4) is more than twice that of loose-fill cellulose, the cellulose may actually be less expensive in terms of insulating value per dollar. Of the insulation materials commonly used for refrigerated rooms, loose-fill cellulose is usually the least costly, followed by batts and blankets, then various foam sheet materials, and finally sprayed or foamed-in-place materials, which are the most expensive. Sprayed-on and foamed-in-place insulations have the added advantage of sealing an otherwise leaky structure and thereby greatly reducing infiltration. Sprayed-on foam also significantly reduces labor and material costs because an interior panel wall is not required. Certain types of foam insulation may constitute a fire hazard if carelessly handled, and care should therefore be exercised. Check local fire and building codes. In selecting any insulation material, carefully consider the cost associated with installation and any additional material costs.

2.4.6 Effects of moisture on insulation materials

In most types of insulation the flow of heat energy is impeded by small cells of trapped air distributed throughout the material. When the insulation absorbs moisture, the air is replaced by water and the insulating value is greatly reduced. For this reason, insulation should be kept dry at all times. With the exception of most plastic foam insulations, which are essentially waterproof, all insulation materials must be used with a suitable vapor barrier. A 4-mil polyethylene sheet is normally installed on the warm side (outside) of the insulation, the opposite of the normal practice for house construction. This placement prevents the formation of condensation on and within the insulating material. The vapor barrier sheet must be continuous from floor to ceiling. Where two sheets join, they should overlap 12 inches and be positively sealed (for example, with duct tape) doors and other hardware Items. The door is a critical part of a cooling facility. Improperly built or maintained doors can waste large quantities of energy. Doors should have as much insulation as the walls and should be well weather stripped to reduce the infiltration of warm air. Door gaskets should always provide a good seal. Door seals can be checked by inserting a thin sheet of paper between the door and the seal area and then closing the door. The seal is acceptable only if resistance is felt when the paper is pulled out. Remember that a large single sliding or swinging door is much easier to keep tight than a set of double swinging doors.

All large doors have a tendency to sag over time unless they are diagonally braced and well supported. Use only the best grade of hinges and latches. Be sure that the door can be opened from the inside. Plastic strip curtains are often added to reduce energy loss when the door must remain open for long periods. These curtains allow free entry and exit by people, produce, and fork trucks but block the mixing of inside and outside air, which can waste a substantial amount of energy. Although there are many ac-ceptable designs, three door section details that have been proven in actual use are shown in Figure 3.

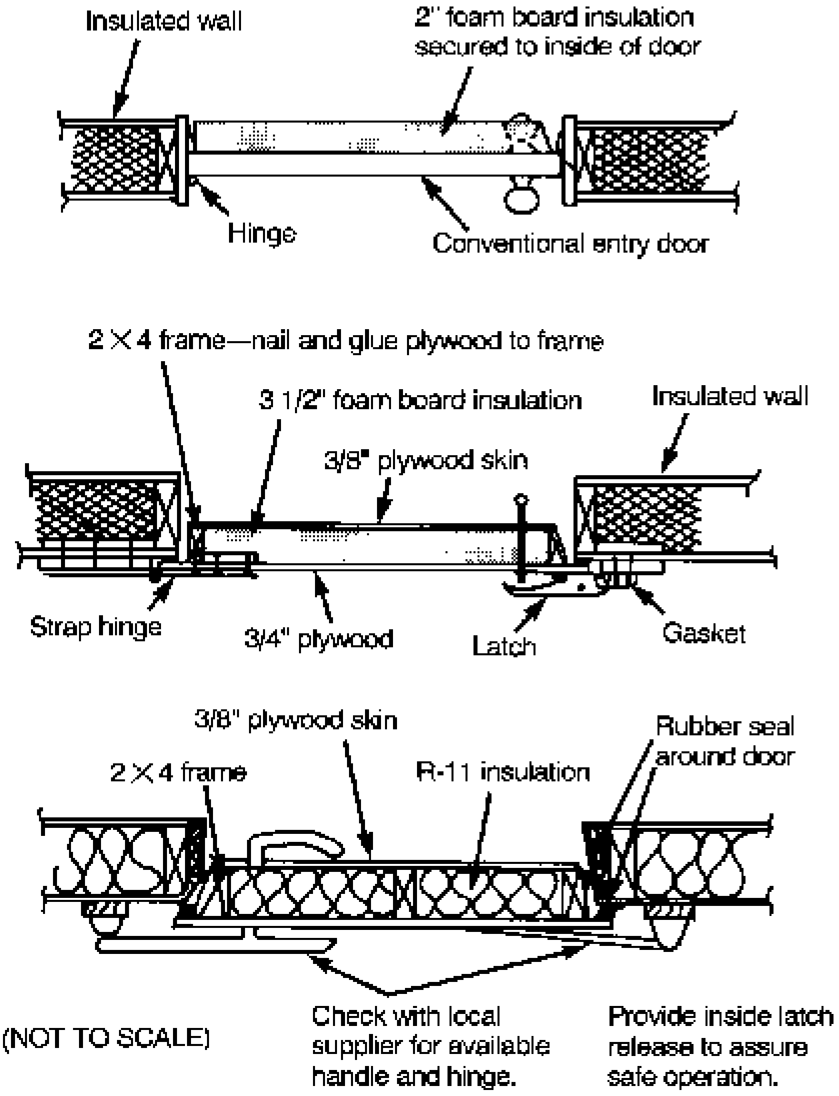


Figure 2.13 Three acceptable door designs.

2.4.7 Calculation of refrigeration heat load

The optimal storage temperature must be continuously maintained to obtain the full benefit of cold storage. To make sure the storage room can be kept at the desired temperature, calculate the required refrigeration capacity using the most severe conditions expected during operation. These conditions include the mean maximum outside temperature, the maximum amount of produce cooled each day, and the maximum temperature of the produce to be cooled. The total amount of heat that the refrigeration system must remove from the cooling room is called the *heat load*. If the refrigeration system can be thought of as a heat pump, the refrigerated room can be thought of as a boat leaking in several places with an occasional wave splashing over the side. The leaks and splashes of heat entering a cooling room come from several sources:

Heat conduction - heat entering through the insulated walls, ceiling, and floor;

Field heat - heat extracted from the produce as it cools to the storage temperature;

Heat of respiration - heat generated by the produce as a natural by-product of its respiration;

Service load - heat from lights, equipment, people, and warm, moist air entering through cracks or through the door when opened. .

Heat conduction (HC). Heat is conducted into the cooling room through the walls, ceiling, and floor. The amount of heat flowing through these surfaces is a function of their thermal resistance (R-value), their area, and the temperature difference between one side and the other.

$$\text{HC (Btu/hr)} = \frac{\text{Wall area (sq ft) X Temp. Difference (F)}}{\text{R-value (sq ft F/Btu)}} \qquad (2.23)$$

2. Field Heat on Agricultural Products

The second source of heat is the warm produce brought into the cooling facility. The heat energy it contains is called *field heat*. The amount of field heat is usually calculated from the mean maximum monthly temperature in this example, 80 F. The apples are to be cooled from a field temperature of 80 F to the optimum cold storage temperature of 32 F within 24 hours.

Field heat, FH, is the product of the specific heat, SH, of the crop (the amount of heat energy it holds per degree), the difference, DT, between the field temperature and the storage temperature, and the weight, W, of the produce.

$$\text{FH (Btu/hr)} = \text{SH (Btu/lb/F) X DT (F) X W (lb)} \qquad (2.24)$$

Heat of respiration. The third source of heat is the respiration of the crop itself. Horticultural crops are alive and give off heat as they respire. The amount of heat produced depends on the temperature, the crop, and the conditions and treatment the crop has received.

Service load. The fourth source of heat comprises a number of miscellaneous items and is called the *service load*. It includes heat given off by equipment such as lights and fans and by people working in the storage room, heat brought into the storage area by warm air when the door is opened, and heat that enters by air infiltration past faulty door gaskets and through other cracks. The amount of heat contributed by these sources is usually very difficult to deter-mine accurately. Service load is therefore dealt with collectively and estimated to equal 10 percent of the heat from the other three sources: conductance, field heat, and heat of respiration. The service load, SL, is therefore:

2.4.8 Sizing the refrigeration systems

As discussed previously, refrigeration systems are rated by how much heat they will move or displace in a given length of time. The standard unit of rating is the ton. Since 1 ton of refrigeration equals 288,000 Btu per 24 hours, or 12,000 Btu per hour

2.4.9 Other factors to consider in a cooling facility

Condensation and humidity- The cooling coils of the refrigeration system (Figure 4) must be colder than the air in the room if the air is to be cooled. The larger the temperature difference, the greater the rate of heat transfer and the smaller (and less expensive) the cooling coils. However, the colder the coil surface, the more water vapor from the air will condense on the coils, either as a liquid or as ice. Evaporator coil condensation represents wasted refrigeration capacity and should be minimized. Allowing hot, humid air to enter the cooling room is particularly costly because the refrigeration system must not only cool the air but also condense the additional water vapor.

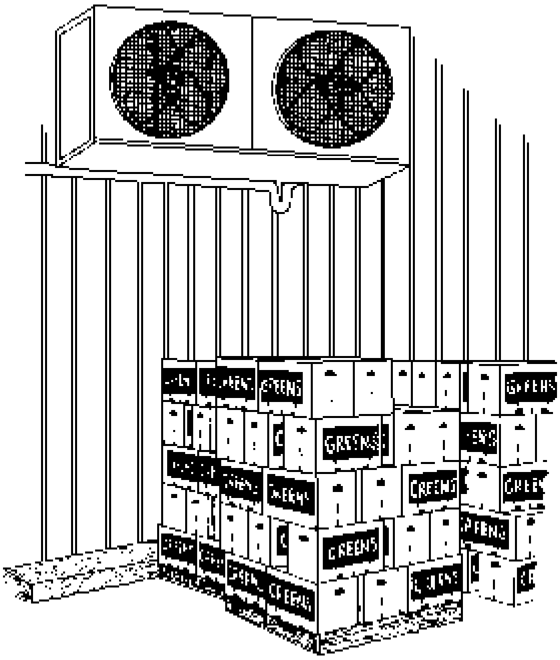


Figure 2.14 Evaporator coils inside a cooling room.

Besides substantially reducing the energy efficiency of the system, condensation of water reduces the relative humidity of the air. Since the optimum storage humidity for most produce is 90 percent or greater, either moisture must be added with a humidifier or the difference between the air and coil temperatures must be minimized. The temperature difference can be reduced by increasing the size of the coils enough that the air-to-coil temperature differential is 5 F or less. Not all refrigeration contractors are aware of the special needs of produce cooling, so when purchasing a system be sure to specify a 5 F maximum air-to-coil differential. The system will be slightly more expensive, but the benefits will soon pay for the difference in cost. Table 8 lists the recommended maximum coil-to-air temperature differential for various relative humidities.

Table 2. 5 Maximum Evaporator Design Temperature Differential

Desired Relative Humidity (percent)	Design Temperature Differential (F)
98	5
95	8
92	9
90	10
88	11
86	12
84	13
82	14
80	15
76	16
70	18

If the cooling room temperature is below 36 F, the coil temperature must be below freezing, and ice will therefore accumulate on the coil surface. The ice acts as an insulator, greatly reducing the coil's capacity to absorb heat from the air. This ice must be removed periodically by some type of defrosting mechanism, such as electrical resistance heaters, a warm water spray, or the momentary reversing of the refrigerant flow. If the refrigeration system has sufficient capacity, it may be allowed to remain off for 6 to 8 hours to let the ice melt naturally without adding supplemental heat. Mechanisms designed specifically to aid de-frosting introduce heat into the room to melt evapor-ator ice, thus adding to the total cooling load. The amount of heat added, although small, should be taken into account when calculating refrigeration unit size.

Sanitation and maintenance; It is essential that storage rooms and containers be clean and sanitary. All accumulations of condensation water should be piped outside. Clean all storage rooms thoroughly before filling them. If molds are found growing inside the room, disinfect the surfaces with a 0.25 percent solution of sodium hypochlorite (1 gallon of household chlorine bleach in 20 gallons of water) applied with a high-pressure washer. Allow the room surfaces to air dry for several days. Refrigeration coils, fans, and ducts should be inspected and cleaned regularly. Refrigeration coils in particular can become clogged with dust and dirt, substantially decreasing their thermal efficiency.

2.5 Color Measurement of Stored Agricultural Products

The color measurement is normally done in an indirect or direct way. Direct method employ the use of digital color meter or spectrophoto meter to estimate the color changes of foods directly in color values approved by international color commission (CIL).It views object just like human eye. The indirect method utilizes computer vision system (CVS) in which the object image is captured using a digital camera of a standard pixel in RBG form then a computer software produces the RGB equivalent in color values. These values can be converted in CIL-Lab value by the use of a formula listed below (Yam and Papadakis, 2004), the method is simpler and faster compared to other method (Maskan, 2001). Hunter Laboratory system is a type of measuring color systems. It has proven valuable in describing visual color deterioration and providing useful information for quality control in various fruits and vegetables during drying and storage such as mango slices (Akoy *et al*., 2008), kiwifruit slices (Mohammadi *et al*., 2008) and spinach (Dadali *et al*., 2007) . The color parameters are expressed as L (lightness), a (redness/greenness) and b (yellowness/blueness). The Hunter “L” value represents the lightness or darkness of a sample on a scale of 0 to 100 (100 being white and 0 being black). Hunter “a” value represents the greenness or redness of the sample (-50 being green and +50 being red). Hunter “b” value is also rated on a scale of -50 to +50, with -50 representing blue and +50 representing yellow. L*,a* and b* estimation are (Mohammadi *et al*., 2008);

$$L^{*} = \frac{Lightness}{255} \times 100 \qquad (2.25)$$

$$a^{*} = \frac{240a}{255} - 120 \qquad (2.26)$$

$$b^{*} = \frac{240b}{255} - 120 \qquad (2.27)$$

Where, a, b and l (lightness) are the CVS values. a*, b* and L* are actual CIL values, ∆E indicates the total color change of a sample in comparison to color values of an ideal sample having color values of L*, a* and b*.. The total color change (∆E) parameter is calculated as follows (Ozilgin., 2011):

$$\Delta E = \left[(L^{*} - L^{**})^{2} + (a^{*} - a^{**})^{2} + (b^{*} - b^{**})^{2} \right]^{0.5} \qquad (2.28)$$

Where, L* is the lightness of samples at storage time1; L** is the lightness of dried samples at storage time2; a* is the redness of samples at storage time1; a** is the redness of dried samples; b* is the yellowness of fresh samples at storage time1 and b** is the yellowness of dried samples at storage time2.

Browning index (BI) represents the purity of brown color and is considered as an important parameter associated with browning (Mohammadi et al., 2008). The browning index after drying was calculated as follows (Dadali et al., 2007b):

$$BI = \frac{[100(x - 0.31)]}{0.17} \qquad (2.29)$$

$$x = \frac{(a^{**} + 1.75L^{**})}{(5.645L^{**} + a^{*} - 3.012b^{**})} \qquad (2.30)$$

L,a and b as defined above.

2.6 Storage Studies of Dried Tomato

Studies of storage of dried tomatoes were conducted both nationally and internationally. Peter (2011) stored dried tomato in a polyethylene film at ambient condition for a period of six month measuring some quality indicators monthly. The quality indicators measured were, vitaminC, vitamin A, calcium, phosphorous, potassium, b-carotein and color. Mildred et al,(2006) investigated the changes in amino acid of dried tomato under storage condition. An increased of amino acid was found to be independent of storage temperature. A simultaneous decrease in certain amino acids was accelerated at higher storage temperature; this loss of amino acids may be involved in non-enzymatic browning reactions. Hossain et al (2009) investigated the effect of moisture content (18%,24%,30%),storage temperature and time on color, ascorbic acid lycopene and flavonoids of dried tomato halves stored at 20^{O}C and 5^{O}C for five month. All the quality indicators significantly decreases at higher temperature and moisture content, while no significant difference were recorded at low temperature and low moisture content. The higher temperature storage can be improved with packaging. Bilge et al (2012) analyzed the color stability of dried tomato based of storage time, temperature and packaging. Color was measured using color meter CR4000, color stability was achieved with vacuum packaging at temperature of 20^{0}C for a period of nine month. Camargo et al. (2012) investigated the shelf life of dried tomato stored at ambient and 4^{0}C temperatures for 90 days. Both the appearance and sensory characteristics of the ambient stored tomato fell below consumer expectation, while refrigerated storage maintained its characteristics throughout the storage period.

2.7 Moisture Content and Total Solids of Agricultural Products

2.7.1 Moisture content of foods

The moisture content of foods varies greatly as shown in Table 2.6. Harris (1999). Water is a major constituent of most food products. The approximate, expected moisture content of a food can affect the choice of the method of measurement. It can also guide the analyst in determining the practical level of accuracy required when measuring moisture content, relative to other food constituents.

Forms of Water in Foods- The ease ofwater removal fromfoods depends on how it exists in the food product. The three states of water in food products are:

1. Free water: This water retains its physical properties and thus acts as the dispersing agent for colloids and the solvent for salts.
2. Adsorbed water: This water is held tightly or is occluded in cell walls or protoplasm and is held tightly to proteins.
3. Water of hydration: This water is bound chemically, for example, lactose monohydrate; also some salts such as $Na_2SO_4 \cdot 10H_2O$. Depending on the form of the water present in a food, the method used for determining moisture may measure more or less of the moisture present. This is the reason for official methods with stated procedures AOAC (2007). However, several official methods may exist for a particular product. For example, the AOAC International methods for cheese include: Method 926.08, vacuum oven; 948.12, forced draft oven; 977.11, microwave oven; 969.19, distillation AOAC (2007). Usually, the first method listed by AOAC International is preferred over others in any section.

Sample Collection and Handling-These procedures are perhaps the greatest potential source of error in any analysis. Precautions must be taken to minimize inadvertent moisture losses or gains that occur during these steps. Moisture Content of Selected Foods

Table 2. 6 Moisture Content of some Food Items

Food Item	Percent Moisture (Wet Basis)
Cereals, bread, and pasta Wheat flour, whole-grain	10.3
White bread, enriched (wheat flour)	13.4
Corn flakes cereal	3.5
Crackers saltines	4.0
Macaroni, dry, enriched	9.9
Dairy products	
Milk, reduced fat, fluid,	89.3
Yogurt, plain, low fat	85.1
Cottage cheese, low fat or 2% milk fat	80.7
Cheddar cheese	36.8
Ice cream, vanilla	61.0
Fats and oils	
Margarine, regular, hard, corn, hydrogenated	15.7
Butter, with salt	15.9
Oil-soybean, salad, or cooking	0
Fruits and vegetables	
Watermelon, raw	91.5
Oranges, raw, California navels	86.3
Apples, raw, with skin	85.6
Grapes, American type, raw	81.3
Raisins	15.3
Cucumbers, with peel, raw	95.2
Potatoes, microwaved, cooked in skin,flesh and skin	72.4
Snap beans, green, raw	90.3
Meat, poultry, and fish Beef, ground, raw, 95% lean	73.3
Chicken, broilers and fryers, light meat, meat and skin, raw	68.6
Finfish, flatfish (flounder and solespecies), raw	79.1
Egg, whole, raw, fresh	75.8
Nuts Walnuts, black, dried	4.6
Peanuts, all types, dry roasted with salt	1.6
Peanut butter, smooth style, with salt	1.8
Sweeteners	
Sugar, granulated	0
Sugar, brown	1.3
Honey, strained or extracted	17.12

US Department of Agriculture, Agricultural Research Service 2009) USDA National Nutrient Database for Standard Reference. Release 22. Nutrient Data Laboratory Home Page, http://www.ars.usda.gov/ba/bhnrc/ndl

Obviously, any exposure of a sample to the open atmosphere should be as short as possible. Any heating of a sample by friction during grinding should be minimized. Headspace in the sample storage container should be minimal because moisture is lost from the sample to equilibrate the container environment against the sample. It is critical to control temperature fluctuations since moisture will migrate in a sample to the colder part. To control this potential error, remove the entire sample from the container, reblend quickly, and then remove a test portion . To illustrate the need for optimum efficiency and speed in weighing samples for analysis, Bradley and Vanderwarn 2005 showed, using shredded Cheddar cheese (2–3 g in a 5.5-cm aluminum foil pan), that moisture loss within an analytical balance was a straight line function. The rate of loss was related to the relative humidity. At 50% relative humidity, it required only 5 s to lose 0.01% moisture. This time doubled at 70% humidity or 0.01% moisture loss in 10 s. While one might expect a curvilinear loss, the moisture loss was actually linear over a 5-min study interval. These data demonstrate the necessity of absolute control during collection of samples through weighing, before drying.

Oven drying methods

In oven drying methods, the sample is heated under specified conditions, and the loss of weight is used to calculate the moisture content of the sample. The amount of moisture determined is highly dependent on the type of oven used, conditions within the oven, and the time and temperature of drying. Various oven methods are approved by AOAC International for determining the amount of moisture in many food products. The methods are simple, and many ovens allow for simultaneous analysis of large numbers of samples. The time required may be froma few minutes to over 24 h.

Any oven method used to evaporate moisture has as its foundation the fact that the boiling point of water is 100◦C; however, this considers only pure water at sea level. Free water is the easiest of the three forms of water to remove. However, if 1 molecular weight (1 mol) of a solute is dissolved in 1.0 L of water, the boiling point would be raised by 0.512°C. This boiling point elevation continues throughout the moisture removal process as more and more concentration occurs. Moisture removal is sometimes best achieved in a two-stage process. Liquid products (e.g., juices, milk) are commonly predried over a steam bath before drying in an oven. Products such as bread and field-dried grain are often air dried, then ground and oven dried, with the moisture content calculated from moisture loss at both air and oven drying steps. Particle size, particle size distribution, sample sizes, and surface area during drying influence the rate and efficiency of moisture removal.

Decomposition of Other Food Constituents

Moisture loss from a sample during analysis is a function of time and temperature. Decomposition enters the picture when time is extended too much or temperature is too high. Thus, most methods for food moisture analysis involve a compromise between time and a particular temperature at which limited decomposition might be a factor. One major problem exists in that the physical process must separate all the moisture without decomposing any of the constituents that could release water. For example, carbohydrates decompose at 100◦C according to the following reaction:

$$C_6H1_2O_6 \rightarrow 6C + 6H_2O \tag{2.30}$$

The moisture generated in carbohydrate decomposition is not the moisture that we want to measure. Certain other chemical reactions (e.g., sucrose hydrolysis) can result in utilization of moisture, which would reduce the moisture for measurement. A less serious problem, but one that would be a consistent error, is the loss of volatile constituents, such as acetic, propionic, and butyric acids; and alcohols, esters, and aldehydes among flavor compounds. While weight changes in oven drying methods are assumed to be due to moisture loss, weight gains also can occur due to oxidation of unsaturated fatty acids and cer Carpenter (1995) obtain other compounds. Nelson and Hulett determined that moisture was retained in biological products to at least 365◦C, which is coincidentally the critical temperature for water. Their data indicate that among the decomposition products at elevated temperatures were CO, CO2,

CH_4, and H_2O. These were not given off at any one particular temperature but at all temperatures and at different rates at the respective temperature in question.

Temperature Control

Drying methods utilize specified drying temperatures and times, which must be carefully controlled. Moreover, there may be considerable variability of temperature, depending on the type of oven used for moisture analysis. One should determine the extent of variation within an oven before relying on data collected from its use. Consider the temperature variation in three types of ovens: convection (atmospheric), forced draft, and vacuum. The greatest temperature variation exists in a convection oven. This is because hot air slowly circulates without the aid of a fan. Air movement is obstructed further by pans placed in the oven. When the oven door is closed, the rate of temperature recovery is generally slow. This is dependent also upon the load placed in the oven and upon the ambient temperature. A 10◦C temperature differential across a convection oven is not unusual. This must be considered in view of anticipated analytical accuracy and precision. A convection oven should not be used when precise and accurate measurements are needed. Forced draft ovens have the least temperature differential across the interior of all ovens, usually not greater than 1◦C. Air is circulated by a fan that forces air movement throughout the oven cavity. Forced draft ovens with air distribution manifolds appear to have added benefit where air movement is horizontal across shelving. Thus, no matter whether the oven shelves are filled completely with moisture pans or only half filled, the result would be the same for a particular sample. This has been demonstrated using a Lab- Line oven (Melrose Park, IL) in which three stacking configurations for the pans were used (Eaton,*et al*., 2005). In one configuration, the oven shelves were filled with as many pans holding 2–3 g of Cheddar cheese as the forced draft oven could hold. In the two others, one-half of the full load of pans with cheese was used with the pans (1) in orderly vertical rows with the width of one pan between rows, or (2) staggered such that pans on every other shelf were in vertical alignment. The results after drying showed no difference in the mean value or the standard deviation. Two features of some vacuum ovens contribute to a wider temperature spread across the oven. One feature is a glass panel in the door. Although from an educational point of view, it may be fascinating to observe some samples in the drying mode; the glass is a heat sink. The second feature is the way by which air is bled into the oven. If the air inlet and discharge are on opposite sides, conduct of air is virtually straight across the oven. Some newer models have air inlet and discharge manifold smounted top and bottom. Air movement in this style of vacuum oven is upward from the front and then backward to the discharge in a broad sweep. The effect is to minimize cold spots as well as to exhaust moisture in the interior air.

Types of Pans for Oven Drying Methods

Pans used for moisture determinations are varied in shape and may or may not have a cover. The AOAC International moisture pan is about 5.5 cm in diameter with an insert cover. Other pans have covers that slip over the outside edge of the pan. These pans, while reusable, are expensive, in terms of labor costs to clean appropriately to allow reuse. Pan covers are necessary to control loss of sample by spattering during the heating process. If the cover is metal, it must be slipped to one side during drying to allow for moisture evaporation. However, this slipping of the cover also creates an area where spattering will result in product loss. Examine the interior of most moisture ovens and you will detect odor and deposits of burned-on residue, which, although undetected at the time of occurrence, produce erroneous results and large standard deviations. Eaton et, al. (2005). Consider the use of disposable pans whenever possible; then purchase glass fiber discs for covers. At 5.5 cm in diameter, these covers fit perfectly inside disposable aluminum foil pans and prevent spattering while allowing the surface to breathe. Paper filter discs foul with fat and thus do not breathe effectively. Drying studies done on cheese using various pans and covers have shown that fat does spatter from pans with slipped covers, and fiberglass is the most satisfactory cover.

Handling and Preparation of Pans

The preparation and handling of pans before use requires consideration. Use only tongs to handle any pan. Even fingerprints have weight. All pans must be oven treated to prepare them for use. This is a factor of major importance unless disproved by the technologist doing moisture determinations with a particular type of pan. Disposable aluminum pans must be vacuum oven dried for 3 h before use. At 3 and 15 h in either a vacuum or forced draft oven at 100◦C, pans varied in their weight within the error of the balance or 0.0001g. Eaton et, al. (2005) . Store dried moisture pans in a functioning desiccators. The glass fiber covers should be dried for 1 h before use.

Control of Surface Crust Formation (Sand Pan Technique)

Some food materials tend to form a semi permeable crust or lump together during drying, which will contribute to erratic and erroneous results. To control this problem, analysts use the sand pan technique. Clean, dry sand and a short glass stirring rod are pre weighed into a moisture pan. Subsequently, after weighing in a sample, the sand and sample are admixed with the stirring rod left in the pan. The remainder of the procedure follows a standardized method if available; otherwise the sample is dried to constant weight. The purpose of the sand is twofold: to prevent surface crust from forming and to disperse the sample so evaporation of moisture is less impeded. The amount of sand used is a function of sample size. Consider 20–30 g sand/3 g sample to obtain desired distribution in the pan. Similar to the procedure, applications, and advantages of using sand, other heat-stable inert materials such as diatomaceous earth can be used in moisture determinations, especially for sticky fruits. The inert matrices such as sand and diatomaceous earth function to disperse the food constituents and minimize the retention of moisture in the food products. However, the analyst must ascertain that the inert matrix used does not give erroneous results for the assay because of decomposition or entrapped moisture loss. Test the sand or other inert matrix for weight loss before using in any method. Add approximately 25 g of sand into a moisture pan and heat at 100°C for 2 h and weigh to 0.1mg. Add 5 ml of water and mix with the matrix using a glass rod. Heat dish, matrix, cover, and glass rod for at least 4 h at 100◦C, reweigh. The difference between weighing must be less than 0.5mg for any suitable matrix Covington AK (ed) (1980).

Calculations

Moisture and total solids contents of foods can be calculated as follows using oven drying procedures:

%Moisture (wt/wt) = (wtH_2O in sample) / (wt of wet sample) × 100 (2.31)

%Moisture (wt/wt)=(wt of wet sample − wt of dry sample) / (wt of wet sample) × 100 (2.31)

%Total solids (wt/wt) =(wt of dry sample / wt of wet sample) × 100 (2.32)

Forced Draft Oven- When using a forced draft oven, the sample is rapidly weighed into a pre-dried moisture pan covered and placed in the oven for an arbitrarily selected time if no standardized method exists. Drying time periods for this method are 0.75–24 h , depending on the food sample and its pretreatment; some liquid samples are dried initially on a steam bath at 100°C to minimize spattering. In these cases, drying times are shortened to 0.75–3 h. A forced draft oven is used with or without a steam table pre-drying treatment to determine the solids content of fluid milks (AOAC Method 990.19, 990.20). An alternative to selecting a time period for drying is to weigh and reweigh the dried sample and pan until two successive weightings taken 30 min apart agree within a specified limit, for example, 0.1–0.2mg for a 5-g sample. The user of this second method must be aware of sample transformation, such as browning which suggests moisture loss of the wrong form. Lipid oxidation and a resulting sample weight gain can occur at high temperatures in a forced draft oven. Samples high in carbohydrates should not be dried in a forced draft oven but rather in a vacuum oven at a temperature no higher than 70◦C.

Vacuum Oven- By drying under reduced pressure (25–100mm Hg), one is able to obtain a more complete removal of water and volatiles without decomposition within a 3–6-h drying time. Vacuum ovens need a dry air purge in addition to temperature and vacuum controls to operate within method definition. In older methods, a vacuum flask is used, partially filled with concentrated sulfuric acid as the desiccant. One or two air bubbles per second are passed through the acid. Recent changes now stipulate an air trap that is filled with calcium sulfate containing an indicator to show moisture saturation. Between the trap and the vacuum oven is an appropriately sized rotameter to measure air flow (100–120 ml/min) into the oven. The following are important points in the use of a vacuum drying oven:

1. Temperature used depends on the product, such as 70◦C for fruits and other high-sugar products. Even with reduced temperature, there can be some decomposition.
2. If the product to be assayed has a high concentration of volatiles, you should consider the use of a correction factor to compensate for the loss.
3. Analysts should remember that in a vacuum, heat is not conducted well. Thus pans must be placed directly on the metal shelves to conduct heat.
4. Evaporation is an endothermic process; thus, a pronounced cooling is observed. Because of the cooling effect of evaporation, when several samples are placed in an oven of this type, you will note that the temperature will drop. Do not attempt to compensate for the cooling effect by increasing the temperature, otherwise samples during the last stages of drying will be overheated.
5. The drying time is a function of the total moisture present, nature of the food, surface area per unit weight of sample, whether sand is used as a dispersant and the relative concentration

of sugars and other substances capable of retaining moisture or decomposing. The drying interval is determined experimentally to give reproducible results.

Microwave Analyzer-Determination of moisture in food products has traditionally been done using a standard oven, which, though accurate, can take many hours to dry a sample. Other methods have been developed over the years including infrared and various types of instruments that utilize halogen lamps or ceramic heating elements. They were often used for “spot checking” because of their speed, but they lacked the accuracy of the standard oven method. The introduction of microwave moisture/solids analyzers in the late 1970s gave laboratories the accuracy they needed and the speed they wanted. Microwave moisture analysis, often called microwave drying, was the first precise and rapid technique that allowed some segments of the food industry to make in-process adjustment of the moisture content in food products before final packaging. For example, processed cheese could be analyzed and the composition adjusted before the blend was dumped from the cooker. The ability to adjust the composition of a product in-process helps food manufacturers reduce production costs, meet regulatory requirements, and ensure product consistency. Such control could effectively pay for the microwave analyzer within a few months. A particular microwave moisture/solids analyzer (CEM Corporation, Matthews, NC), or equivalent, is specified in the AOAC International procedures for total solids analysis of processed tomato products (AOAC Method 985.26) and moisture analysis of meat and poultry products (AOAC Method 985.14). The general procedure for use of a microwave moisture/solids analyzer has been to set the microprocessor controller to a percentage of full power to control the microwave output. Power settings are dependent upon the type of sample and the recommendations of the manufacturer of the microwave moisture analyzer. Next, the internal balance is tared with two sample pads on the balance. As rapidly as possible, a sample is placed between the two pads, then pads are centered on the pedestal, and weighed against the tare weight. Time for the drying operation is set by the operator and "start" is activated.

The microprocessor controls the drying procedure, with percentage moisture indicated in the controller window. Some newer models of microwave moisture analyzers have a temperature control feature to precisely control the drying process, removing the need to guess appropriate time and power settings for specific applications. These new models also have a smaller cavity that allows the microwave energy to be focused directly on the sample.

There are some considerations when using a microwave analyzer for moisture determination: (1) the sample must be of a uniform, appropriate size to provide for complete drying under the conditions specified; (2) the sample must be centrally located and evenly distributed, so some portions are not burned and other areas are under processed; and (3) the amount of time used to place an appropriate sample weight between the pads must be minimized to prevent moisture loss or gain before weight determination. Sample pads also should be considered. There are several different types, including fiberglass and quartz fiber pads. For optimum results, the pads should not absorb microwave energy, as this can cause the sample to burn, nor should they fray easily, as this causes them to lose weight and can affect the analysis. In addition, they should absorb liquids well. Another style of microwave oven that includes a vacuum system is used in some food plants. This vacuum microwave oven will accommodate one sample in triplicate or three different samples at one time. In 10 min, the results are reported to be similar to 5 hr in a vacuum oven at 100◦C. The vacuum microwave oven is not nearly as widely used as conventional microwave analyzers, but can be beneficial in some applications. Microwave drying provides a fast, accurate method to analyze many foods for moisture content. The method is sufficiently accurate for routine assay.

Infrared Drying- Infrared drying involves penetration of heat into the sample being dried, as compared with heat conductivity and convection with conventional ovens. Such heat penetration to evaporate moisture from the sample can significantly shorten the required drying time to 10–25 min. The infrared lamp used to supply heat to the sample results in a filament temperature of 2000–2500 K (degrees Kelvin). Factors that must be controlled include distance of the infrared source from the dried material and thickness of the sample. The analyst must be careful that the sample does not burn or case harden while drying. Infrared drying ovens may be equipped with forced ventilation to remove moisture air and an analytical balance to read moisture content directly. No infrared drying moisture analysis techniques are approved by AOAC International currently. However, because of the speed of analysis, this technique is suited for qualitative in-process use.

Chemical Method:

Karl Fischer Titration- The Karl Fischer titration is particularly adaptable to food products that show erratic results when heated or submitted to a vacuum. In a Karl Fischer volumetric titration, the Karl Fischez reagent (KFR) is added directly as the titrant if the moisture in the sample is accessible. However, if moisture in a solid sample is inaccessible to the reagent, the moisture is extracted from the food with an appropriate solvent (e.g., methanol). (Particle size affects efficiency of extraction directly.) Then the methanol extract is titrated with KFR.

The obnoxious odor of pyridine makes it an undesirable reagent. Therefore, researchers have experimented with other amines capable of dissolving iodine and sulfur dioxide. Some aliphatic amines and several other heterocyclic compounds were found suitable. On the basis of these new amines, one component reagents (solvent and titrant components together) and two-component reagents (solvent and titrant components separate) have been prepared. The one-component reagent may be more convenient to use, but the two-component reagent has greater storage stability. Before the amount of water found in a food sample can be determined, a KFR water (moisture) equivalence (KFReq) must be determined. The KFReq value represents the equivalent amount of moisture that reacts with 1ml of KFR.

Standardization must be checked before each use because the KFReq will change with time. The KFReq can be established with pure water, a water-in-methanol standard, or sodium tartrate dihydrate. Pure water is a difficult standard to use because of inaccuracy in measuring the small amounts required. The water-in-methanol standard is premixed by the manufacturer and generally contains 1mg of water/ml of solution. This standard can change over prolonged storage periods by absorbing atmospheric moisture. Sodium tartrate dehydrate ($Na_2C4H_4O6{\cdot}2H_2O$) is a primary standard for determining KFReq. This compound is very stable, contains 15.66% water under all conditions expected in the laboratory, and is the material of choice to use. The KFReq is calculated as follows using sodium tartrate dihydrate:

$$\text{KFReq } (\text{mgH}_2\text{O/ml}) = (36 \text{ gH}_2\text{O/molNa}_2\text{C4H}_4\text{O}_6 \cdot 2\text{H}_2\text{O} \times S \times 1000) / (230.08 \text{ g/mol} \times A) \quad (2.33)$$

where:

KFReq = Karl Fischer reagent moisture equivalence

S = weight of sodium tartrate dihydrate (g)

A = ml of KFR required for titration of sodium tartrate dehydrate

Once the KFReq is known, the moisture content of the sample is determined as follows:

$$\%H_2O = \text{KFReq} \times \text{Ks } S \times 100 \qquad (2.34)$$

where:

KFReq = Karl Fischer reagent water (moisture) equivalence

Ks = ml of KFR used to titrate sample

S = weight of sample (mg)

Plate 2.1: Automated Karl Fischer volumetric titration unit. (Courtesy of Mettler-Toledo, Columbus, OH.)

The major difficulties and sources of error in the Karl Fischer titration methods are as follows:

1. Incomplete moisture extraction. For this reason, fineness of grind (i.e., particle size) is important in preparation of cereal grains and some foods.

2. Atmospheric moisture. External air must not be allowed to infiltrate the reaction chamber.

3. Moisture adhering to walls of unit. All glassware and utensils must be carefully dried.

4. Interferences from certain food constituents. Ascorbic acid is oxidized by KFR to dehydroascorbic

acid to overestimate moisture content; carbonyl compounds react with methanol to form acetals and release water to overestimate moisture content (this reaction also may result in fading endpoints); unsaturated fatty acids will reactwith iodine, so moisture content will be overestimated.

Dielectric Method- The electrical properties of water are used in the dielectric method to determine the moisture content of certain foods, by measuring the change in capacitance or resistance to an electric current passed through a sample. These instruments require calibration against samples of known moisture content as determined by standard methods. Sample density or weight/volume relationships and sample temperature are important factors to control in making reliable and repeatable measurements by dielectric methods. These techniques can be very useful for process control measurement applications, where continuous measurement is required. These methods are limited to food systems that contain no more than 30–35% moisture. The moisture determination in dielectric-type meters is based on the fact that the dielectric constant of water (80.37 at 20◦C) is higher than that of most solvents. The dielectric constant is measured as an index of capacitance. As an example, the dielectric method is used widely for cereal grains. Its use is based on the fact that water has a dielectric constant of 80.37, whereas starches and proteins found in cereals have dielectric constants of 10. By determining this properly on samples in standard metal condensers, dial readings may be obtained and the percentage of moisture determined from a previously constructed standard curve for a particular cereal grain.

2.8 Measuring the Thermal Conductivity of Solid Materials using Searle Apparatus

Sample Preparation:

Sample were grinded with the grinding machine in to a fine powdered in to 19micron, thereby making the sample to be well homogenized and pore in to a die of about 4cm in diameter. Pellet were made using hydraulic press machine for different Number of tons. Measurements were carried out for about 300s to 600s using thermal conductivity instrument.

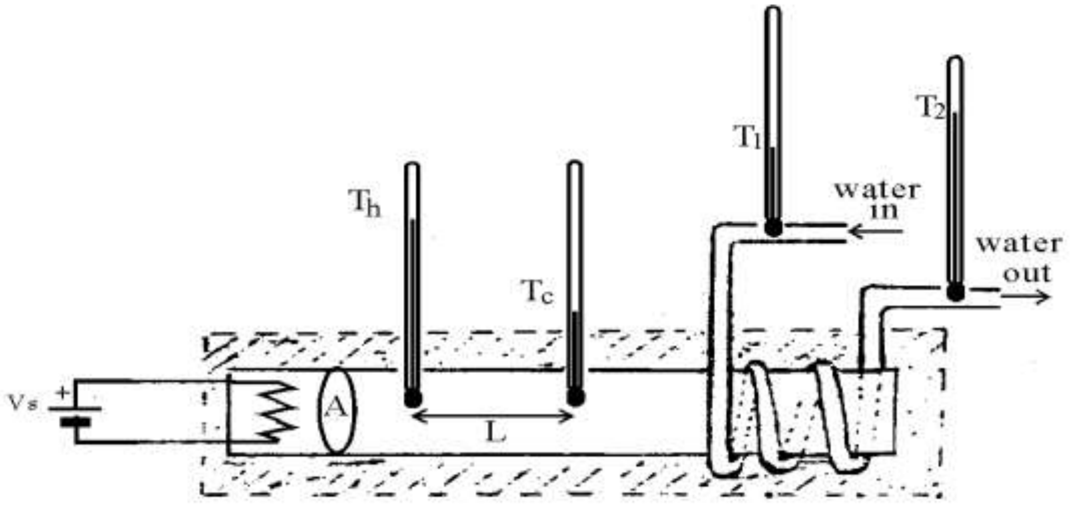


Figure 2.15 Searle's apparatus for measuring thermal conductivity of Solid materials

Experimental set-up:

Using Searle's apparatus (shown below) to measure the thermal conductivity of solid materials. We input heat at one end of the bar by means of an electrical power supply. The other end of the bar we cool by wrapping tubing around it through which water flows at a constant rate. The flowing water will carry off the heat reaching the cold end of the sample bar. In this way we eventually get a balance between the heat input on one end, and the heat carried away at the other end. As a result the temperature at each position of the bar becomes constant in time; we have reached what is called a dynamic equilibrium. The adjective "dynamic" is used since heating and cooling goes on continuously, and there is equilibrium because their net effect is to produce no change). We will now use a technique that applies, at least in principle, to every dynamic equilibrium: we can verify our measurements by measuring the heat flowing *out* as well as by the heat flowing *in*, since they have the same magnitude. We can thus measure the thermal conductivity twice, and a comparison of the two results will give us a good indication of the accuracy of our measurements. When the water carries off heat from the cold end of the sample bar, its temperature increases; by measuring this temperature increase, we can measure the heat output. We must be careful to keep the water flow constant; this can be done using a device called a constant pressure head.

Equation:

$$VIL = A(T_1 - T_2)$$

2.9 Cement Stabilization

Soil stabilization according to Reddy, 2008, is the alteration of any property of a soil to improve its engineering performance. The chief factors affecting stabilization are soil type, cement content, compaction and method of mixing with soil type being the most important (Reddy,2008). The modification of the properties of soil-water-air system makes the soil compatible with desired applications in construction (Hashim, 2010). One of the main functions of the stabilizing medium is to reduce the swelling properties of the soil through forming a rigid framework with the soil mass, enhancing its strength and durability (Anifowose, 2000)]. Portland cement is the most widely used stabilizer for earth stabilization. Cement has the ability to reduce liquid limit (LL) and increase plasticity index (PI) and hence increases the workability of soil. The addition of chemical stabilizers like cement and lime has twofold effects of acceleration of flocculation and promotion of chemical binding. The chemical binding depends upon the type of stabilizers employed (Janz and John 2002). The study of Guettala, 2002 revealed that soils with Plasticity Index (PI) less than 15% are suitable for cement stabilization. In cement stabilization Mesbah, 2004 observed that the content of the cement binder in the mix ranges between 4% and 10% of the soil dry weight. However, Fetra, 2004 posited that if the content of the cement binder is greater than 10% it becomes uneconomical for the production of CSEB.

2.10 Stabilized Pressed Blocks

The materials used for the construction of wall are normally required to possess adequate compressive strength and erosion resistance. Such properties of the soil can be improved by stabilizing it with cementious admixtures such as cement and lime Reddy,2008. The strength of stabilized soil can further be improved by the process of compaction which leads to higher densities, thereby higher compressive strength and better resistance to erosion. Exploring the stabilization and compacting techniques, a cheap yet strong and durable material for wall construction is the stabilized earth block. The merit of these blocks is low-cost, use of locally available material, blocks can be made at site with no transportation cost and simplicity in manufacture (Reddy, 2008 and Janz,2002). It was noted that the strength of such blocks increases with density. CSEB brick requires compaction whether it is static, dynamic or vibro-static methods (Fetra, 2011). In preparing the soil for block production, there is need for careful and correct selection of the soil to get the best result and after the mix was put in the mould, it should be given proper compaction. Proper curing should also be made which prevents rapid drying. A striking contrast between CSEB and conventional bricks is the energy consumed during the production process and carbon emission. CSEB creates 22 kg CO_2/tonne compare to that of concrete blocks (143 kg CO_2/tonne), common fired clay bricks (200 kg CO_2/tonne) and aerated concrete blocks (280-375 kg CO_2/tonne) during production.. In average, cement stabilized earth bricks consumed less than 10% of the input energy as used to manufacture similar fired clay and concrete masonry unit [8]. Production of CSEB requires moderate to low skilled worker since the CSEB manufacture is very simple. It only takes 3 stages process which are: soil preparation, mix compression and the curing (Fetra, 2004 and Guatella, 2002).

2.11 Rehydration Ratio

Fast and complete rehydration is an important property of dried products. The ability to rehydrating itself is affected by the drying conditions, texture characteristics of the dried product, to name but a few (Lewiki, 1998). Drying may cause the osmotic pressure in cell walls to decrease. This means that the increase of water absorption and volume occurs as a result of swollen hydrophilic compounds such as starch and cellulose Keymak, 2002). In addition to water gain, rehydration may also cause soluble solid loss, which is associated with the loss of vitamins, sugar, amino acids and minerals. The rehydration ratio (*RR*), given by the ratio of rehydrated sample mass to the dried sample mass. The equations used to describe kinetics are found in Table 2.7.

Table 2. 7 Equations used to describe the kinetics of rehydration.

Name	Equation Name
Exponential	$RR = RRe - (RRe - 1)\exp(-k.t)$ (2)
Peleg	$RR = (RRe - 1/k2) + t/(k1 + k2.t)$ (3)
Weibull	$RR = RRe + (1 + RRe)\exp(- t/\beta)\alpha$ (4)

RR: rehydration ratio; RRe: saturation rehydration ratio

where *k* is the kinetic constant (min-1), *t* is the time (min), *α* and *β* are parameters from the Weibull equation.

The indices proposed by Lewicki, 1998 were employed to provide information about the influence of absorbed water fluxes and lixiviated solids on material mass increase. The indices are listed in Table 2:8

Table 2.8: Description of the indices used for rehydration.

Equation	Description
$WAC = M_{rh}(100 - S_{rh}) - M_d (100 - S_d) / M_0 (100 - S_0) - M_d(100 - S_d)$ (5)	Water Absorption Capacity
$DHC = M_{rh} . S_{rh} / M_d . S_d$ (6)	Dry Matter Holding Capacity
$RA = WAC . DHC$ (7)	Rehydration Ability

The capacity of water absorption by the dried material is given in Equation 5. It is the ratio of the mass of absorbed water during rehydration to the mass of water removed during drying, where *m* is the sample mass, *s* is the dried solid content (g/g in dry basis) and *rh, d e 0* are subscripts meaning rehydrated, dried and initial sample, respectively. *WAC* varies from 0 to 1 and indicates how much drying reduced the capacity of the product to absorb water. Equation 6 provides information about the capacity of the material to retain soluble solids, as well as the damages to the tissues and their permeability to solute. This also varies from 0 to 1.

Equation 7 evaluates the damages caused by the drying and rehydration processes and the ability of the dried product to rehydrate. Values of *RA* are in the range of 0 to 1. The smaller is *RA* the greater is the damage to the vegetable tissue.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

The materials used in this research were categorized into four groups, construction materials, vegetable materials, packaging materials and instrumentation materials. The project site was at the research reserve field of the Department of Agricultural and Bio-resources Engineering, Ahmadu Bello University, Samaru –Zaria, Kaduna State-Nigeria.

3.1.1 Construction materials

The materials include; lateritic soil, thatch(Hyparrhenia colina), cement, sandcrete blocks (150 mm, thick), rammed earth blocks (100 mm, thick), gravels, sand, wooden poles, planks, plywood, nails, polyethylene film, polypropylene curtains, 2x4 and 2x6 wood section, roofing zinc, cereglat and water. Others are the electrical materials; air-conditioner, distribution box, sockets, switches, service cable, line cables, lamp holders and florescence lamps, sourced within Zaria- Nigeria.

3.1.2 Vegetable materials

The vegetables used were; Baobab Leaves, Okra and Tomato. The tomato was sourced from the Hayin Gada Shika tomato fields in Shika, Okra was purchased from Giwa market and the Baobab leaves were purchased and harvested from Kudan Bushes, all around Zaria, Kaduna State-Nigeria.

3.1.3 Packaging materials

The packaging material includes; Food grade Polypropylene Film (glass type, 0.01mm) and Carton. Food grade polypropylene film was acquired from Viva Plastic Company in Lagos and carton was purchased in Zaria.

3.1.4 Instrumentation materials

Table 3.1: List of Instrumentation Materials used

S/No.	Instrumentation materials	Specification	Sensitivity
01	Rammed earth block mould	230 x 110 x 100 mm	
02	Soil sieve	B52	32µm
03	Hygrometer		
04	Soil stress testing machine		
05	Compression testing machine		
06	Relative humidity meter	0-100%	0.01%
07	Digital thermometer	0-750 oC	0.01 oC
08	Infra-red thermometer	-30 – 750 oC	0.01oC
09	Grain hardness tester		
10	Digital scale	0- 3000gm	0.1gm
11	Autoclave	0-200oC	0.01oC
12	Digital camera	16 mega pissels	
13	Measuring tape	0-100m	0.02m
14	Photo box	$0/45^o$	
15	Questionnaire	50- 100 people	

Software used; MarpleSim 6.0, Gretl 2.0, Matlab, Adobe Photoshop 7.0, CFD 2.0 ,SAS, Excel

3.2 Methods

3.2.1 Baseline survey on dried vegetables and agricultural cold storages facilities in North Western Nigeria.

Rapid appraisal method (Haina *et al*., 2015) was applied in acquiring information on the agricultural cold storage in some selected areas of north western Nigeria. Kano, Kaduna and Katsina state were sampled out for the survey. These states are the hub of most of the cold room in the zone and are highest producers and consumers of dried vegetables (Ofor, 2007). A team of cold room construction engineers were consulted and data were acquired for the locations and ownership of cold rooms in the states within the study areas. Structured questionnaire (Appendix, 5) was designed to capture: cold room type, compressor capacity, evaporator capacity, room size, construction materials, insulation materials, agricultural products stored, room temperature setting, storage capacity, constrains faced and cost of materials of construction. From the consultants, most of the cold rooms are concentrated at the headquarters of the states and in some few developed towns of some states, 50 of the identified cold rooms were physically served (rapid appraisal) with the questionnaire. Due to limited number of cold rooms within the study areas, the survey was extended to North central (Abuja) and North east (Bauchi) cities. The data generated were tabulated and analyzed using excel count-tif tool. For the dry vegetables 100 farmers and marketers in Kaduna, Kano and Katsina states were served with a questionnaire.

3.2.2 Design and construction of an appropriate cool storage system for the dried vegetables

Design procedure: -

(i) Design concept

The cool room should be predominantly made from local construction materials and has low level construction technology with low energy consumption.

(ii) Design considerations

The construction material has to be renewable

Locally available

Low-cost

Low thermal conductivity

Have simplicity of forming

Techno-economic status of vegetable producers and marketers must be considered

Both natural and artificial cooling methods are going to be considered.

Double or cavity wall as shown in Figure 3.1 is going to considered in the room design (for ease of heat control).

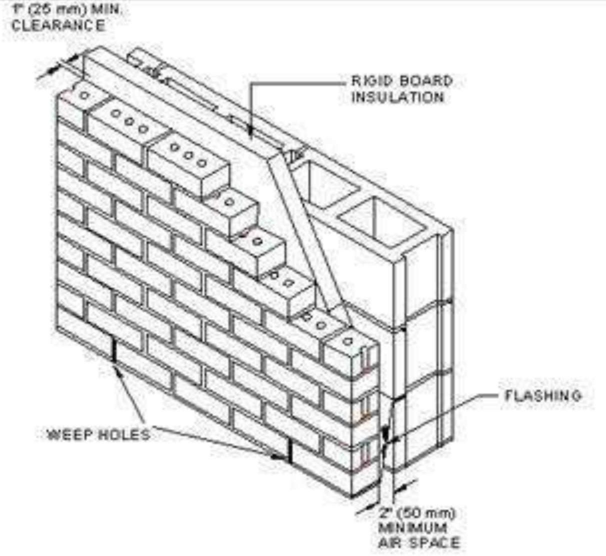


Figure 3.1: Typical Cavity Wall

(iii) Construction materials selection

Walling material: According to the survey conducted, commercially available walling materials in Nigerian building materials market for cold room includes; aluminum / polystyrene panels, steel/polystyrene panels. Other materials readily available for construction in the country are lateritic soils, durable woods, sandcrete blocks, adobe blocks and thatching materials.

Cost of aluminum/polystyrene panel = N83, 028/m^2

Cost of aluminum angle as column = N25, 000/length

These materials are nonrenewable and non-degradable, do not conforms to the above design consideration; as such using stabilized lateritic earth compressed blocks was considered as recommended by Unite Nations Shelter Commission, 2009. Block or brick structural walls provide an efficient combination of structural durability, good building envelope serviceability, attractive appearance, fire and sound resistance, and low construction and maintenance costs. A cavity wall was adopted for this design and from the insulation selection thatch material was recommended to be inserted in to the cavity of the walls of the cool room.

Selection of the laterite soil: The three major laterite soil excavation quarries around Zaria area were investigated for compliance with recommended Nigerian standards (Waziri, 2013). Three samples were taken at the excavation site of the Dufa-dufa borrow pit along Hunkuyi road, the Biye quarries by the Biye village and the DAC quarries behind College of Agriculture farm Samaru-Zaria. These quarries serve soil user for over a hundred years. The samples were taken to Civil Engineering Department of Ahmadu Bello University for classification, determination of Atterberge limits and bulk density according to the recommended standards (BS1377&812 and Abejide, 2007). The results obtained were tabulated and documented (Appendix 3).

Molding of the blocks: From the test results, Dufa-dufa soil conforms to the United Nation Shelter Commission recommendation and therefore adopted for wall construction of the room. A British standard mould for ramped earth blocks of block size (230x110x100mm) was adapted; this mould was acquired from Civil Engineering Department of the Ahmadu Bello University, Zaria (Plate3.1.0, 3.2 & 3.3).

Plate3.1: Rammed Earth Blocks Mould

Plate3.2: Moulded Blocks

Plate 3. 3: Samples of produced stabilized laterite blocks

The structured analysis of lateritic soil from Dufa-dufa quarries gave 70% Sand, 24%Clay and 6% Silt which was close to UN shelter commission recommendation (70%, 23%,7%). The tipper loads of soil were transferred to the construction site (Department of Agricultural and Bio-resources Engineering) and the soil was crushed and sieved using BS No.57 sieve. To stabilize the soil, 6% cement was applied to stabilize the soil mix (Abejide, 2007). Finally soil moulding consistency test was conducted and the result was achieved at soil: cement: water mix ratio of 16:1:3.

First sample of the blocks in the said ratio was produced and cured in concrete laboratory of Civil Engineering Department, ABU-Zaria. After five days curing the blocks were tested in compression (average moisture content of 12%). The strength exceeded the walling earth block limit of $2N/mm^2$ (Waziri, 2013). Mass production of the block proceeded; the product was cured and stored in the laboratory of Agricultural Engineering Department (Plate3.3). While at storage, samples of blocks were taken weekly to laboratory for compression test prior to utilization and the data generated were documented.

Foundation forming materials: From the BS building code (Abejide, 2007)., polypropylene sheet, concrete and thatch were considered for the foundation materials.

Roofing materials: Afara wood, lateritic blocks, laterite mix for rendering and polypropylene sheet were selected.

Door materials: Afara wood (for frames), ply wood panels, grass thatch insulation and polypropylene heat repelling sheet were selected.

(iv) Cool room design

Cool room size: A prototype size of 1500 x 2000 x 2700 mm similar to John, 2012 was adopted, couple to the block thickness of 110 mm and a cavity spacing of the same block thickness. Two rooms each of total volume of 8.1m^3 were considered for construction.

Foundation design: . Soil bearing strength of the project site was measured; two soil samples were taken at the depth of 3m and taken to Civil Engineering Department soil mechanics laboratory for the test and results documented. A strip foundation was adopted for the design of the cool room Depth and with of foundation were computed as;

Estimating load on foundation, considering a cavity wall of the laterite block with thatch material as insulation:

Loads on foundation

i) Load due laterite blocks

ii) Load due to sandcrete blocks

iii) Load due to insulation material

iv) Wind load

v) Load due to roof, floor and also 2person on top

It was assumed that load due to dried vegetables was on damp proof course concrete

Number of laterite block per a given wall (N) considering the longer wall in cavity form

N = Surface Area/(L_b +M_t) (H_b+ M_t)   (Mijinyawa,2004)

Where; L_b = length of block (m), H_b = height of block (m)

M_t = motar thickness (m)

Surface Area (outer wall) = 2.66 x 2.925 = 7.7815 m2

Laterite block dimension, L_b = 0.230m and H_b = 0.110 m

M_t = 0.040m

N = 7.7815/ (0.230 + 0.040) (0.100 + 0.040) = 206blocks per the outer wall

For the inner wall

Surface Area = 2.440 x 2.925 7.137 m^2

N = 7.137/ (0.230 + 0.040) (0.100 + 0.040) = 189 blocks

Total blocks per wall section = 206 + 189 = 395

Adding 10% for load optimization

Blocks needs of the wall = 395 + 40 =435 bocks

Weight of one laterite block = 3.78 kg

Total weight of literite blocks on the foundation = 435 x 3.78 x9.81 = 16.131kN

Mass of insulation material (thatch)

Mi = ρ x v, ρ= thatch bulk density(kg/m3) and v = cavity volume(m^3)

ρ = 56 kg/m3 and v =0.110 x 7.7815 = 0.856 m^3

Mi = 338 x 0.856 = 50 kg

Weight due to insulation material on foundation = 50 x 9.81 = 490.5N

Sandcrete blocks (150mm size) was used for substructure for moisture proofing

No. of sandcrete blocks for 2m length of wall = 15. For two rows of the blocks for cavity wall

Total blocks for the foundation = 15 x2 =30

Avarage mass of one sandcrete block = 18.28kg

Weight due to sandcrete blocks on foundation = 30 x 18.28 x 9.81 = 5.38kN

Wind load on the wall (W)

$W = 0.05\ CAV^2$

Where, C = pressure coefficient, for rectangular wall geometry C=1 (Mijnyawa, 2006)

A = crossectional area of wall facing wind direction (m^2)

V = wind speed (km/hr)

For the chosen wall

A = 7.7815m2 V = 112km/hr (IAR Metro unit, 2004)

$W = 0.05 \times 1 \times 7.7815 \times 112^2 = 4.88kN$

This load act on the outer wall of the cavity, can yield stress ($^{\delta}$)

$^{\delta} = W/A = 4880/7.7815 = 627.1\ N/m^2$

From the laterite block stress test the block endures up to $1621N/m^2$

Thus, the block can withstand the wind load.

Load due on the foundation = Laterite block load +Sandcrete block load + Insulation load+ Wind load + (load due to roofing, floor and two persons)

Assuming load due to roofing, floor and two persons to amount to 15% of the four loads

Load due on the foundation = 16.131 + 5.38 + 2.84 + 4.88 + (15/100 x 29.231) = 33.611kN

This load acts on the wall span of 2m length.

33.611/2 = 16.805 kN/m

To calculate the foundation depth, the mean soil bearing strength as measured in the Civil Engineering based on BS code = $178.2\ kN/m^2$.

Based on BS code the actual design load = 1.6 x 16.805 = 26.888kN/m

Foundation depth = 26.888/178.2 = 15cm

Foundation width = 33.61 x1.6/178.2 x 1 = 30cm, three laterite blocks were to be laid in the foundation such that the width of one will serve as the cavity spacing. The width of the block is 11cm, therefore three give a total of 33cm. thus the foundation width was up scaled to 33cm.

Plate 3.4:Hard core foundations installation

Plate3.5:Foundation insulation

v) Insulation Selection

According to the design consideration, bio-insulation was considered, five materials; Koalin, Thatch grass, Thatch reed, Air and stabilized laterite soil material were considered, thermal conductivity of these materials were tested using Searl test instrument in liaison with Physic Department of Ahmadu Bello University-Zaria. The physical properties of the thatch material harvested in the premises of ABU were measured in processing laboratory of Department of Agricultural and Bio-resources Engineering. Cost and availability were investigated and selection was made based on the decision matrix as contained in Table 3.1;

Table 3.2: Insulation selection decision matrix

Material	Conductivity W/mk	Cost	Availability	Simplicity of forming
Kaolin	0.5325	High	Limited	Simple
Stabilized laterite soil block	0.08906	Low	Available	Simple
Thatch grass	0.05	Very low	Readily available	Very simple
Air	0.03	Non	Readily available	Very simple
Thatch reed	0.6589	High	Available	Simple

Air and Thatch proved to have more convenient condition to be used as insulation material. However, air thermal conductivity is affected by several factors, to that effect a practical situation of cool room was modeled using MapleSim 6.0 software to ascertain which among the two materials serve better. All the thermal and physical properties of these materials were inputted in to the model as measured (appendix 1). The block diagrammed of the model shown in Figure 3.2 below represents the cavity wall, the thatch and air positioned in the cavity. The model curves were generated and presented in results.

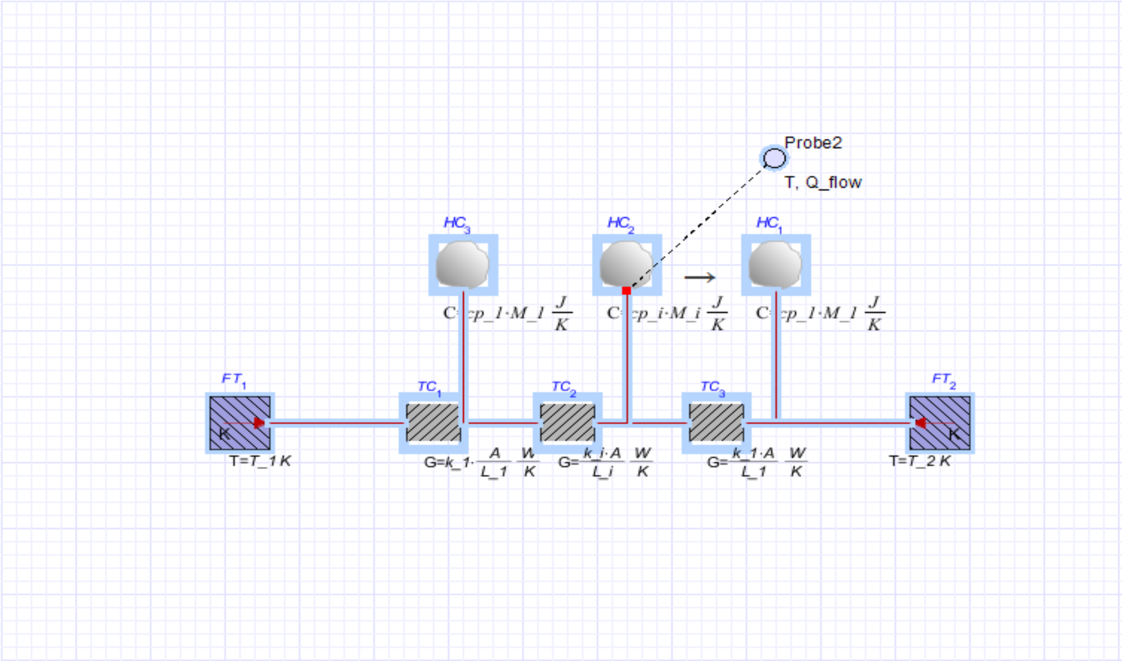


Figure 3.2: Block diagram of the insulation modeling

Quantity of thatch required for the room: Foundation; installation volume x thatch density =

1.5 x 2 x 0.304 x 56.4 = 51.4 kg

Walls = cavity volumes x thatch density = ((3 x 2.1x0.1) 2 + (3 x 3.1x 0.1) 2) x 56.4 = 176kg

Roof = 1.9 x 2.4 x 0.304x 56.4 = 78.2kg; Total = 51.4 + 78.2 +176 = 305.6 kg

Plate 3.6: Thatch (Hyparrhenia collina) material used

3.2.3 Selection of cooling equipment for the Storage

The walls heat gains, foundation and roof heat contributions as well as the products heat to be removed were considered as heat loads to be used for the selection of the cooling equipment. The heat transfer equations used are indicated below.

3.2.3.1 Overall heat transfer coefficient (U)

The overall heat transfer coefficient equation for multiple wall design as given by ASHRAE (2015); was used as:

$$U = \frac{1}{(\frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3} + \cdots .....)} \qquad 3.1$$

Where, x = thickness of each layer 1, 2, 3…... (m)

k = heat conductivity of each layer

For Air film, the overall heat transfer coefficient equation for three wall layer is presented as

$$U = \frac{1}{\frac{1}{f_o} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3} + \frac{1}{f_i}} \qquad 3.\ 2$$

Where, f_o= insulating effect of outer air film.

f_o= 6.5 when the building is exposed to high air velocity.

f_i = 1.65 when the building is not exposed to high air velocity.

f_i = insulating effect of inside air film.

3.2.3.2 Determination of quantity of wall heat

The quantity of heat to be removed is determined using equation 3.3 as give by Chris, (2010)

$$. \ Q = UA\Delta T \qquad 3.3$$

Where, Q = quantity of heat required to be removed

U = the overall heat transfer coefficient (W/m^2K)

A = Surface area based on outside dimension (m^2)

ΔT = changes in temperature (^oK)

3.2.3.3 *Determination of quantity of product heat to be removed*

The quantity of product heat to be removed is determined using the equation 3.3 as given by Chris, (2010)

$$Q_{12} = M_p C_p (T_1 - T_2) \qquad 3.4$$

Where, Q_{12} = quantity of product heat to be removed

M_p = Mass of the product (kg)

C_p = Specific heat capacity of the product (J/kgK)

T_1& T_2= Initial and final temperature of product (K)

3.2.3.4 *Quantity of heat to be removed Wall 1, 2, 3 and 4*

The wall1 consist of two composite materials, viz Laterite block and Thatch. The thatch was positioned at the centre of two laterite blocks thereby formed three layers of laterite-thatch-laterite composition. Using equation3. 2, the heat transfer coefficient U_{w1} becomes

$$U_{w1} = \frac{1}{\frac{1}{fo}+\frac{x_1}{k_1}+\frac{x_2}{k_2}+\frac{x_3}{k_3}+\frac{1}{f_i}} \qquad 3.5$$

Where, x_1, x_2, x_3 = thickness of laterite, thatch and laterite layers, respectively = 0.11 m

k_1, k_2, k_3 = Heat conductivity of laterite, thatch and laterite layer respectively

$k_{1=}$ 0.08906 W/mK = k_3

$k_{2=}$ 0.05 W/mk

f_o= 6.5

f_i = 1.65

$$U_{w1} = \frac{1}{\frac{1}{6.5}+\frac{0.11}{0.08906}+\frac{0.11}{0.05}+\frac{0.11}{0.08906}+\frac{1}{1.65}}$$

U_{w1} = 0.1842 W/m^2/K

The Storage walls were uniformly prepared and laid. Therefore, the heat transfer coefficient for wall 1 is same as wall 2, 3 and 4.

The quantity of heat to be removed from the wall 1 and wall 3 of area 7.7805 m^2 is determined using equation 3.3 as;

$$Q_{w1} = 0.1842 \times 7.7805 \times (310 - 293)$$

Q_{w1} = 24.36 Watts

Therefore, heat to be removed from wall 3 is same as Q_{w1}, then Q_{w3} = 24.36 Watts

Likewise, the quantity of heat to be removed from the wall 2 and wall 4 of area 6.318 m^2 is determined using equation 3.3

$$Q_{w2} = 0.1842 \times 6.318 \times (310 - 293)$$

Q_{w2} = 19.784 Watts

Therefore, heat to be removed from wall 4 is same Q_{w2}, then Q_{w4} = 19.784Watts

Quantity of heat to be removed from roof

The roof composed of two composite material viz, Laterite block and thatch. Therefore, the heat transfer coefficient of the roof is determined using the equation 3.2.

$$U_r = \frac{1}{\frac{1}{f_o} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{1}{f_i}}$$

Where the terms remain the same as define earlier.

$$U_r = \frac{1}{\frac{1}{6.5} + \frac{0.11}{0.08906} + \frac{0.3}{0.05} + \frac{1}{1.65}}$$

U_r= 0.1251W/m^{2}K

The quantity of heat required to be removed from the roof was determined using equation 3.3

$$Q_r = 0.1251 \times 5.7456 \times (310 - 293)$$

Q_r= 12.22 Watts

Quantity of Heat to be removed from Floor

The floor area consists of concrete (150mm thick) embedded with thatch material of 300mm thick. The measured temperature of the soil at 1.5 m depth was 27 °C. The heat transfer coefficient of the floor area is determined using equation3.2 as follows.

$$U_f = \frac{1}{\frac{1}{f_o} + \frac{x_c}{k_c} + \frac{x_t}{k_t} + \frac{1}{f_i}}$$

Where x_c and x_t = the thickness of concrete and thatch respectively (m)

k_c and k_t= Heat conductivity of concrete and thatch respectively ($W/m^2/K$)

$$U_f = \frac{1}{\frac{1}{1.65} + \frac{0.15}{1.4} + \frac{0.3}{0.05} + \frac{1}{1.65}}$$

U_f = 0.1366 $W/m^2/K$

The quantity of required to be remove from the floor is determined using the equation 3.3.

$$Q_f = 0.1366 \times 5.7456 \times (300 - 293)$$

Q_f = 5.494 Watts

Product Heat Removal Q_p

500 kg of dried tomatoes was considered to be stored at the field temperature of 37 °C and cold storage temperature maintained at 20 °C. The specific heat capacity if dried tomato is 3.978 kJ/kg/K (Mohsenin, 1980). The Quantity of field heat to be removed is determined using equation 3.4.

$$Q_p = 500 \times 3.978 \times (37 - 20)$$

Q_p = 33813 kJ

Considering 16 hours operation, product heat Q_p amount to 587 Watts

Auxiliary Heat

Auxiliary heat is considered as other sources of heat to the storage room specifically, the light bulb, two workmen, cartons, air temperature changes through door. Certainly, 20 percent of total quantity of heat to be removed by the Air conditioner was allotted to salvage this in the design. This is clearly stated in table 3.2.

Table 3. 3 : Heat calculations summary

S/N	Units	Heat Transfer Coefficient U ($W/m^2/K$)	Heat Q (Watts)	Area A (m^2)
1	Wall 1	0.1842	24.36	7.7805
2	Wall 2	0.1842	19.784	6.318
3	Wall 3	0.1842	24.36	7.7805
4	Wall 4	0.1842	19.784	6.318
5	Floor	0.1366	5.494	5.7456
6	Roof	0.1251	12.22	5.7456
7	Product	Nil	587	Nil
8	Auxiliary (20%) sub-total	Nil	138.60	Nil
9	Total		831.602	

The total Quantity of heat Q_T to be removed for effective storage of the dried tomato under the stated storage conditions and medium is 831.602 Watts.

Selection of air conditioner for the storage

The air conditioner was selected on the basis of heat load capacity requirement. The type and size of air conditioner was selected by considering the total quantity of heat Q_T of 831.602 Watt required to be removed, which is equivalent to 1.11 hp. Therefore, Air conditioner of 1.5 hp was suitable for the storage and it is also available in the market, and thereby selected.

3.2.4 Wood (rafter) design at roof section

The component of roof section which carried the laterite block and thatch material as the insulating component was made primary with wood. The roof was design to resist failure due to laterite block weight on the wood material, the mortar, constituted thatch material and two professional personnel on top.

Blocks needed per room = 140

Unit weight of the block = 3.6 kg

Total weight of the block on wood section = 140 × 3.6 = 504 kg

Total load due to block on wood = 5.0 kN

Likewise, estimated mass of mortar at 5 cm depth is 2 kN

Mass of the thatch material on top of wooden component determined as follows

$$M_{th} = \rho_t \times v \qquad 3.5$$

Where M_{th},= Mass of the thatch material kg

ρ_t= Density of the thatch (56.4 kg/m^3)

v = volume occupied by the thatch (0.6 m^3)

Therefore, the mass of thatch was computed as 34 kg equivalent to 0.344 kN load.

Considering the load of two professional personnel on top of the wood section having average weight of 80 kg each. Then, both personnel weighed 160 kg equivalent to 1.6 kN.

Total Load on the wooden section = laterite block + Mortar weight + Thatch + Personnel

= 5 + 2 + 0.344 + 1.6

= 8.944 kN

= 9 kN

Apara wood was selected,

and mean tensile stress of Afara = 15N/mm^2

Wood section crossectional area (A)

(A) = 9000 /15 = 600 mm^2

Therefore, 10 by 15cm section is adequate for the rafter.

3.2.5 Electrical work on the structure

AutoCad was used to design the circuitry works and the number of materials required. Detailed drawings were also generated (Appendix 2).

3.2.6 Cool room temperature modeling

Similarly, the cool room heating when there is energy failure and the cooling after dried vegetable (Tomato) was loaded and Air Conditioner thermostat was set at 20°C were modeled using thatch as insulation material with same lateritic soil block (Fig3.10). The parametric data of the room contents (Appendix 1), the four walls, ceiling and floor were loaded in to the software; prob2 measures the room temperatures per second as shown in the block diagram (Fig.3.3). Simulations were run at 1000 times per minute speed using MapleSim software and models were generated.

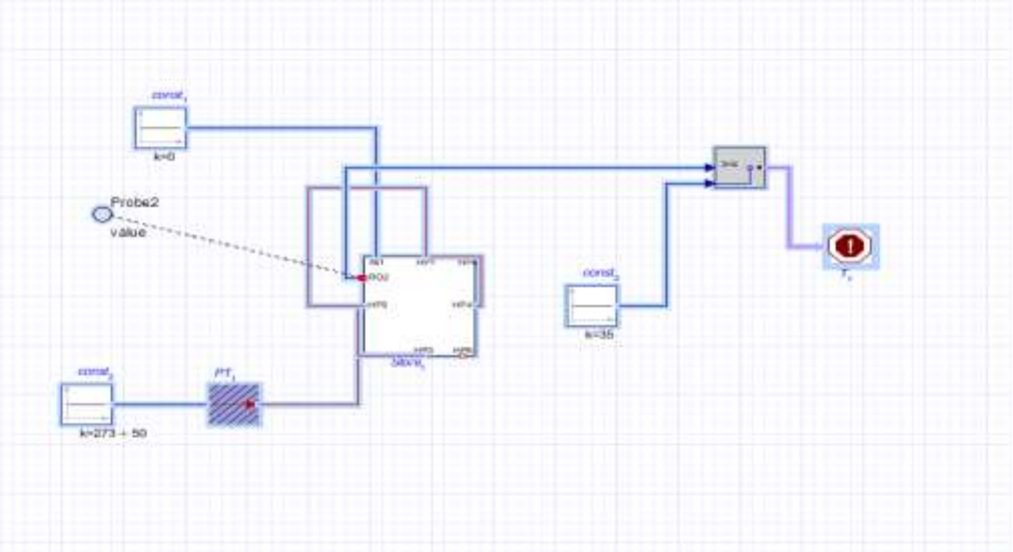


Figure3.4. Block diagram of the Cool room model

The model curves were generated and times and room temperatures presented. The time to reach 20^{o}C temperature when AC was on and time to reach environmental temperature when AC was off were predicted, the results were documented

3.2.7Cool room construction

Messing and bricklayers were employed and trained on the principle of the cool room, all drawings explained. Substructure and super structure of the cool room were constructed according to the drawings (Drawing No. 1-8) (Appendix 2). The constructed rooms are shown in plate3.6.

Plate 3.7 : Room under costruction

Plate 3.8: Pictorial view of the rooms

3.2.8 Cool room project cost implication

Mansonry cost, electrical cost, test cost, instrumentation cost were computed and presented in the Tables 3.3 -3.6.

Table3. 4: Masonry cost

S/No	Item	Unit Cost(₦)	Unit	Total (₦)
01	Laterite Block	35	4,500	157,500
02	Thatch	200	20Bundle	4,000
03	Water	5	2000lt	10,000
04	Rendering soil	25,000	1	25,000
05	Sandcrete Block	110	350	38,500
06	Sand	500	10Barrow	5,000
07	Polypropylene	2,000	3	6,000
08	Workman ship	75,000	-	75,000
	Total			321,000

Table3. 5: Electrical cost

S/No	Item	Unit Cost (₦)	Unit	Total (₦)
01	AC(1.5hp)	130,000	2	260,000
02	2.5mm Wire Roll	52,000	1	52,000
03	1.5mm Wire Roll	38,000	1	38,000
04	DB (6-star block)	15,000	1	15,000
05	Supply Cable	300	20yrds	6,000
06	Cut-out ceramic 100ams	1,200	3	3,600
07	Socket 15amps (top plug)	1,200	2	2,400
08	Switch with pattress	700	4	2,800
09	Labour	-	-	20,000
	Total			400,000

Table 3. 6: Test cost

S/No	Item	Unit Cost (₦)	Unit	Total (₦)
01	Soil (Atterberg, classification, density)	25,000	-	25,000
02	Soil bearing	12,500	-	12,500
03	Thermal Conductivity	75,000	-	75,000
04	Laterite Block Strength	4,000	-	4,000
05	Mould Rent	15,000	-	15,000
	Total			131,500

Table 3. 7: Instrumentation cost

S/No	Item	Unit Cost (₦)	Unit	Total (₦)
01	Temperature Sensor	45,000	1	45,000
02	RH/Temperature Meter	45,000	1	45,000
03	Digital Camera	45,000	1	45,000
04	Photo Box	6,000	1	6,000
05	Drawings	15,000	2	30,000
	Total			171,000

Electricity consumption cost- total hours of available electricity for the four month (from University bulk metering unit) = 75.84hr

Power unit consumed = 75.84 x 1.14Kw = 86.5 kWh

Price per unit = ₦26

Electricity cost = 86.5 x 26 = ₦2, 249; for the two rooms = ₦ 4,498

Grand Total = 321,000 + 400,000 + 131,500 + 171,000 +4,498 = N 1,027,998 .00

Total Cool rooms area utilized = 2 x 3 = 6m^2

Cost of Cool room per square meter = ₦171, 333./m^2

Assuming Earth building life span of 50years

Annual cost of the cool room = 1, 027, 998.00/50x2 =₦10, 280

Cost of storage-for room storage capacity of 500 kg

Storage cost per kg of product = 10280/ 500 = ₦20.56

3.2.9 Performance evaluation of the cool room

The performance evaluation was grouped into two parts, the first group constituted the no load test in which no vegetable materials were loaded in to the cool room. The second group was the test in which vegetable materials were loaded into the cool room.

The no load test: The two constructed cool rooms were labeled room one and room two in which the room by the right-hand side of the approach was labeled room one and that of the left-hand side room two. Hydro-thermal environmental measurements were conducted on the rooms according to Lu, (2019) and Sukai, (2008). The room's walls were gridded into 20 cm x20 cm both inside and outside including roofs and floors; center point temperature of each grid was measured without putting air conditioner on, using a calibrated infra-red digital thermometer. The measurement was repeated at 5hrs interval within a day; ambient temperatures and corresponding relative humidity were also measured. The air space in each room was divided in to three and gridded as above, space towards the roof, mid-room space and space towards the floor. Temperatures and relative humidity of the room air were measured at the three levels. Similar experiments were conducted with the AC set at the storage temperatures, time to reach the 7/8 of the set temperature and air throw were also measured (ASHRAE,2009). The data generated (Appendix6) was analyzed using Statistical Analysis System (SAS).

Test while on load: The test designed includes three different dried vegetables, the Tomato, Okra and Baobab leaves (objective one) at two levels, those dried using departmental driers and those dried by farmers. These materials were packaged in 0.01mm thick polypropylene food grade film at 500gms each and re-packaged in carton (10pieces) for the room's storage (Gordon,2013). The packages were labeled according to the three products and drying method and loaded on a wooden pallet in each room. Storage temperatures of 20^{o}C and 25^{o}C were selected according to Bilge *et al*. (2012) and Hossaini *et al.* (2009) and set on the air conditioner in each room accordingly and closed for experimentation, however each of these vegetables was prepared according to farmer storage method and used as control. For ease of sampling data tabulation, the three crops were coded as:

KK = Baobab , T = Tomato and KB = Okra

For drying methods, storage temperature and control, we have;

TD20 = Tomato dried using dryer and stored at 20°C

TD25 = Tomato dried using dryer and stored at 25 °C

TDC = Tomato dried using dryer stored as control

TF20 = Tomato dried by farmer and stored at 20°C

TF25 = Tomato dried by farmer and stored at 25°C

TFC = Tomato dried by farmer stored as control

Similar sequence was obtained for the Baobab and Okra products.

A factorial design in completely randomized design was adopted, with storage temperature, time of storage and drying method as factors. Six quality describing parameters were investigated under the storage condition. Temperature was at two levels, storage time five levels and drying method two levels and all were repeated three times(Appendix13). Inferential statistics analysis was conducted on the generated data using Statistical Analysis System software (SAS).

Six quality describing parameter were measured at interval of three weeks for four months (Idah, 2011); color, solid content, moisture content, rehydration ratio, microbial and water activity.

i) Colour measurement: Indirect colour measurement method was used by applies computer vision system (CVS) in which the vegetable sample(10gm) image was captured using a digital camera of 16 mega pixel in RBG form using a photo box at 45/0 position (Leo,2004), then a computer software (Adobe Photoshop) produces the RGB equivalent in color values. These values can be converted in CIL-Lab value by the use of equation 3.6 -3.9(Yam and Papadakis, 2004),

$$L* = \frac{Lightness}{255} \times 100 \quad 3.6$$

$$a* = \frac{240a}{255} - 120 \quad 3.7$$

$$b* = \frac{240b}{255} - 120 \quad 3.8$$

The colour parameters are expressed as L (lightness), a (redness/greenness) and b (yellowness/blueness). The Hunter “L” value represents the lightness or darkness of a sample on a scale of 0 to 100 (100 being white and 0 being black). Hunter “a” value represents the greenness or redness of the sample (-50 being green and +50 being red). Hunter “b” value is also rated on a scale of -50 to +50, with -50 representing blue and +50 representing yellow. L*, a* and b* estimation (Mohammadi *et al*., 2008); ΔE indicates the total colour change of a sample in comparison to color values of an ideal sample having color values of L*, a* and b*. The total colour change (ΔE) parameter was calculated using equation 3.7 (Ozilgin., 2011):

$$\Delta E = \left[(L*-L**)^2 + (a*-a**)^2 + (b*-b**)^2 \right]^{0.5} \quad 3.9$$

The data generated for the three dried vegetables stored in the two cool rooms and controls were recorded in three repetitions and documented (Appendix12).

ii) Moisture content and solid content measurement: The moisture and solid contents were measure in accordance with AOAC, 2007. Forced draft oven, sample pans and weighing balance were instrumented for work. Samples weighing 10gms of the three dried vegetables as labeled were picked from the cool room and control store and loaded in to oven at 130^{o}C for 3hrs. The moisture content and solid contents were calculated using equations 3.10,3.11 and 3.12.

%Moisture (wt/wt) = (wtH2O in sample /wt of wet sample) × 100 3.10

%Moisture (wt/wt) = (wt of wet sample − wt of dry sample/ wt of wet sample) ×100 3.11

%Total solids (wt/wt) = (wt of dry sample /wt of wet sample) × 100 3.12

iii) Water activity (a_w): The equilibrium relative humidity of all the samples was measured while inside its carton and inside their respective storages (packs) with the digital relative humidity meter and water activity was calculated as:

a_w = ERH/100[18] 3.13

Where:

aw = water activity

ERH = equilibrium relative humidity.

iv) Rehydration ratio: Rehydration ratio was measured according to Mohammed *et al,* (2010), in which 10gms sample of the vegetables were soaked in 300 mls of boiling water for 80 minutes. The mass of the sample before soaking and mass of sample after soaking were measured using digital weighing balance (0.01gm). The ratio of mass after soaking to mass before soaking gave the rehydration ratio. The measurement was repeated three times for all the samples picked from the storages and documented (Appendix7).

v) Microbial load: All the samples taken were labeled and transferred to Microbiology Department of Ahmadu Bello University for professional Bacteria and Fungus loads determination. Tests were conducted according to their standards; results were collected and documented (Appendix 13).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Survey of dried vegetables

The survey of dried vegetables was conducted within the North West zone of Nigeria in 2016, the results obtained is as shown in Table 4.1.

Table 4. 1 Results of Baseline Survey on Dried Vegetables (2016)

Crop	Wt./Tiya (gm)	Lowest Price, ₦ (February)	Peak Price, ₦ (May up)	Storage Method	Drying Method	Limitation	Sales Rank
Baobab	363	60	120	PE Room	Open Sun drying	Heat	1
Okra	544	200	350	PE Room	Open Sun drying	heat/ humidity	2
Tomato	908	150	400	,,	,,	Heat/humidity/mould	3
Pepper (Irrig	454	280	600	,,	,,	Heat	4
Pepper(Rain	544	250	500	,,	,,	Heat	4
Sorrel	45.4 Ball	10	10	,,	,,	Humidity/mould	7
Sorrel fruit(B/W)	454	400	600	,,	,,	,,	6
Moringa	91	150	150	,,	,,	Heat	8
Karkashi	635	600	600	,,	,,	Heat	5

From the results it could be seen that the Baobab leaves are the most consumed dried vegetables in the surveyed region, the Okra follows and the Tomato came third. These crops are widely used in making soups and stews for the traditional condiments and rice, in other words they significantly provide the nutritional requirement of our communities at a minimum cost. All the crops value chain has seasonality and are stored for ease of market controls.

4.1.2 Cold room survey

The results of cold room survey are presented Table4.2

Table 4. 2 Cold Room Survey Summary

S/No	Parameter	Remarks
01	Products Stored	Fresh Fish, Chicken
02	Coldroom Dimension (ft)	20 x 20 x8 min to 120 x 50 x 8 max
03	Material of Construction	Aluminum Panel, Aluminum Angle Iron, Coal Tar
04	Insulation Material	Polystyrene
05	Insulaation Thickness (inch)	4 min to 6 max
06	Compressor size (hp)	10 min to 35 max
07	Evaporator size (hp)	10 min to 25 max
08	Storage Capacity (tone)	13 min to 104 max
09	Storage Duration	1 week

Among all the cold rooms surveyed, none was found to have the history of storing vegetables, they rather store fresh fish and chicken. They were designed for commercial purposes, the operators has no any linkage with vegetable processing or marketing. The major constraints identified with cold room in relation to dried vegetables storage are the room humidity and fish odour. Even if well packaged since the storage period is long, the moisture sorption can change the quality of the vegetable. Furthermore, the storage temperature of the fish and vegetables are different as such they can’t be combined in the same room space. The costs of fabricating these cold rooms are high as such storage cost could also be high, this can raise the price of the vegetables to out of reach of consumers.

4.1.3 Soil test

The results of soil test are indicated in Table4.3.

Table 4. 3 Summary of Soil Test Result

Sample	Location	Aggregation S%, ST%CL%	Liquid Limit %	Plastic Limit %	Plasticity Index	Shrinkage%
A	Biye	68,29,3	56.5	41.6	14.9	15
B	DAC	79,19,2	33.5	21.45	12.05	13.6
C	Dufadufa	70,23,7	36.2	21.8	14.4	12.9

Biye lateritic soil contains less sand compared to the other two soil samples and has high shrinkage. Dufadufa lateritic soil conformed to the International Shelter Commission of United Nations Standards for lateritic soils for rammed earth blocks with moderate sand, silt content and high clay content.

4.1.3 Block compression test

The produced stabilized laterite blocks were tested in compression and Table4.4 presents the mean results. The thermal conductivity test results are indicated in Table 4.5.

Table 4. 4 Blocks Compression Test Result

Week	Shed cured Blocks Force (N)			Stress N/mm2	Open cured Blocks (N)			Stress N/mm2
	S1	S2	Mean		O1	O2	Mean	
1	20	18	19	0.75	17	18	17.5	0.69
2	28	25	26,5	1.05	18	27	22.5	0.89
3	23	16	19.5	0.77	20	15	17.5	0.69
4	29	27	28	1.11	28	23	25.5	1.08
5	30	28	29	1.15	20	20	20	0.79
6	33	32	32.5	1.29	20	18	19	0.75
7	42	40	41	1.62	25	23	24	0.95

The produced compressed laterite blocks were cured in the shade and under open sun. The blocks cured under the shade turns to be stronger than the open sun cured blocks. The strength of the shade cured blocks increases with days of curing while the blocks cured in the open sun do not show increase strength with days of curing. In seven weeks of curing the shade cured blocks had compressive strength of up to 1.62 N/mm^2 while open sun cured has 0.95 N/mm^2(Table4.4). Therefore the shade cured blocks has twice compressive strength as the open sun cured blocks.

4.1.4 Thermal conductivity test

Results of thermal conductivity of the four materials tested are shown in Table 4.5:

Table 4. 5Test Result of Thermal Conductivity of four bio-insulation materials

S/No.	Sample ID	Voltage (V)	Current (A)	Weight (g)	Thickness (cm)	Density (kg/m^3)	Moisture %(wb)	Conductivity (Wm^{-1}k^{-1})
1	S-A (1)	11.0	5.9	5.94	0.251	1981	2.9	0.2655
2	S-A (2)	13.0	6.0	5.01	0.213	1964	2.9	0.2528
3	S-A (3)	12.0	6.1	8.04	0.320	2103	2.9	0.2466
4	S-A (4)	13.0	6.5	5.69	0.220	2165	2.9	0.3305
5	S-A (5)	13.0	6.5	4.91	0.188	2186	2.9	0.5325
6	S-B (1)	13.0	5.8	3.00	0.121	2075	3.1	0.0532
7	S-B (2)	13.0	5.8	3.21	0.130	2067	3.1	0.0605
8	S-B (3)	13.0	5.9	3.23	0.125	2163	3.1	0.0781
9	S-B (4)	12.5	6.3	3.15	0.134	1968	3.1	0.0840
10	S-B (5)	13.0	5.8	3.17	0.128	2073	3.1	0.1695
11	S-C (1)	12.0	5.8	6.00	0.243	2067	7.0	0.3363
12	S-C (2)	12.5	6.0	7.07	0.275	2152	7.0	0.4102
13	S-C (3)	12.5	5.8	6.84	0.257	2228	7.0	0.3706
14	S-C (4)	13.0	5.8	5.05	0.184	2297	7.0	0.4403
15	S-C (5)	13.0	5.8	6.85	0.253	2266	7.0	0.4326
16	S-D (1)	13.0	5.8	3.15	0.220	1198	10	0.2363
17	S-D (2)	13.0	5.8	3.48	0.243	1299	10	0.2928
18	S-D (3)	13.0	5.8	3.38	0.227	1246	10	0.3296
19	S-D (4)	13.0	5.7	2.35	0.149	1320	10	0.4541
20	S-D (5)	11.5	5.0	2.42	0.155	1307	10	0.3644
21	S-E (1)	12.0	6.6	6.25	0.490	1068	12	0.2854
22	S-E (2)	13.0	6.2	5.28	0.376	1176	12	0.2918
23	S-E (3)	13.5	6.2	3.67	0.259	1186	12	0.3445
24	S-E (4)	13.0	6.0	3.42	0.230	1245	12	0.4620
25	S-E (5)	13.0	5.9	3.54	0.238	1246	12	0.6589

NB:

S-A; Kaolin- Sawdust Block (5:1)

S-B; Cement Stabilized Laterite Block (6%) and 14month old

S-C; Cement Stabilized Laterite Block (6%) and 5month old

S-D; Thatch (Hyparrhenia Collin)

S-E; Reed (Hyparrhenia rufa)(zana)

Five samples of renewable materials were tested (Table 4.5); the stabilized laterite blocks 14 months old gave the least mean thermal conductivity of 0.0891 W/m K, Kaolin sawdust blocks and Thatch follows with 0.326 W/m K and 0.335 W/m K. The stabilized laterite blocks 5months old and the Reed materials had 0.4 W/Mk and 0.409 W/m K, this results is in close agreement with the findings of Steven,2005. The stabilized laterite blocks 14-month-old has 4.5 times lower thermal conductivity than the same blocks but 5months old of production. Paired t-test result indicated significant difference of the thermal conductivity values of the two blocks at 5% level.

4.1.6 Some properties of the thatch

Table 4.6 shows the insulation material physical properties results

Table 4. 6 Dimensional properties of the thatch

S/N	Thatch Stem Diameter (mm)		
	Bottom	Middle	Top
1	4.8	4.5	3.0
2	6.78	4.51	3.38
3	5.12	4.29	3.11
4	4.91	4.68	4.33
5	5.81	4.95	3.18
6	7.24	5.32	2.27
7	5.81	5.39	2.58
8	5.84	6.13	2.85
9	6.56	7.07	4.13
10	5.55	4.04	2.55
mean	5.84	5.09	3.14

Length of the Thatch; 1.3 m.1.45 m and 1.5 m, mean length = 1.42 m

Bulk Density of Thatch = 56.4kg/m^3

Moisture content of Thatch, sample1,10.9%; sample2,5.6%; sample3,5.6%

Average = 7.4%

Bale circumference at 30 cm above cutting point = 205 cm

Price /Bale = ₦200 (2015)

The thatch materials which are wild grasses, single grass unit consists of a tapered stem diameter in which the mean stem diameter at the bottom(towards ground) was 5.84 mm, middle portion had 5.09 mm and the top measured 3.14 mm diameter. It started from ground with 5.84mm diameter and ends at 3.14 mm. The mean length of the single grass was 142 mm and the bulk density was 56.4 kg/m^3. The mean grass moisture content at the time of measurement was 7.4% (wb). The thatch grasses were packaged in bundles and the mean bale circumference at 30cm above cutting point was 205 cm.

4.1.7 Insulation material quality model

Figure4.1 is the insulation quality modeling results and insulation thickness selection model.

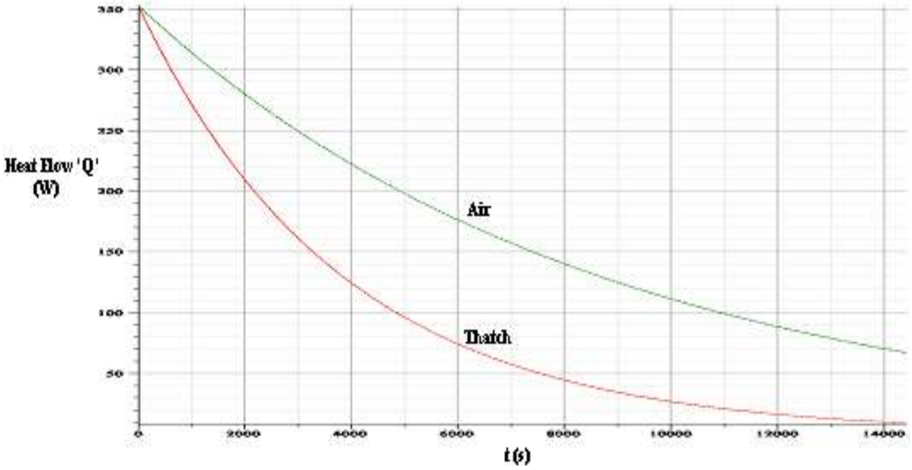


Figure4.1: Heat flow Model of the thatch and air insulation

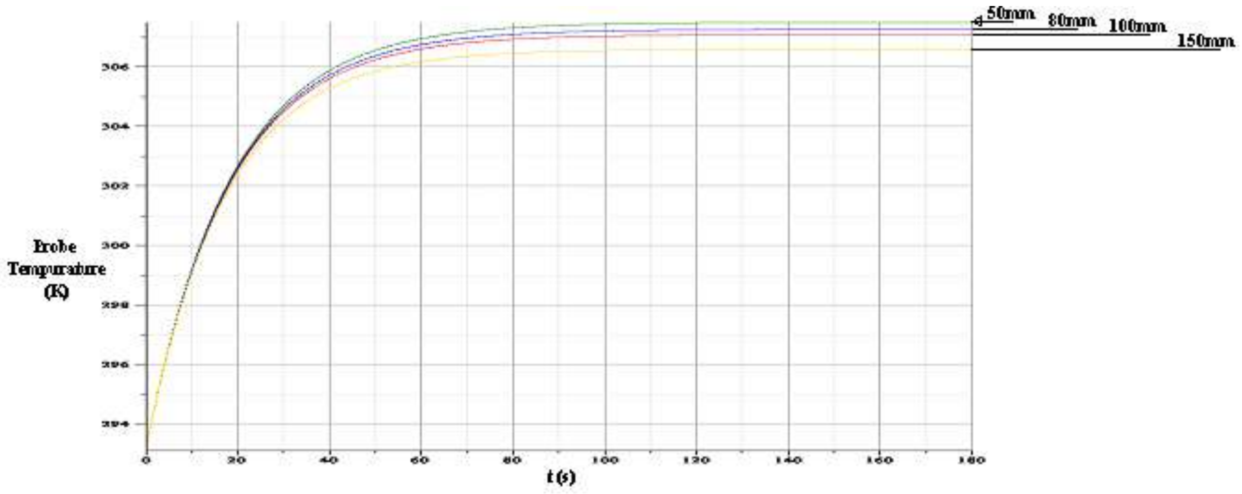


Figure4.2: Thatch insulation temperatures Model (at various thickness (50-150mm))

The model curve in Figure.4.1 shows how heat flows from the outside of the cool room to inside through the walling arrangement and insulation installations. Thatch and Air were simulated, from the model curve more heat flows when air was installed, whereas less heat flows when thatch was installed. After about 4hrs of operating the cool room heat flow through the thatch decrease to bearest minimum while that of air still remains high. Therefore, the Thatch turns to be better insulation material compared to air.

After selecting thatch as insulation material another modeling (Figure.4.2) was used in selecting appropriate insulation thickness. Various thicknesses were simulated, 50 mm, 80 mm, 100 mm and 150 mm. The temperature rise across each insulation thickness was examined. The thicker the insulation material the less the temperature across it and according to the specification of the walling blocks interpolation between 100 mm and 150 mm gave 110 mm thickness.

4.1.8 Cooling and heating of the cool room

The results of modeling the cooling and heating of the cool room when AC was switched on and off are presented Figure.4.3 and Figure.4.4 respectively.

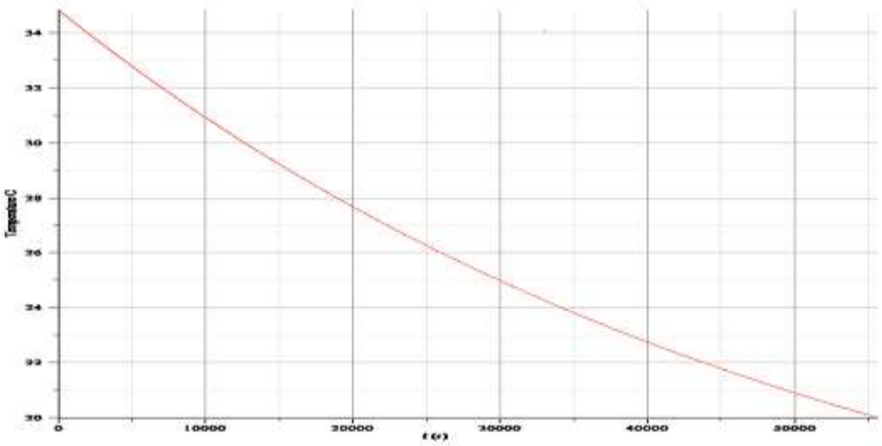


Figure 4.3: Cool room cooling Model

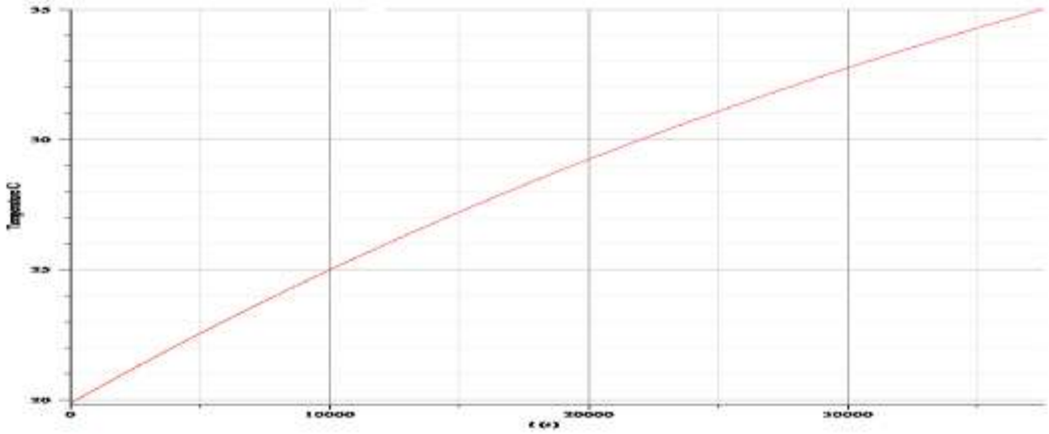


Figure 4.4: Cool room heating Model

Simulation model (Fgure.4.3) gave the result of when will the cool room reach AC set temperature (20^{o}C) at vegetables full load from the environmental temperature. The model curve indicated that within 15.3hrs of operation, the cool room will reach the AC set temperature. When electricity was off, in other words when AC stopped, the model (Figure.4.4) indicated that the cool room will heat to 25(^{o}C) within 12.5hrs, this extraction from the model was as a result of the thermal measurement of the rooms during the no load test which gave all-round temperature of 25(^{o} C).

4.1.9 Performance evaluation of the cool room

Descriptive and inferential statistic was used in analyzing the data obtained from both no load and on load test of the cool room.

4.1.9a No load test

The summary of the results are as shown in Tables 4.7a -q;

Table 4.7 a Room 1 wall temperatures (^{o}C) at 9am

Part of cool room		N	Minimum	Maximum	Sum	Mean	Std Dev	Variance
Wall1	Inside	48	24.60	27.20	1234.80	25.7250	.67114	.450
	Outside	48	18.40	28.20	1082.80	22.5583	2.90677	8.449
Wall2	Inside	48	23.80	28.80	1230.40	25.6333	.81927	.671
	Outside	48	17.20	28.00	1016.00	21.1667	3.21627	10.344
Wall3	Inside	48	24.80	26.40	1234.60	25.7208	.39083	.153
	Outside	48	17.20	20.40	906.40	18.8833	.69139	.478
Roof	Inside	48	24.30	25.20	1182.70	24.6396	.20498	.042
	Outside							
Door	Inside	20	24.60	24.80	492.60	24.6300	.07327	.005
	Outside	20	20.60	20.80	414.10	20.7050	.09987	.010
Floor	Inside	48	20.20	27.40	1263.48	26.3225	.99443	.989

Table 4.7 b Room 1 wall temperatures (^{o}C) at 2.00pm,

Part of cool room		N	Minimum	Maximum	Sum	Mean	Std Dev	Variance
Wall1	Inside	48	24.80	27.20	1231.40	25.6542	.62670	.393
	Outside	48	27.00	40.20	1523.20	31.7333	4.15002	17.223
Wall2	Inside	48	24.20	26.80	1198.80	24.9750	.64131	.411
	Outside	48	25.20	30.40	1308.10	27.2521	.93217	.869
Wall3	Inside	48	24.20	25.80	1210.40	25.2167	.48084	.231
	Outside	48	24.40	28.40	1228.80	25.6000	.76742	.589
Roof	Inside	48	24.60	26.60	1212.20	25.2542	.36376	.132
	Outside							
Door	Inside	32	27.80	28.40	900.40	28.1375	.12636	.016
	Outside	32	30.00	39.00	1062.20	33.1937	2.21169	4.892
Floor	Inside	48	22.60	27.40	1268.90	26.4354	.68773	.473

Table 4.7 c Room 1 wall temperatures (^{o}C) at 12.00 mid night,

Part of cool room		N	Minimum	Maximum	Sum	Mean	Std Dev	Variance
Wall1	Inside	48	25.20	27.20	1252.60	26.0958	.56265	.317
	Outside	48	17.80	20.40	904.40	18.8417	.70253	.494
Wall2	Inside	48	20.20	26.80	1234.00	25.7083	.91880	.844
	Outside	48	16.80	20.00	886.30	18.4646	.79319	.629
Wall3	Inside	48	25.20	26.20	1235.40	25.7375	.28029	.079
	Outside	48	17.80	20.40	908.50	18.9271	.61670	.380
Roof	Inside	48	25.20	25.80	1226.40	25.5500	.20000	.040
	Outside							
Door	Inside	20	23.00	25.20	488.00	24.4000	.44010	.194
	Outside	20	18.00	19.60	372.20	18.6100	.52103	.271
Floor	Inside	48	25.40	27.20	1263.80	26.3292	.49248	.243

Table 4.7 d Room 1 wall temperatures (^{o}C) at 5.00am,

Part of cool room		N	Minimum	Maximum	Sum	Mean	Std Dev	Variance
Wall1	Inside	48	24.20	26.60	1217.00	25.3542	.60948	.371
	Outside	48	14.80	18.20	783.20	16.3167	.78370	.614
Wall2	Inside	48	23.60	26.00	1192.80	24.8500	.59430	.353
	Outside	48	13.20	17.20	724.80	15.1000	.80741	.652
Wall3	Inside	48	24.20	25.44	372.60	24.6250	.56519	.650
	Outside	48	14.80	15.60	799.80	15.7458	.24807	.684
Roof	Inside	48	24.40	25.60	1194.50	24.8854	.30387	.092
	Outside	48	20.60	26.80	1244.40	25.9250	.86011	.740
Door	Inside	20	22.80	23.80	466.80	23.3400	.26036	.068
	Outside	20	15.60	18.60	330.60	16.5300	1.08244	1.172
Floor	Inside	48	20.60	26.80	1244.40	25.9250	.86011	.740

At 5.00am Wall2 showed a minimum outside temperature of 13.2 ^{o} C which was the least among the remaining walls(Table4.7d), but the corresponding inside room temperature of the same wall was 24^{o}C. This wall was facing east which was the direction of flow of monsoon wind of the season. Wall1, wall3 were the closest in cooling with 14^{o}C and 15^{o}C, at the same time their corresponding insde room temperature fluctuate around 24^{o}C. At this time despite the outside cold temperatures the inside wall temperature fluctuates around 25^{o}C. Looking at wall temperatures at 2.00pm, Wall1 had the maximum outside temperature of 40.2^{o}C with

corresponding inside of 27^{o}c. The door outside temperature of 39^{o}C follows with its corresponding inside temperature of 28.4^{o}C. However, looking at the mean temperatures from Table 4.7(a-d) it could be seen that the inside wall temperatures fluctuate around same 25^{o}C. The remaining times of 12.00 mid night and 9.00am indicated same mean inside wall temperature pattern (Table 4.7a and Table4.7c). At this juncture we could say that whether the outside wall temperature is hot or cold, the mean inside wall temperatures remain around 25^{o}C. This room was 75% shaded by a tree (natural cooling). Furthermore, the mean room space air temperature stands at 24^{o}C while the maximum air temperature fluctuates around 25^{o}C (Table4.7e). Within the same space the mean air relative humidity was 44% and it was maximum towards the roof at 49.9 %(Table4.7f), all the measurements were done without air condition.

Table 4.7 e Room 1 inside space temperature (^{o}C), at 9.00am,

Cool room space	N	Minimum	Maximum	Sum	Mean	Std Dev	Variance
Towards Roof	30	22.20	24.50	717.90	23.9300	.53185	.283
Middle	48	24.40	25.20	1183.90	24.6646	.19731	.039
Towards Floor	30	24.50	24.80	739.30	24.6433	.08584	.007

Table 4.7 f Room 1Relative Humidity (%) of the Room1 at 9.00am ,

Cool room space	N	Minimum	Maximum	Sum	Mean	Std Dev	Variance
Towards Roof	30	41.20	49.90	1298.50	43.2833	2.18065	4.755
Middle	30	41.30	45.00	1317.40	43.9133	.96481	.931
Towards Floor	30	42.20	45.90	1322.50	44.0833	.74189	.550

Table 4.7 g Room 1 wall temperatures (^{o}C) with AC(set at 20^{o}c),

Part of cool room		N	Minimum	Maximum	Sum	Mean	Std Dev	Variance
Wall1	Inside	36	23.80	27.60	938.30	26.0639	.90148	.813
	Outside	36	33.80	40.40	1394.80	38.7444	1.73146	2.998
Wall2	Inside	36	24.00	27.40	947.00	26.3056	.63514	.403
	Outside	36	30.40	40.20	1364.60	37.9056	1.75629	3.085
Wall3	Inside	36	24.80	26.40	948.40	26.3444	1.80704	3.265
	Outside	36	33.60	38.40	1276.00	35.4444	1.14554	1.312
Roof	Inside	36	24.00	27.60	918.40	25.5111	.93129	.867
	Outside	36	31.00	36.40	1386.74	34.7052	1.2671	1.285
Door	Inside	36	23.40	27.80	904.80	25.1333	1.19523	1.429
	Outside	36	36.20	43.80	1417.40	39.3722	1.73775	3.020
Floor	Inside	36	23.80	27.40	931.60	25.8778	.93476	.874

Table 4.7 h Room 1 inside space temp with AC(set at 20^{o}c),

Cool room space	N	Minimum	Maximum	Sum	Mean	Std Dev	Variance
Towards Roof	36	18.00	27.40	827.60	22.9889	2.11671	4.480
Middle	36	21.00	24.70	824.40	22.9000	1.11918	1.253
Towards Floor	36	20.90	24.30	809.90	22.4972	1.11342	1.240

Table 4.7 i Room 1 inside space RH% with AC(set at 20^{o}c),

Cool room space	N	Minimum	Maximum	Sum	Mean	Std Dev	Variance
Towards Roof	36	28.50	45.20	1345.70	37.3806	4.55737	20.770
Middle	36	36.10	39.40	1350.40	37.5111	.95102	.904
Towards Floor	36	36.40	40.40	1395.60	38.7667	1.17668	1.385

With the air conditioner set on at 20^{o}C, the mean inside wall temperatures fluctuates around 25^{o}C while the maximum outside wall temperature stood at 43.8^{o}C. The mean room space air temperature was 22^{o}C and the mean relative humidity was 37% (Tables 4.7.7-9).

Table 4.7 j Room2 Wall Temperature at 6.26 am

Part of cool room		N	Minimum	Maximum	Sum	Mean	Std Dev	Variance
Wall1	Inside	48	22.60	24.80	1130.60	23.5542	.54615	.298

	Outside	48	13.60	16.20	703.00	14.6458	.56000	.314
Wall2	Inside	48	22.20	24.60	1129.20	23.5250	.52774	.279
	Outside	48	13.80	17.20	729.50	15.1979	.86060	.741
Wall3	Inside	48	22.80	24.40	1119.00	23.3125	.29436	.087
	Outside	48	15.00	15.80	741.40	15.4458	.20312	.041
Roof	Inside	48	23.00	23.60	1123.00	23.3958	.13985	.020
	Outside	48	14.80	16.40	726.80	15.1417	.35957	.129
Door	Inside	32	21.80	22.20	709.10	22.1594	.11876	.014
	Outside	32	15.20	15.80	493.40	15.4187	.16350	.027
Floor	Inside	48	23.20	24.40	1153.40	24.0292	.23697	.056

Table 4.7 k Room2 Wall Temperature at 10.00 am

Part of cool room		N	Minimum	Maximum	Sum	Mean	Std Dev	Variance
Wall1	Inside	48	23.40	25.20	1163.40	24.2375	.50302	.253
	Outside	48	20.20	23.2.0	1237.80	21.5787	.3041	.325
Wall2	Inside	48	23.20	24.60	1156.00	24.0833	.31645	.100
	Outside	48	4.80	24.60	1044.40	21.7583	2.77158	7.682
Wall3	Inside	48	23.80	24.60	1149.70	23.9521	.15844	.025
	Outside	48	20.80	22.20	1028.80	21.4333	.36978	.137
Roof	Inside	16	23.40	23.60	374.80	23.4250	.06831	.005
	Outside	48	23.40	25.20	1176.20	24.5042	.45051	.203
Door	Inside	48	23.00	24.00	1141.40	23.7792	.20727	.043
	Outside	32	24.00	25.80	803.80	25.1188	.44245	.196
Floor	Inside	48	24.00	24.80	1180.00	24.5833	.19714	.039

Table 4.7 l Room2 Wall Temperature at 12.50 am

Part of cool room		N	Minimum	Maximum	Sum	Mean	Std Dev	Variance
Wall1	Inside	48	23.00	24.40	1171.20	24.4000	2.69878	0.283
	Outside	48	17.00	19.60	875.80	18.2458	.66427	.441
Wall2	Inside	48	23.80	24.60	1164.40	24.2583	.18431	.034
	Outside	48	17.20	19.40	858.10	17.8771	.55820	.312
Wall3	Inside	48	23.50	24.60	1164.90	24.2687	.20333	.041
	Outside	48	17.00	24.20	860.70	17.9312	3.49511	0.416
Roof	Inside	48	23.80	24.40	1161.40	24.1958	.15153	.023
	Outside	48	16.00	17.20	812.80	16.9333	.44690	.200
Door	Inside							
	Outside							
Floor	Inside	48	23.60	24.60	1171.60	24.4083	.27041	.073

For room 2 which was fully shaded by trees, W1 had the minimum outside temperature of 13.6^{o}C with corresponding inside temperature of 22. 6^{o}C.Wall2 has the maximum outside temperature of 17.2^{o}C having corresponding inside temperature of 24.6^{o}C at the time (table 4.7.10), the mean inside wall temperature fluctuates around 23^{o}C within the 24hrs of thermal measurement. The floors turn to be warmer, the mean inside room temperature of room 2 (23^{o}C) turn to be cooler than that of room1(25^{o}C). Furthermore, the room space air temperature stood at 23^{o}C and the mean air relative humidity revolves around 40%(measured in December).

Table 4.7 m Room2 Inside air space temperature without AC,

Cool room space	N	Minimum	Maximum	Sum	Mean	Std Dev	Variance
Towards Roof	30	22.60	23.10	689.00	22.9667	.10613	.011
Middle	30	22.00	27.60	683.50	22.7833	.91955	.846
Towards Floor	30	22.09					

Table 4.7 n Room2 inside space Relative Humidity,

Cool room space	N	Minimum	Maximum	Sum	Mean	Std Dev	Variance
Towards Roof	30	43.00	48.20	1342.20	44.7400	1.19383	1.425
Middle	30	38.10	42.20	1220.10	40.6700	1.07420	1.154
Towards Floor	30	32.60	39.80	867.80	35.9267	7.87063	61.947

Table 4.7 o Room2 inside space Air temp AC set at 25 Oc,

	N	Minimum	Maximum	Sum	Mean	Std Dev	Variance
Towards Roof	36	19.50	29.20	879.60	24.4333	2.35590	5.550
Middle	36	19.50	29.20	879.60	24.4333	2.35590	5.550
Towards Floor	36	22.40	28.20	846.90	23.5250	1.00210	1.004

Table 4.7 p Room2 inside space Relative Humidity, with AC set at 25°C

Cool room space	N	Minimum	Maximum	Sum	Mean	Std Dev	Variance
Towards Roof	36	28.70	40.20	1302.40	36.1778	3.36521	11.325
Middle	36	28.70	40.20	1302.40	36.1778	3.36521	11.325
Towards Floor	36	33.70	39.90	1389.40	38.5944	1.03591	1.073

Table 4.7 q Room2 Wall Temperature with AC set at25oc by 12.50 am

Part of cool room		N	Minimum	Maximum	Sum	Mean	Std Dev	Variance
Wall1	Inside	36	20.40	25.40	835.80	23.2167	1.42739	2.037
	Outside	36	33.00	38.80	1267.60	35.2111	1.41174	1.993
Wall2	Inside	36	23.20	26.40	885.80	24.6056	.56868	.323
	Outside	36	34.00	37.20	1279.10	35.5306	.73049	.534
Wall3	Inside	36	23.80	29.40	892.20	24.7833	.96732	.936
	Outside	36	32.40	35.80	1231.80	34.2167	.89746	.805
Roof	Inside	36	23.40	27.00	914.00	25.3889	.74710	.558
	Outside							
Door	Inside	36	23.80	30.00	951.20	26.4222	1.66426	2.770
	Outside	36	34.20	39.40	1356.60	37.6833	1.37019	1.877
Floor	Inside	36	24.08	25.60	898.46	24.9572	.31915	.102

When air conditioner of the room2 was set at 25°C, the mean inside walls temperature fluctuate around 25°C even at the corresponding outside temperature of 37.6°C. The mean relative humidity drop down to 36% and room2 space air temperature reach 24°C.

4.19b Load performances

Analysis for color change

Using ANOVA(Appendix15), difference analysis (Duncan) was conducted on all the six quality indication parameters at 0.05 level of significance and effect of the major factors that affect quality of the vegetable was investigated(Temperature and Time of storage). Table4.7.1 shows the effect of temperature on the colour change of the three dried vegetables stored in the storage structure. Looking at Tomato column, there was no significant difference (0.05 level)in change of colour between Tomato dried using dryer stored at 20°C and 25°C where as significant difference exists between Tomato's dried by farmers when stored at the same temperatures. Both the controls exhibited the highest color change, the farmer dried control had the highest color change. Similarly, the okra dried using dryer did not show any significant difference between 20°C and 25°C storage temperature at 0.05level but significant difference exists between the farmer dried okra at the same temperatures at 0.05 level of significance. Significant difference exists between the dryer dried control and same sample stored in the storage structure. Okra dried using drier stored at 20°C gave the minimum colour change. The samples of Baobab showed significant difference at all storage temperatures, but the one dried using drier has the least color change. For the three vegetables, the samples stored at 20°C had minimum color change.

Table4.7. 1: Temperature based colour difference analysis.

Temperature	BAOBAB	OKRA	TOMATO
D20	6.62e	11.28d	15.44c
D25	12.01b	13.63d	15.59c
DC	7.91d	20.35c	17.45c
F20	8.88c	34.71a	19.68c
F25	14.44a	24.17c	20.29ab
FC	9.55c	29.74b	23.5a
F-value	75.405	1095.664	1270.889
p-value	0.000	0.000	0.000

The effect of storage time upon color change is presented in Table4.7.2, with Tomatoes samples appears to show significant difference from day 21 to 84 days of storage and stabilizes at the 105 days of storage. Okra seems to follow the same pattern but Baobab had initial change between 21 to 42days then stabilizes up to 84days. In both Tomato and Okra at the beginning of the storage the colour change was at a slow mode but sharpened up after the mid storage time, however the Baobab colour change was at slow mode all through.

Table4.7. 2 : Time based color difference analysis.

Time (days)	BAOBAB	OKRA	TOMATO
21	6.76c	14.04c	8.04d
42	9.49b	30.38a	11.44c
63	9.70b	25.05b	25.82a
84	9.49b	16.87c	20.15b
105	14.07a	24.51b	25.76a
F-value	74.112	29.736	3.704
p-value	0.000	0.000	0.006

Analysis for moisture contents

The results of moisture and solid content of tested products is presented in Tablles4.4 7.3-.7.4.

Table4.7. 3: Moisture content and solid content time related analysis

	N	Tomato		Okra		Baoba	
Time(days)		Moisture	Solid content	Moisture	Solid content	Moisture	Solid content
0	6	6.27d	93.73a	8.42c	91.58a	7.08b	92.92a
21	18	7.61cd	92.39ab	9.78ab	90.22ab	8.77b	91.23a
42	18	7.94cd	92.06ab	7.056	92.94a	8.50b	91.50a
63	18	9.00bc	91.00bc	10.61ab	89.39ab	9.22b	90.78a
84	18	10.44b	89.56c	12.11a	87.89bc	11.89a	88.11b
105	18	13.94a	86.05c	13.17a	86.83c	12.17a	87.83b
F-value		14.052	14.052	9.443	9.443	7.686	7.686
p-value		0.000	0.000	0.000	0.000	0.000	0.000

Means with same letters are not significantly different at 0.05

As shown in the Table 4.7.3, the moisture content of Tomato did not change significantly at 0.05 level from day 0 up to 42 days afterwards the moisture began changing steadily up to day 105. Whereas the corresponding solid content followed similar pattern but afterward became steady up the end of the storage time. Change of Okra moisture content and its solid content indicated significant difference at 0.05 level from day zero of storage up to day 63 the stabilizes up to the end of the storage. The Baobab moisture content remained without difference too up to 63 days in the store but began changing after wards, its solid content follow suit. From day 63 rainy seasons has begun in earnest (July-August).

Table4.7. 4: Moisture content and Solid content temperature related analysis

	N	Tomato		Okra		Baoba	
Temperature		Moisture	Solid content	Moisture	Solid content	Moisture	Solid content
D	3	6.40c	93.60a	9.63bcd	90.37ab	6.80d	93.20a
D20	15	9.20bc	90.80ab	11.33abc	88.7cd	10.35ab	89.67bcd
D25	15	8.27bc	91.73ab	10.40abcd	89.60bc	10.21ab	89.79bcd
DC	3	12.67a	87.33c	13.67a	86.33d	11.12ab	88.88cd
F	15	6.13c	93.87a	7.20d	92.80a	7.37cd	92.63a
F20	15	9.00bc	91.00ab	8.13cd	91.87ab	8.51cd	91.49abc
F25	15	7.87c	92.13a	7.73d	92.27a	8.53cd	91.47ab
FC	15	11.73ab	88.27c	12.00ab	88.00cd	11.93a	88.07d
F-value		5.021	5.021	6.704	6.704	3.312	3.312
p-value		0.000	0.000	0.000	0.000	0.004	0.004

Tomato dried using dryer stored at 20°C and 25°C had no significant moisture content difference at 0.05level but significant difference exists with its control this agrees with Sarafadeen, 2017. The farmer dried Tomato showed similar trend but the farmer dried Tomato turn to be drier. Okra shows similar pattern with Tomato but Baobab gave a pattern in which the farmer dried product turns to be moister. All the solid contents followed the moisture content trend.

Bacterial and Fungal load of the vegetables (colony) analysis

Bacteria and Fungi loads on the three stored vegetable as measured was analyesd based on the major factors and results are presented in Tables 4.7.5 and Table.4.7.6.

Table4.7. 5 : Bacteria and Fungi time related analysis

	N	Tomato		Okra		Baoba	
Time(days)		Bacteria	Fungi	Bacteria	Funai	Bacteria	Fungi
0	2	15000.0a	45500.0a	326500a	117500a	1155500.0a	64500.0a
21	6	107500.0a	79000.0a	13200.0c	28450.0c	15166.7b	27666.7a
42	6	28833.3a	33666.7a	56333.3bb	37166.7c	10666.7b	29166.7a
63	6	97583.3a	58333.3a	30753.3c	51666.7b	19500.0b	11166.7a
F-value		0.828	0.778	27.867	3.562	4.755	1.299
p-value		0.497	0.523	0.000	0.038	0.015	0.309

From Table.4.7.5, there was no significant difference between the mean values of the Bacteria and Fungai load over the period of 63 days of storage of Tomato and Baobab but significant difference exists on Okra. The identified bacteria was Weissela Spp and Pediococcus Spp as well as the fungi was A. parasiticus,, all their colony forming units are in agreement with Farahna, 2016.

Table4.7. 6: Bacteria and Fungi temperature related analysis

	TOMATO		OKRA		BAOBAB	
Temperature	BACTERIA	FUNGI	BACTERIA	FUNGI	BACTERIA	FUNGI
D	21000.000a	73000.000a	230000.000b	55000.000b	2300000.00a	2300000.00a
D20	26166.667a	56000.000a	46000.000c	50666.667b	31666.67b	31666.67b
D25	81666.667a	30666.667a	19373.333d	39833.333c	15666.67b	15666.67b
DC	34333.333a	10333.333a	16666.667	17000.000	20666.67b	20666.67b
F	9000.000a	18000.000a	423000.000a	180000.000a	11000.00b	11000.00b
F20	96666.667a	99666.667a	30466.667c	67333.333b	10666.67b	10666.67b
F25	28666.667a	94000.000a	66400.000c	36400.000c	10333.33b	10333.33b
FC	200333.333a	51333.333a	21666.667d	23333.333c	1666.67b	1666.67b
f-VALUE	0.892	1.131	25.382	5.219	1775.922	1775.922
P-VALUE	0.541	0.406	0.000	0.006	0.000	0.000

At all storage temperatures Tomato show no significant difference in Bacteria and Fungi load, but Okra exhibit differences at 0.05level of significance (Table4.7.6). Here too Baobab follows Tomato pattern, microbial load turns to be higher and unstable in Okra.

Rehydration Ratio analysis

The of Rehydration Ratio analysis is presented in Table.4.7.7.

Table4.7. 7: Rehydration ratio temperature related analysis

Type	Tomato	Okra	Baobab
D	4.07a	7.20a	5.93a
D20	3.59a	6.77a	4.15c
D25	3.51a	6.60a	4.13c
DC	3.25b	6.33b	3.67c

F	3.53a	6.47b	6.07a
F20	3.00b	6.71a	5.32b
F25	3.07b	6.33b	5.33b
FC	2.86b	6.01b	5.07b
F-value	3.598	3.934	40.448
p-value	0.002	0.001	0.000

Rehydration ratio of dryer dried Tomato stored at 20^{o}C and 25^{o}C showed no significant difference at 0.05 level, similarly that of the farmer dried ones behaved the same way but the rehydration ratio of the dryer dried Tomato was higher than the farmers dried Tomato (Table 4.7.7) Significant difference was observed in Okra store at 20^{o}C and 25^{o}C, there was no significant difference between the means of all the controlled sample except in Baobab. Okra has the highest rehydration ratio, followed by Tomato.

Table.4.7.8 presented the result of soaking the vegetable at different times, this was intended to see if heating energy can be saved.

Table4.7. 8 : Rehydration ratio at various soaking time

Soaking time(min)	Tomato	Okra	Baobab
120	3.57a	6.78a	5.44a
40	3.13a	6.23b	4.5925b
80	3.38a	6.65a	4.845b
F-value	2.883	5.846	21.673
p-value	0.062	0.004	0.000

The rehydration ratio of the three dried vegetables were compared at 120min, 80min and 40 min soaking time, from Table.4.7.8 there was no significant difference in the soaking time of Tomato in other word you can use any of the soaking time, soaking at 40min. saves energy cost. In Okra differences exist but 120min gave the best rehydration ratio. For Baobab there was significant difference between 120min and 40 and 80min but 120min gave the highest rehydration ratio. The effect of time of storage on rehydration ratio result is presented in Table.4.7.9.

Table 4.7. 9: Rehydration ratio storage time related analysis

Time	Baobab	Okra	Tomato
0			
21	0.515b	0.580a	0.722a
42	0.605b	0.560a	0.598a
63	0.703ab	0.612a	0.627a
84	0.743a	0.66a	0.673
105	0.748a	0.705a	0.703a
Total	0.6630	0.6237	0.6647
F-value	3.280	0.757	0.621
p-value	0.027	0.563	0.652

The rehydration ratio of Baobab kept steady up to 63 days but significant difference emerged from day 84 to the end of the storage time. Okra did not show any significant change over time as well as Tomato.

Water activity

Table4.7. 10: Water activity analysis

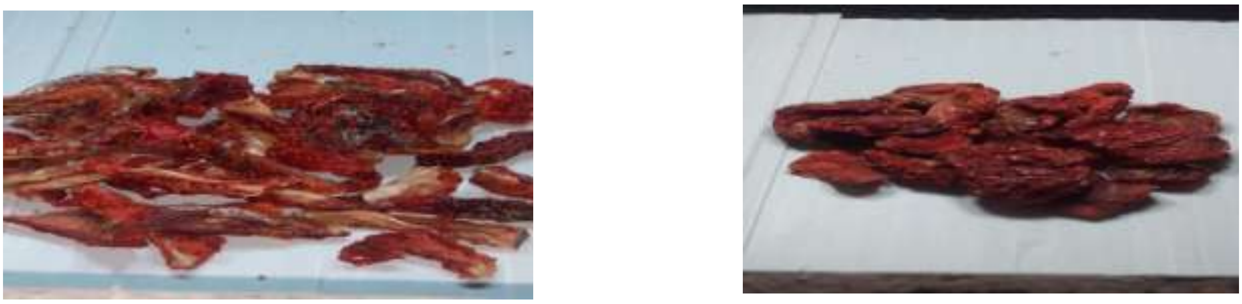
Temperature	Baobab	Okra	Tomato
DC	0.834a	0.788a	0.852a
FC	0.838a	0.862a	0.872a
D20	0.594b	0.546b	0.576b
D25	0.586b	0.554b	0.574b
F20	0.556b	0.498b	0.556b
F25	0.57b	0.494b	0.558b
Total	0.6630	0.6237	0.6647
F-value	8.533	20.395	23.276
p-value	0.000	0.000	0.000

The water activity of all the vgetables stored at 20^{o}C and 25^{o}C are not significantly different at 0.05 level but water activity of the controls were significantly different from others. The water activity of the controls turns to be higher (0.80) above the recommended values upper limit of 0.7 for dried vegetables.

General Discussion

For the benefit of farmers and the products users, the results can be elucidated as;

Tomato- the outcome from the storage method tested indicated that both the tomato dried using farmer’s method and the modern drier can be stored in this system without color change or soaking quality change. During the experiment, the same tomato stored in ordinary room as the farmers practice turns black and has poor soaking quality. This can be seen in the photographs of the tomato at various storage time (Plate 4.1).

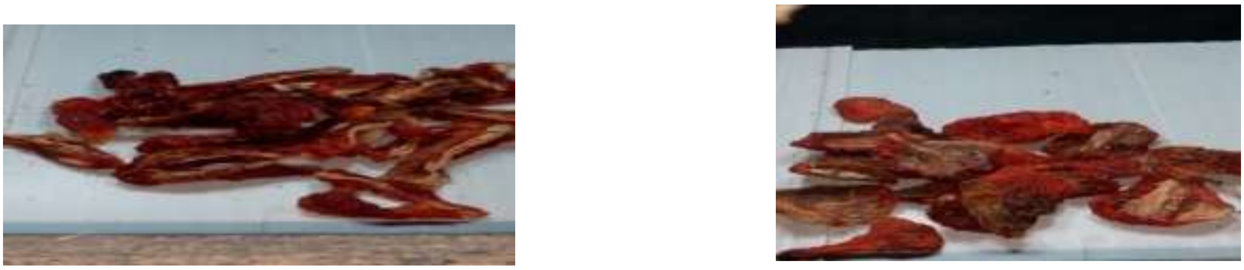


Td(dryer) day zero

Tf(farmer) day zero

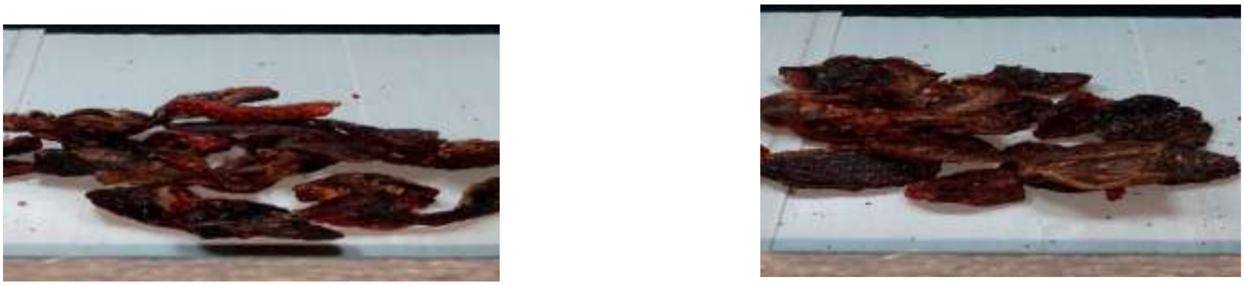
Td(dryer) 20^{o}C day 105

Tf(farmer) 20^{o}C day 105



Td(dryer 25^{o}C day 105

Tf(dryer) 25^{o}C day 105



Tdc(ordinary room) day 105

Tfc (ordinary room) day 105

Plate: 4.1 Physical colour outcome of stored tomatoes

KBD(dryer) day zero

KBF(farmer) day zero

KBD (dryer) 20^{o}C day 105

KBF(farmer) 20^{o}C day 105

KBD (dryer 25^{o}C day 105

KBF (dryer) 25^{o}C day 105

KBC (ordinary room) day 105

KBC (ordinary room) day 105

Plate: 4.2 Physical colour outcome of stored okra

KKD (dryer) day zero KKF(farmer) day zero

KKD (dryer) 20°C day 105 KKF(farmer) 20°C day 105

KKD (dryer 25°C day 105 KKF (dryer) 25°C day 105

KKC (ordinary room) day 105 KKC (ordinary room) day 105

Plate: 4.3 Physical colour outcome of stored baobab

Okra - the marketable color was maintained by the storage method(Plate 4.2) but the product moisture turn to increase at upper part of August. The soaking quality was also good, however the okra stored in ordinary room showed several changes in quality.

Boabab leaves- There were significant color changes in Baobab leave within then period of storage (Plate 4.3). However, the products by famer showed better rehydration quality.

CHAPTER FIVE
SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

Cool storage system made of stabilized laterite soil blocks was constructed to store dried vegetables. The room walls, floor and roof were insulated against heat gain using thatch grass (Hyparrhenia Collin). Natural cooling using trees and artificial cooling using Air Conditioner was applied as room cooling method. At natural cooling only, the inside room temperature of the room stood at 25^{o}C for all environmental temperatures while the inside room relative humidity increases as the environmental humidity increase. Three dried vegetables were stored in the rooms for four month, six quality indicating parameters were investigated (microbial, colour, water activity, solid content, moisture content and rehydration ratio), controlled samples were kept according to the traditional storage method The outcome indicated that the three dried vegetables can be stored for four months in the cool room without significant change in quality, in other word their market qualities were retained.

5.2 Conclusion

An appropriate vegetables storage system was designed and constructed; within the processes a dried vegetable products survey was conducted. It became obvious that Baobab leaves; Okra and Tomato were the most produced and marketed dried vegetables in North Western Nigeria. Survey on agricultural cold storages indicated none were used for storage of vegetable either in dried or fresh form. The cost of the cold room facility and its running cost were found to be above the reach of present vegetable production system. Renewable materials were used in the design and construction of cool storage system. A window AC was selected to serve as refrigeration to the storage system. Both no load and load tests were conducted on the two constructed rooms, hydro-thermal measurements of the two-room indicated that the mean inside room temperatures (walls &space) of the rooms at natural cooling revolved around 25^oC but room2 which was 100% tree shaded turns to be cooler with 23^oC at all environmental temperature. The corresponding inside room relative humidity stood at 43%. When Air-conditioner was set at 20^oC for room1, after three hours the mean inside room temperature stood at 22^oC and room2 was set at 25^oc also gave 26^oC.Generally, as the outside relative humidity increase the inside room humidity also increase more especially in the month of August.

After loading the three dried vegetables in the two rooms and set room1 to 20^oC and room2 to 25^oC, Tomato and Okra did not show significant color change at both set temperature. The mean moisture content for 2.5month storage ranges 6.2% (wb) to 9.0% after which it shot up to 14% towards August. The solid content did not show changes except in the controlled samples. Rehydration ratio and water activity of sampled stored in the rooms were stable at but the controlled sample show higher value above the recommended values. Since the rooms can cool naturally down to 23^oc and the stored crops did not show significant difference in quality indicating parameters tested, there is no need of using artificial cooling (air conditioner).

5.2 Recommendations

The following recommendations are hereby made;

1. The three stored dried vegetables can be stored without significant change in quality for at least four month.
2. The cool room can be operated with only natural cooling more especially when tree density is increased.

3. Stabilized laterite blocks intended to be used in a thermo-sensitive activity should be cured for one year to allow achieving low value of thermal conductivity.
4. Thatch grasses can be used as insulation materials.
5. The cool room should have moisture barrier installed to control inside room humidity rise.

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APPENDICES

Appendix 1 : Model input parameters

Wall

Inner wall thickness 110mm

Outer wall thickness 110mm

Wall material Stabilized laterite soil (6% cement)

Wall material conductivity 0.523W/moK

Wall cavity depth 50mm,80mm,100mm and 150mm

Wall surface area 5.0m2

Air

Cp air 1.005kJ/kgoK

Air density 1.127 kg/m3

Air conductivity 0.025W/moK

Thatch

Conductivity 0.07W/moK

Density 123kg/m3

Room

Volume 1.5 x 2.0 x 2.4m

Cooler Air conditioner (1.5hp window)

Inside set temperature and RH 20oC, 60%

Environmental temperature

and RH 35oC, 80%

Wooden shelves

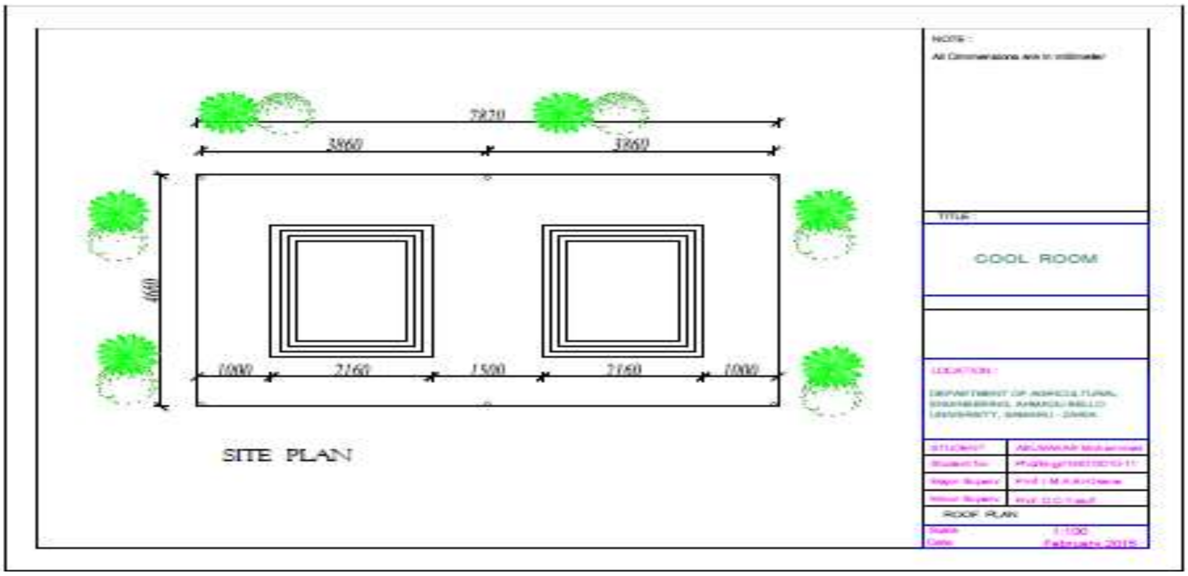
Single florescence bulb

Dried Tomato

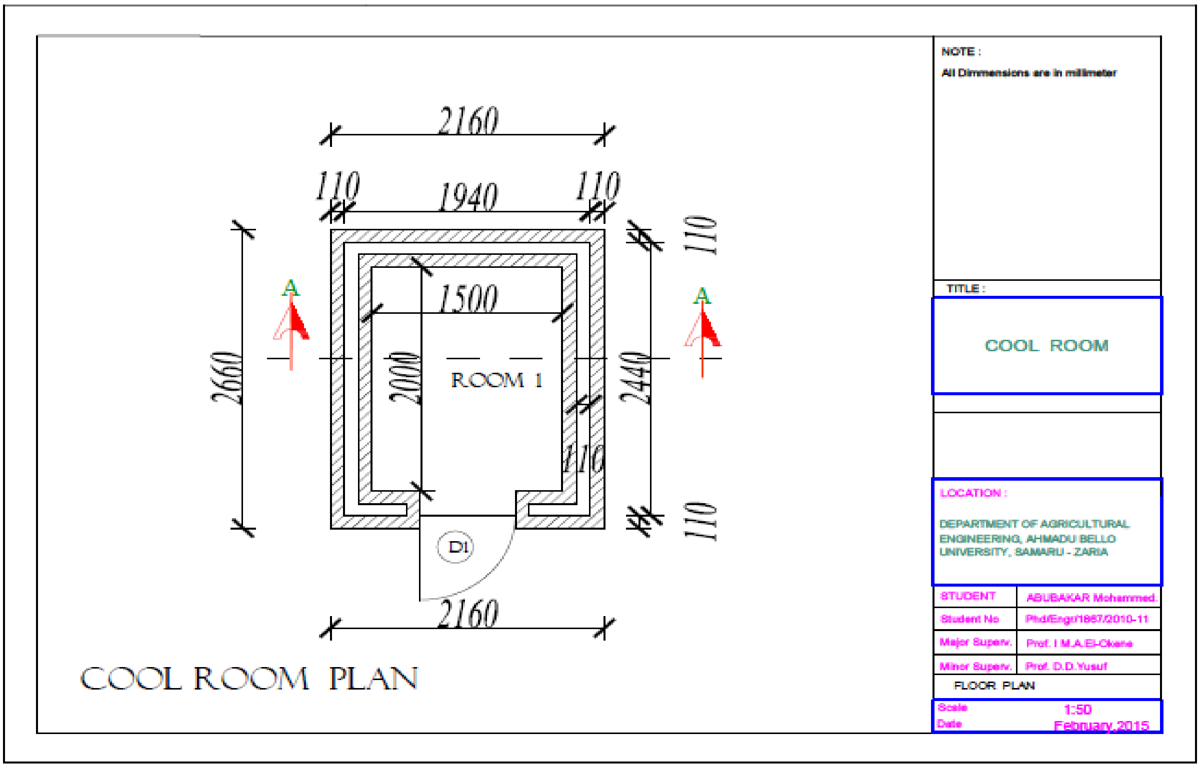
Quantity 500kg, Cp Dried tomato 3.978kJ/kgoC

Density 204kg/m3

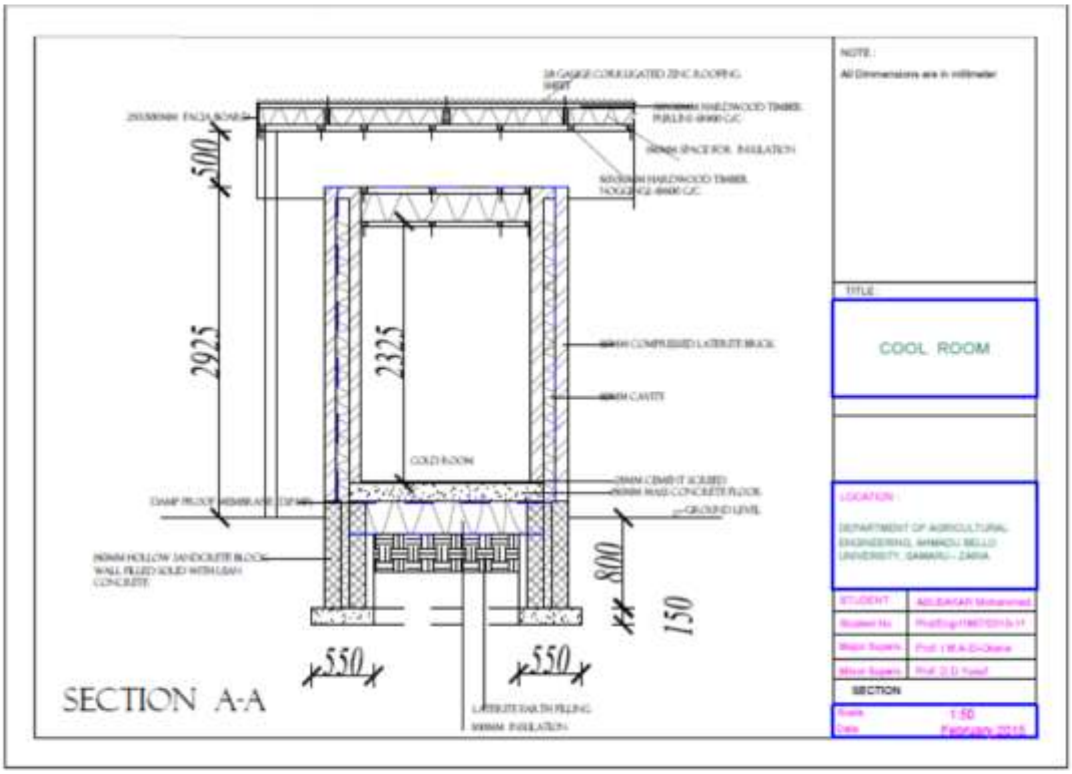
Appendix 2: Drawings from No.1 to No.8 represent the detailed drawing of the cool room structure.



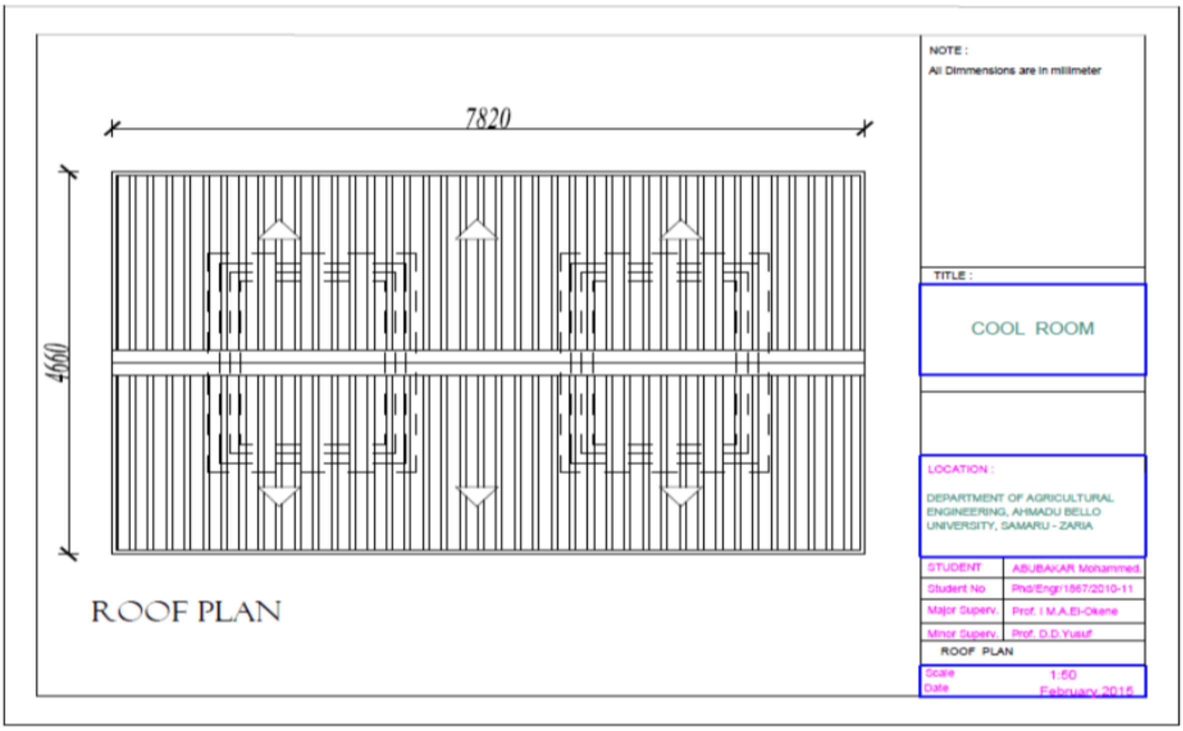
Drawing No.1



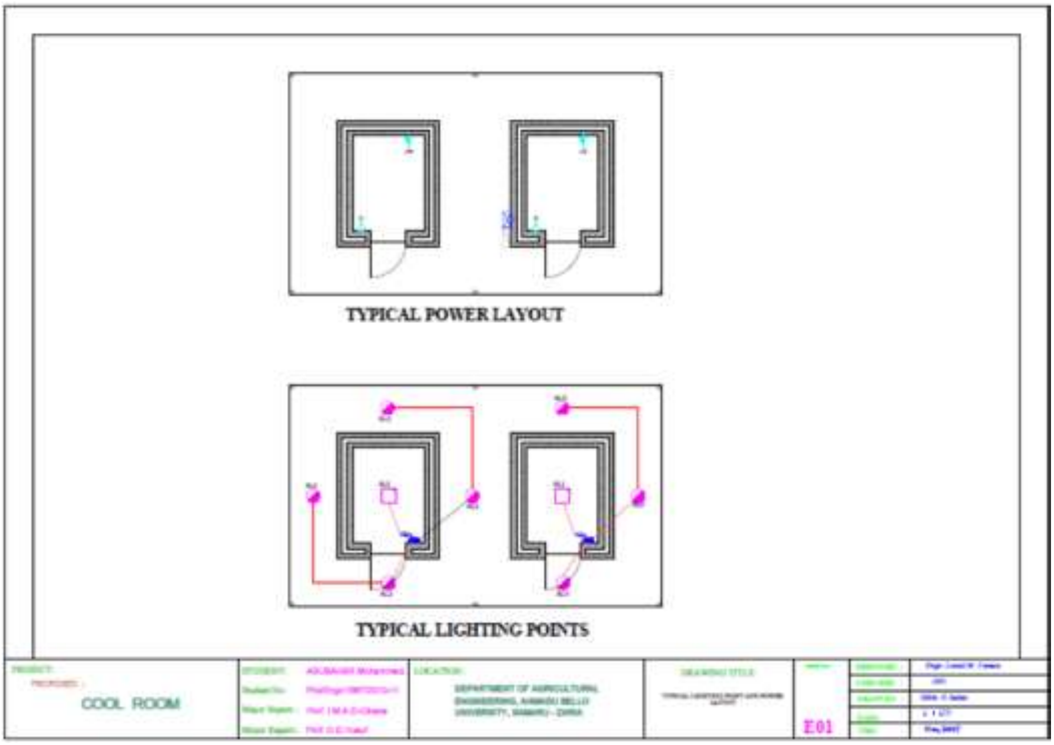
Drawing No.2



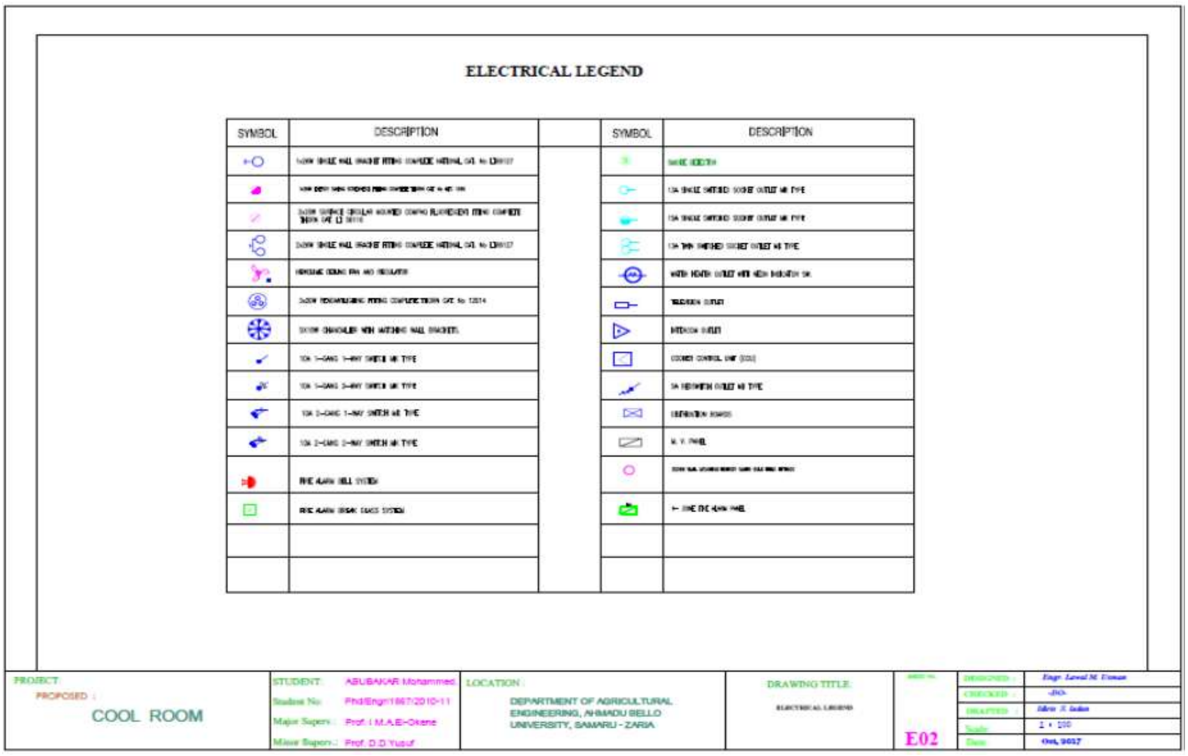
Drawing No. 3



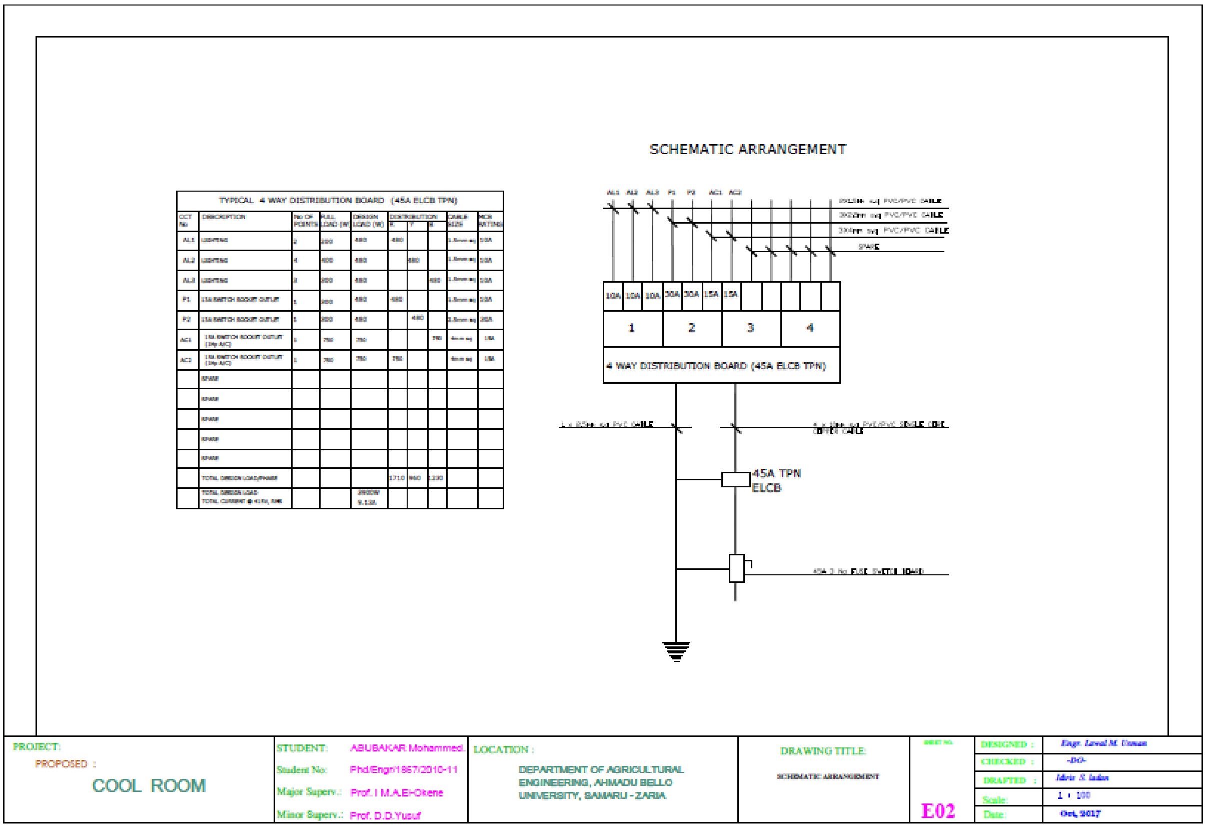
Drawing No.4



Drawing No. 5



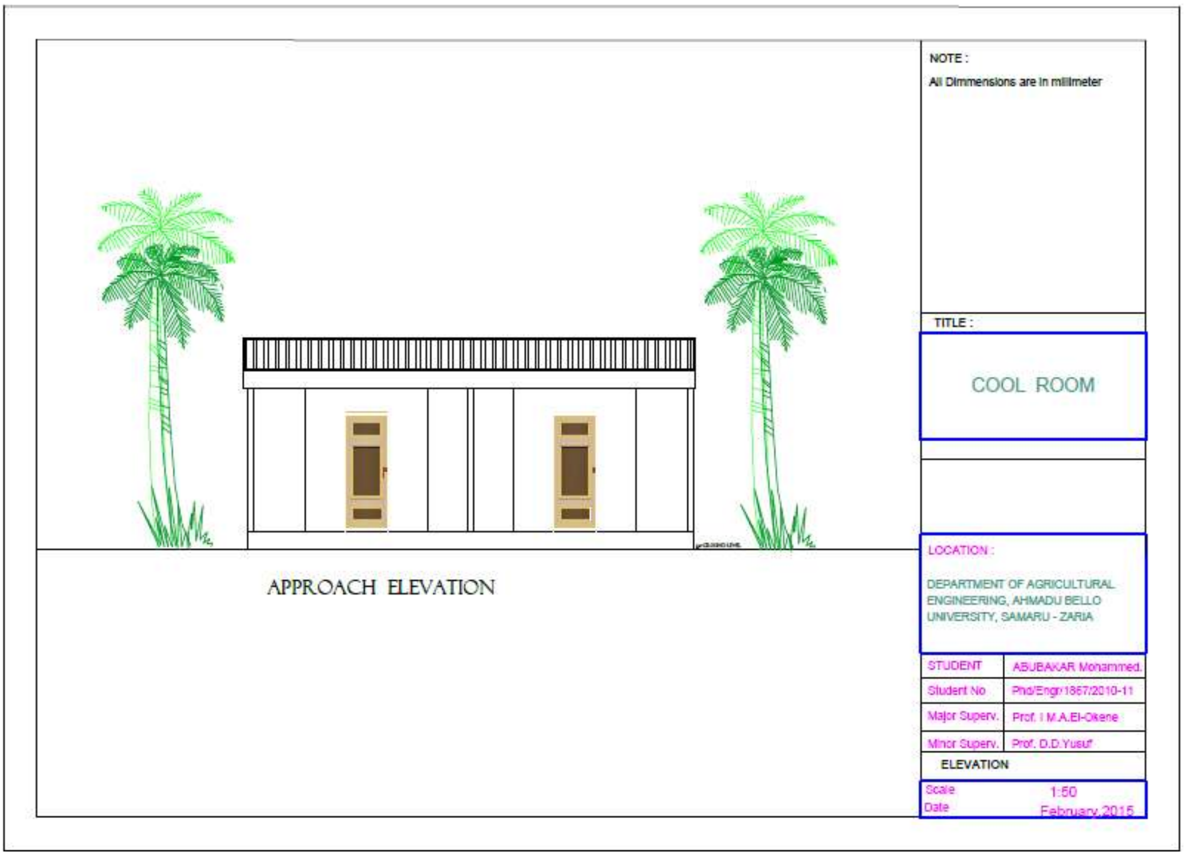
Drawing No. 6



TYPICAL 4 WAY DISTRIBUTION BOARD (45A ELCB TPN)

CCT No	DESCRIPTION	No OF POINTS	FULL LOAD (W)	DESIGN LOAD (W)	DISTRIBUTION R	Y	B	CABLE SIZE	MCB RATING
AL1	LIGHTING	2	200	480	480			1.5mm sq	10A
AL2	LIGHTING	4	400	480		480		1.5mm sq	10A
AL3	LIGHTING	3	300	480			480	1.5mm sq	10A
P1	13A SWITCH SOCKET OUTLET	1	300	480	480			1.5mm sq	10A
P2	13A SWITCH SOCKET OUTLET	1	300	480		480		2.5mm sq	20A
AC1	15A SWITCH SOCKET OUTLET (1Hp A/C)	1	750	750			750	4mm sq	15A
AC2	15A SWITCH SOCKET OUTLET (1Hp A/C)	1	750	750	750			4mm sq	15A
	SPARE								
	SPARE								
	SPARE								
	SPARE								
	SPARE								
	TOTAL DESIGN LOAD/PHASE				1710	960	1230		
	TOTAL DESIGN LOAD TOTAL CURRENT @ 415V, RMS			3900W 9.13A					

Drawing No. 7



Drawing No 8

Appendix 3: Soil samples test results

Sieve Analysis
Date Tested: April 04, 2013
Tested By: Mohammed Abubakar
Project Name: Dried Tomato Storage
Sample A: Biye
Sample Size; 200g

Sieve Size (mm)	Weight Retained(g)	Percent Retained %	Percent Passing %
2.8	28.5	14.25	85.75
1.4	6.1	3.05	82.7
0.71	18.5	9.25	73.45
0.425	29.4	14.7	58.75
0.36	6.1	3.05	55.7
0.212	7.3	3.65	52.05
0.15	3.9	1.95	50.1
0.075	4.5	2.25	47.85
Pan			

Hydrometer Analysis
Test Date: April 04, 2013
Tested By: Mohammed Abubakar
Hydrometer Number 152 H
Specific Gravity of Solids: 2.56
Dispersing Agent: Sodium Hexametaphosphate
Weight of Soil Sample: 94gm
Meniscus Correction: +0.2

SA

TIME	H. R. R	TEMP.	FACTOR F	H=17.67-0.176R	COR. H R	PART. SIZE	K	% PASSING
0.17	50	26	0.04022	8.87	49.8	0.2905223	1.61	39.990909
0.25	48.1	26	0.04022	9.2044	47.9	0.2440449	1.61	38.465152
0.5	46.3	26	0.04022	9.5212	46.1	0.1755104	1.61	37.019697
1	45	26	0.04022	9.75	44.8	0.1255869	1.61	35.975758
2	44.1	26	0.04022	9.9084	43.9	0.0895218	1.61	35.25303
4	43.2	26	0.04022	10.0668	43	0.0638055	1.61	34.530303
8	41.7	26	0.04022	10.3308	41.5	0.045705	1.61	33.325758
15	38.2	26	0.04022	10.9468	38	0.034359	1.6	30.51515

							1	2
30	36.4	26	0.04022	11.2636	36.2	0.0246445	1.61	29.069697
60	34.1	26	0.04022	11.6684	33.9	0.0177367	1.61	27.222727
120	31.4	26	0.04022	12.1436	31.2	0.0127946	1.61	25.054545
240	14.3	26	0.04022	15.1532	14.1	0.0101062	1.61	11.322727
360	7.2	27	0.03978	16.4028	7	0.0084913	1.61	5.6212121
720	5.4	28	0.03934	16.7196	5.2	0.0059949	1.61	4.1757576
1440	3.7	26	0.04022	17.0188	3.5	0.0043725	1.61	2.8106061

Plastic, Liquid Limits and Shrinkage(sample A)

Type of Test	LL	LL	LL	LL	LL	
No. of Blows	48	38	28	17	12	
Container No.	F8	84	167	D25	64	
Wt of wet soil&cont.g	23.2	27.2	33.0	35.2	42.4	
Wt of dry soil&cont.g	19.3	22.6	25.3	26.7	31.1	
Wt of cont g	11.6	14.0	11.5	12.4	12.0	
Wt of dry soil g	7.7	8.6	13.8	14.3	19.1	
Wt of moisture g	3.9	4.6	7.7	8.5	11.3	
Moisture content %	50.6	53.5	55.8	59.4	59.2	
Liquid LIMIT						56.5%
Type of Test	PL	PL	PL			
Cont. No.	RK	B2	B4			
Wt of wet soil&cont.g	9.1	9.5	9.3			14.0
Wt of dry soil&cont.g	8.8	9.2	8.9			11.9
Wt of cont g	8.1	8.5	7.9			2.1cm Shrinkage

Wt of dry soil g	0.7	0.7	1.0	
Wt of moisture g	0.3	0.3	0.4	
Moisture content %	42.9	42.9	40	
Plastic Limit				41.6%

Sieve Analysis
Date Tested: April 04, 2013
Tested By: Mohammed Abubakar
Project Name: Dried Tomato Storage
Sample B: Hayin Dogo
Sample Size: 200g

Sieve Size (mm)	Weight Retained(g)	Percent Retained %	Percent Passing %
2.8	79.8	39.2	60.1
1.4	7.1	3.55	56.55
0.71	15.2	7.6	48.55
0.425	25.2	12.6	36.35
0.36	6.1	3.05	33.3
0.212	6.1	3.05	29.8
0.15	4.2	2.1	27.7
0.075	4.2	2.1	25.6
Pan			

Hydrometer Analysis
Test Date: September 15, 2002
Tested By: Mohammed Abubakar
Hydrometer Number: 152 H
Specific Gravity of Solids: 2.56
Dispersing Agent: Sodium Hexametaphosphate
Weight of Soil Sample: 51.2 gm
Meniscus Correction: +0.2

SB

TIME	H. R. R	TEMP.	FACTOR F	H=17.67-0.176R	COR. T R	PART. SIZE	K	% PASSING
0.17	26.8	26	0.04022	12.9532	26.6	0.35108	1.61	21.360606
0.25	24	26	0.04022	13.446	23.8	0.2949637	1.61	19.112121
0.5	23.4	26	0.04022	13.5516	23.2	0.2093883	1.61	18.630303
1	22.1	26	0.04022	13.7804	21.9	0.1493045	1.61	17.586364

2	21.8	26	0.04022	13.8332	21.6	0.1057763	1.61	17.345455
4	20.2	26	0.04022	14.1148	20	0.0755526	1.61	16.060606
8	18.9	26	0.04022	14.3436	18.7	0.053855	1.61	15.016667
15	17.4	26	0.04022	14.6076	17.2	0.0396904	1.61	13.812121
30	16.2	26	0.04022	14.8188	16	0.0282675	1.61	12.848485
60	14.2	26	0.04315	15.1708	14	0.0216975	1.61	11.242424
120	12	26	0.04022	15.558	11.8	0.014482	1.61	9.4757576
240	10.1	26	0.04022	15.8924	9.9	0.0103498	1.61	7.95
360	8.4	27	0.03978	16.1916	8.2	0.0084364	1.61	6.5848485
720	6.4	28	0.03934	16.5436	6.2	0.0059633	1.61	4.9787879
1440	4.1	26	0.04022	16.9484	3.9	0.0043634	1.61	3.1318182

Plastic, Liquid Limits and Shrinkage(sample B)

Type of Test	LL	LL	LL	LL	LL	
No. of Blows	48	38	28	18	11	
Container No.	18	41	X39	10T	88	
Wt of wet soil&cont.g	23.9	26.0	32.8	37.8	41.5	
Wt of dry soil&cont.g	20.8	22.5	28.1	31.8	33.2	
Wt of cont g	11.0	11.1	14.3	14.6	11.0	
Wt of dry soil g	9.8	11.4	13.8	17.2	22.2	
Wt of moisture g	3.1	3.5	4.7	6	8.3	
Moisture content %	31.6	30.7	34.06	34.9	37.4	
Liquid LIMIT						33.5%
Type of Test	PL	PL	PL			
Cont. No.	14B	Q33	U21			
Wt of wet soil&cont.g	12.8	15.7	16.1			14.0
Wt of dry soil&cont.g	12.6	15.5	15.9			12.1
Wt of cont g	11.7	14.5	15.0			1.9cm Shrinkage
Wt of dry soil	0.9	1.0	0.9			

g				
Wt of moisture g	0.2	0.2	0.2	
Moisture content %	22.2	20	22.2	
Plastic Limit				21.45%

Sieve Analysis
Date Tested: April 04, 2013
Tested By: Mohammed Abubakar
Project Name: CEMM315 Lab
Sample C: Dufadufa

Sieve Size (mm)	Weight Retained(g)	Percent Retained %	Percent Passing %
2.8	9.4	4.7	95.3
1.4	2.3	1.15	94.45
0.71	7.1	3.55	90.6
0.425	41.3	20.65	69.95
0.36	17.8	8.9	61.05
0.212	26.9	13.45	47.6
0.15	8.9	4.45	43.15
0.075	7.9	3.95	39.2
Pan	3.1	1.55	37.65

Hydrometer Analysis
Test Date: April 04, 2013
Tested By: Mohammed Abubakar
Hydrometer Number: 152 H
Specific Gravity of Solids: 2.56
Dispersing Agent: Sodium Hexametaphosphate
Weight of Soil Sample: 75.3 gm
Meniscus Correction: +0.2

SC

TIME	H. R. R	T EMP.	FACTOR F	H=17.67-0.176R	COR.T R	PART. SIZE	K	% PASSING
0.17	40.2	26	0.04315	10.5948	40	0.3406456	1.63	32.5
0.25	38.1	26	0.04315	10.9644	37.9	0.2857612	1.63	30.79375
0.5	36.4	26	0.04315	11.2636	36.2	0.2048021	1.63	29.4125
1	35.2	26	0.04315	11.4748	35	0.1461684	1.63	28.4375
2	34.3	26	0.04315	11.6332	34.1	0.1040676	1.63	27.70625
4	32.1	26	0.04315	12.0204	31.9	0.0748015	1.63	25.91875
8	29	26	0.04315	12.566	28.8	0.0540797	1.63	23.4
15	28.8	26	0.04315	12.6012	28.6	0.0395495	1.63	23.2375
30	27.2	26	0.04315	12.8828	27	0.0282765	1.63	21.9375
60	24	26	0.04315	13.446	23.8	0.0204269	1.63	19.3375

120	21.1	26	0.04315	13.9564	20.9	0.0147156	1.63	16.98125
240	12.3	26	0.04315	15.5052	12.1	0.0109677	1.63	9.83125
360	10.5	27	0.03978	15.822	10.3	0.0083396	1.63	8.36875
720	11	28	0.03934	15.734	10.8	0.0058155	1.63	8.775
1440	8.6	26	0.04315	16.1564	8.4	0.0045706	1.63	6.825

Plastic, Liquid Limits and Shrinkage(sample C)

Type of Test	LL		LL		LL		LL	LL	
No. of Blows	48		37		28		17	13	
Container No.	X7		65		67		G5	A50	
Wt of wet soil&cont.g	24.2		26.4		32.2		37.6	41.9	
Wt of dry soil&cont.g	20.8		22.5		27.0		31.4	33.1	
Wt of cont g	10.7		11.3		12.9		15.2	10.7	
Wt of dry soil g	10.1		11.2		14.1		16.2	22.4	
Wt of moisture g	3.4		3.9		5.2		6.2	8.8	
Moisture content %	33.7		34.8		36.9		38.3	39.3	
Liquid LIMIT									36.2%
Type of Test		PL		PL		PL			
Cont. No.		M5		Q27		JA2			
Wt of wet soil&cont.g		15.3		13.2		13.4			14.0
Wt of dry soil&cont.g		15.1		12.9		13.0			12.2
Wt of cont g		14.0		11.7		11.2			1.8cm Shrinkage
Wt of dry soil g		1.1		1.2		1.8			
Wt of moisture g		0.2		0.3		0.4			
Moisture content %		18.2		25		22			
Plastic Limit									21.8%

Test Result Summary

Sample	Location	Aggregation S%,ST%CL%	Liquid Limit %	Plastic Limit %	Plasticity Index	Shrinkage%
A	Biye	68,29,3	56.5	41.6	14.9	15
B	Hayin Dogo	79,19,2	33.5	21.45	12.05	13.6
C	Dufadufa	70,23,7	36.2	21.8	14.4	12.9

Appendix 4: Soil Grain Size Analysis

Sieve Analysis
Date Tested: April 04, 2013
Tested By: Mohammed Abubakar
Project Name: Dried Tomato Storage
Sample A: Biye
Sample Size; 200g

Sieve Size (mm)	Weight Retained(g)	Percent Retained %	Percent Passing %
2.8	28.5	14.25	85.75
1.4	6.1	3.05	82.7
0.71	18.5	9.25	73.45
0.425	29.4	14.7	58.75
0.36	6.1	3.05	55.7
0.212	7.3	3.65	52.05
0.15	3.9	1.95	50.1
0.075	4.5	2.25	47.85
Pan			

Hydrometer Analysis
Test Date: April 04, 2013
Tested By: Mohammed Abubakar
Hydrometer Number 152 H
Specific Gravity of Solids: 2.56
Dispersing Agent: Sodium Hexametaphosphate
Weight of Soil Sample: 94gm
Meniscus Correction: +0.2

SA

TIME	H. R. R	TEMP.	FACTOR F	H=17.67-0.176R	COR. H R	PART. SIZE	K	% PASSING
0.17	50	26	0.04022	8.87	49.8	0.2905223	1.61	39.990909
0.25	48.1	26	0.04022	9.2044	47.9	0.2440449	1.61	38.465152
0.5	46.3	26	0.04022	9.5212	46.1	0.1755104	1.61	37.019697
1	45	26	0.04022	9.75	44.8	0.1255869	1.61	35.975758
2	44.1	26	0.04022	9.9084	43.9	0.0895218	1.61	35.25303
4	43.2	26	0.04022	10.0668	43	0.063805	1.6	34.53030

						5	1	3
8	41.7	26	0.04022	10.3308	41.5	0.045705	1.61	33.325758
15	38.2	26	0.04022	10.9468	38	0.034359	1.61	30.515152
30	36.4	26	0.04022	11.2636	36.2	0.0246445	1.61	29.069697
60	34.1	26	0.04022	11.6684	33.9	0.0177367	1.61	27.222727
120	31.4	26	0.04022	12.1436	31.2	0.0127946	1.61	25.054545
240	14.3	26	0.04022	15.1532	14.1	0.0101062	1.61	11.322727
360	7.2	27	0.03978	16.4028	7	0.0084913	1.61	5.6212121
720	5.4	28	0.03934	16.7196	5.2	0.0059949	1.61	4.1757576
1440	3.7	26	0.04022	17.0188	3.5	0.0043725	1.61	2.8106061

Plastic, Liquid Limits and Shrinkage(sample A)

Type of Test	LL	LL	LL	LL	LL	
No. of Blows	48	38	28	17	12	
Container No.	F8	84	167	D25	64	
Wt of wet soil&cont.g	23.2	27.2	33.0	35.2	42.4	
Wt of dry soil&cont.g	19.3	22.6	25.3	26.7	31.1	
Wt of cont g	11.6	14.0	11.5	12.4	12.0	
Wt of dry soil g	7.7	8.6	13.8	14.3	19.1	
Wt of moisture g	3.9	4.6	7.7	8.5	11.3	
Moisture content %	50.6	53.5	55.8	59.4	59.2	
Liquid LIMIT						56.5%
Type of Test	PL	PL	PL			
Cont. No.	RK	B2	B4			
Wt of wet	9.1	9.5	9.3			14.0

soil&cont.g				
Wt of dry soil&cont.g	8.8	9.2	8.9	11.9
Wt of cont g	8.1	8.5	7.9	2.1cm Shrinkage
Wt of dry soil g	0.7	0.7	1.0	
Wt of moisture g	0.3	0.3	0.4	
Moisture content %	42.9	42.9	40	
Plastic Limit				41.6%

Sieve Analysis
Date Tested: April 04, 2013
Tested By: Mohammed Abubakar
Project Name: Dried Tomato Storage
Sample B: Hayin Dogo
Sample Size: 200g

Sieve Size (mm)	Weight Retained(g)	Percent Retained %	Percent Passing %
2.8	79.8	39.2	60.1
1.4	7.1	3.55	56.55
0.71	15.2	7.6	48.55
0.425	25.2	12.6	36.35
0.36	6.1	3.05	33.3
0.212	6.1	3.05	29.8
0.15	4.2	2.1	27.7
0.075	4.2	2.1	25.6
Pan			

Hydrometer Analysis
Test Date: September 15, 2002
Tested By: Mohammed Abubakar
Hydrometer Number: 152 H
Specific Gravity of Solids: 2.56
Dispersing Agent: Sodium Hexametaphosphate
Weight of Soil Sample: 51.2 gm
Meniscus Correction: +0.2

SB

TIME	H. R. R	T EMP.	FACTOR F	H=17.67-0.176R	COR.T R	PART. SIZE	K	% PASSING
0.17	26.8	26	0.04022	12.9532	26.6	0.35108	1.61	21.360606
0.25	24	26	0.04022	13.446	23.8	0.2949637	1.61	19.112121
0.5	23.4	26	0.04022	13.5516	23.2	0.2093883	1.61	18.630303
1	22.1	26	0.04022	13.7804	21.9	0.1493045	1.61	17.586364
2	21.8	26	0.04022	13.8332	21.6	0.1057763	1.61	17.345455
4	20.2	26	0.04022	14.1148	20	0.0755526	1.61	16.060606
8	18.9	26	0.04022	14.3436	18.7	0.053855	1.61	15.016667
15	17.4	26	0.04022	14.6076	17.2	0.0396904	1.61	13.812121
30	16.2	26	0.04022	14.8188	16	0.0282675	1.61	12.848485
60	14.2	26	0.04315	15.1708	14	0.0216975	1.61	11.242424
120	12	26	0.04022	15.558	11.8	0.014482	1.61	9.4757576
240	10.1	26	0.04022	15.8924	9.9	0.0103498	1.61	7.95
360	8.4	27	0.03978	16.1916	8.2	0.0084364	1.61	6.5848485
720	6.4	28	0.03934	16.5436	6.2	0.0059633	1.61	4.9787879
1440	4.1	26	0.04022	16.9484	3.9	0.0043634	1.61	3.1318182

Plastic, Liquid Limits and Shrinkage(sample B)

Type of Test	LL	LL	LL	LL	LL	
No. of Blows	48	38	28	18	11	
Container No.	18	41	X39	10T	88	
Wt of wet soil&cont.g	23.9	26.0	32.8	37.8	41.5	
Wt of dry soil&cont.g	20.8	22.5	28.1	31.8	33.2	
Wt of cont g	11.0	11.1	14.3	14.6	11.0	
Wt of dry soil g	9.8	11.4	13.8	17.2	22.2	
Wt of moisture g	3.1	3.5	4.7	6	8.3	
Moisture content %	31.6	30.7	34.06	34.9	37.4	
Liquid LIMIT						33.5%

Type of Test	PL	PL	PL	
Cont. No.	14B	Q33	U21	
Wt of wet soil&cont.g	12.8	15.7	16.1	14.0
Wt of dry soil&cont.g	12.6	15.5	15.9	12.1
Wt of cont g	11.7	14.5	15.0	1.9cm Shrinkage
Wt of dry soil g	0.9	1.0	0.9	
Wt of moisture g	0.2	0.2	0.2	
Moisture content %	22.2	20	22.2	
Plastic Limit				21.45%

Sieve Analysis
Date Tested: April 04, 2013
Tested By: Mohammed Abubakar
Project Name: CEMM315 Lab
Sample C: Dufadufa

Sieve Size (mm)	Weight Retained(g)	Percent Retained %	Percent Passing %
2.8	9.4	4.7	95.3
1.4	2.3	1.15	94.45
0.71	7.1	3.55	90.6
0.425	41.3	20.65	69.95
0.36	17.8	8.9	61.05
0.212	26.9	13.45	47.6
0.15	8.9	4.45	43.15
0.075	7.9	3.95	39.2
Pan	3.1	1.55	37.65

Hydrometer Analysis
Test Date: April 04, 2013
Tested By: Mohammed Abubakar
Hydrometer Number: 152 H
Specific Gravity of Solids: 2.56
Dispersing Agent: Sodium Hexametaphosphate
Weight of Soil Sample: 75.3 gm
Meniscus Correction: +0.2

SC

TIME	H. R. R	T EMP.	FACTOR F	H=17.67-0.176R	COR.T R	PART. SIZE	K	% PASSING
0.17	40.2	26	0.04315	10.5948	40	0.3406456	1.63	32.5
0.25	38.1	26	0.04315	10.9644	37.9	0.2857612	1.63	30.79375
0.5	36.4	26	0.04315	11.2636	36.2	0.2048021	1.63	29.4125
1	35.2	26	0.04315	11.4748	35	0.1461684	1.63	28.4375
2	34.3	26	0.04315	11.6332	34.1	0.1040676	1.63	27.70625
4	32.1	26	0.04315	12.0204	31.9	0.0748015	1.63	25.91875
8	29	26	0.04315	12.566	28.8	0.0540797	1.63	23.4
15	28.8	26	0.04315	12.6012	28.6	0.0395495	1.63	23.2375
30	27.2	26	0.04315	12.8828	27	0.0282765	1.63	21.9375
60	24	26	0.04315	13.446	23.8	0.0204269	1.63	19.3375
120	21.1	26	0.04315	13.9564	20.9	0.0147156	1.63	16.98125
240	12.3	26	0.04315	15.5052	12.1	0.0109677	1.63	9.83125
360	10.5	27	0.03978	15.822	10.3	0.0083396	1.63	8.36875
720	11	28	0.03934	15.734	10.8	0.0058155	1.63	8.775
1440	8.6	26	0.04315	16.1564	8.4	0.0045706	1.63	6.825

Plastic, Liquid Limits and Shrinkage(sample C)

Type of Test	LL	LL	LL	LL	LL	
No. of Blows	48	37	28	17	13	
Container No.	X7	65	67	G5	A50	
Wt of wet soil&cont.g	24.2	26.4	32.2	37.6	41.9	
Wt of dry soil&cont.g	20.8	22.5	27.0	31.4	33.1	
Wt of cont g	10.7	11.3	12.9	15.2	10.7	
Wt of dry soil g	10.1	11.2	14.1	16.2	22.4	
Wt of moisture g	3.4	3.9	5.2	6.2	8.8	
Moisture content %	33.7	34.8	36.9	38.3	39.3	
Liquid LIMIT						36.2%
Type of Test	PL	PL	PL			

Cont. No.	M5	Q27	JA2	
Wt of wet soil&cont.g	15.3	13.2	13.4	14.0
Wt of dry soil&cont.g	15.1	12.9	13.0	12.2
Wt of cont g	14.0	11.7	11.2	1.8cm Shrinkage
Wt of dry soil g	1.1	1.2	1.8	
Wt of moisture g	0.2	0.3	0.4	
Moisture content %	18.2	25	22	
Plastic Limit				21.8%

Test Result Summary

Sample	Location	Aggregation S%,ST%CL%	Liquid Limit %	Plastic Limit %	Plasticity Index	Shrinkage%
A	Biye	68,29,3	56.5	41.6	14.9	15
B	Hayin Dogo	79,19,2	33.5	21.45	12.05	13.6
C	Dufa-dufa	70,23,7	36.2	21.8	14.4	12.9

Appendix 5 ; Cold room survey questionnaire

Ownership	Address	Type of food Prod.Store	Capacity	Room size	Refrigerator/ Compressor hp	Insulation	Insulation thickness
Mr. John Paul	Fish market Kado Abuja	Shrimps, Fish & chicken	10 Tonnes	12 feet by 8, height 8 feet	hp	Foster	4 inch
Mal. Musa Yaro	Fish market Kado Abuja	Fish, Beef & chicken	15 Tonnes	12 by 12Height 8 feet	5 hp	Carrier body	4 inch
Mr. E Moses	Utako market FCT Abuja	Shrimps, beef, fish & chicken	20 Tonnes	16 by 2 Height 8 feet	10 hp	Coplan	4 inch
Mr. Robert	Utako market FCT Abuja	Beef, fish & chicken	10 Tonnes	8 by 8 Height 10 feet	5 hp	Presco	4 inch

Appendix 6: No Load Test Results (test month,25th December 2016)
Walls Temperature(^{o}C) for Room 1(75% shaded against sun rays)

9.00am, envr temp = 20.9, RH = 35.9%

Wall1(Grid(G); 20cm x20cm) Inside, Top to Bottom

G1	G2	G3	G4	G5	G6
24.8	24.6	24.6	24.8	25.0	25.2
25.2	25.4	25.4	25.4	25.4	25.4
25.4	25.4	25.4	25.4	25.2	25.2
25.4	25.4	25.2	25.4	25.4	25.4
25.6	25.6	25.8	25.8	25.8	25.8
25.8	25.8	25.8	26.0	26.0	26.0
26.0	26.0	26.0	26.0	26.4	26.4
26.8	27.2	27.2	27.2	27.2	27.2

Wall1(Grid(G); 20cm x20cm)Outside, Top to Bottom

G1	G2	G3	G4	G5	G6
20.2	20.2	20.2	19.8	19.8	19.6
20.6	20.6	20.6	19.8	19.8	19.8
20.6	20.6	20.6	19.8	19.4	18.8
21.0	20.8	20.8	19.8	19.8	18.4
25.6	23.4	23.4	22.4	21.4	21.6
26.8	27.0	26.0	24.0	24.0	24.0
27.4	27.0	26.0	24.6	24.2	24.2
28.2	28.2	27.6	25.2	24.8	24.4

Wall2 (Grid(G); 20cm x20cm) Inside, Top to Bottom

G1	G2	G3	G4	G5	G6
24.8	24.6	24.6	24.8	24.8	25.0
24.8	24.8	24.8	28.8	25.2	25.4
25.4	25.4	23.8	24.8	25.4	25.4
25.4	25.4	25.4	24.8	25.4	25.4
25.6	25.6	25.6	25.6	25.8	25.8
25.8	25.8	25.8	25.8	26.0	26.2
25.8	26.2	26.2	26.2	26.2	26.2
25.8	26.4	26.8	26.8	27.0	27.0

Wall2(Grid(G); 20cm x20cm) Outside, Top to Bottom

G1	G2	G3	G4	G5	G6
17.6	17.8	17.8	18.2	18.6	18.6
17.8	17.8	17.8	18.2	18.6	18.6
17.2	17.6	18.4	18.4	19.2	19.2
18.4	18.6	19.2	20.1	20.1	20.1
19.8	19.8	22.2	22.2	23.2	23.6
20.8	22.6	23.2	23.2	24.6	25.6
21.4	23.0	24.0	26.6	27.2	27.4
22.0	24.0	26.0	27.1	24.6	28.0

Wall3(Grid(G); 20cm x20cm) Inside, Top to Bottom

G1	G2	G3	G4	G5	G6
25.2	25.4	25.4	25.4	25.4	25.4
25.4	25.4	25.4	25.4	25.4	25.4
25.4	25.4	25.4	25.4	25.4	25.4
25.4	25.4	25.4	24.8	25.4	25.4
25.8	26.0	26.0	26.0	26.0	25.8
26.0	26.0	26.0	26.0	26.0	26.0
26.2	26.2	26.2	26.2	26.2	25.8
26.4	26.4	26.4	26.2	26.2	25.8

Wall3 (Grid (G); 20cm x20cm) Outside, Top to Bottom

G1	G2	G3	G4	G5	G6
17.8	18.2	18.2	18.2	17.8	17.2
18.4	18.4	18.4	18.4	18.4	18.4
18.6	18.6	18.6	18.6	18.4	18.4
18.6	18.8	18.0	19.0	19.0	19.0
19.0	18.8	18.8	19.0	19.2	19.2
18.8	18.6	18.0	19.2	19.4	19.4
19.4	19.4	19.6	19.8	19.8	19.8
19.6	19.8	19.8	20.4	20.0	20.2

Door Side(Grid(G); 20cm x20cm) Inside, Top to Bottom

G1	G2	G3	G4
24.8	24.6	24.6	24.6
24.8	24.6	24.6	24.6
24.6	24.6	24.6	24.6
24.6	24.6	24.6	24.8
24.6	24.6	24.6	24.6

Door Side(Grid(G); 20cm x20cm) Outside, Top to Bottom

G1	G2	G3	G4
20.8	20.6	20.8	20.8
20.8	20.8	20.6	20.6
20.6	20.8	20.6	20.6
20.6	20.8	20.6	20.8
20.7	20.8	20.6	20.8

Floor(Grid(G); 20cm x20cm) Inside to Outside

G1	G2	G3	G4	G5	G6
25.8	25.8	25.8	25.8	26.0	26.0
27.0	26.2	26.2	26.2	20.2	26.2
27.0	26.2	26.2	26.2	26.2	26.2
27.0	26.4	26.4	26.4	26.4	26.4
27.2	26.6	26.4	26.4	26.4	26.4
27.4	26.8	26.6	26.4	26.4	26.4
27.4	26.8	26.4	26.4	26.4	26.4
27.4	27.4	26.48	26.2	26.2	26.4

Roof(Grid(G); 20cm x20cm) Inside to Outside

G1	G2	G3	G4	G5	G6
24.3	24.4	24.4	24.4	24.4	24.4
24.6	24.6	24.6	24.6	24.6	24.6
24.6	24.6	24.6	24.6	24.6	24.6
24.6	24.6	24.6	24.6	24.6	24.6
24.6	24.6	24.6	24.6	24.6	24.6
24.6	24.6	24.6	24.6	24.6	24.6
24.6	24.6	24.6	24.6	24.6	24.6
25.0	25.2	25.2	25.2	25.2	25.0

Room 1 inside space temperature (^{o}C), 9.00am, envr temp = 20.9^{o}C, RH = 35.9%

Close to the Roof(Grid(G); 20cm x20cm)

G1	G2	G3	G4	G5	G6
22.2	22.8	23.1	23.3	23.4	23.5
23.6	23.8	23.8	23.9	23.9	23.9
24.0	24.1	24.1	24.2	24.2	24.2
24.2	24.2	24.3	24.3	24.3	24.3
24.3	24.3	24.4	24.4	24.4	24.5

Middle of the room space

G1	G2	G3	G4	G5	G6
24.5	24.5	24.4	24.4	24.4	24.5
24.5	24.5	24.6	24.6	24.6	24.6
24.6	24.6	24.6	24.6	24.6	24.6
24.6	24.6	24.7	24.7	24.7	24.7
24.7	24.7	24.7	24.7	24.7	24.7

Close to Floor

G1	G2	G3	G4	G5	G6
24.7	24.7	24.6	24.5	24.5	24.6
24.6	24.6	24.6	24.6	24.8	24.5
24.6	24.7	24.7	24.7	24.7	24.6
24.8	24.6	24.8	24.8	24.6	24.7
24.7	24.6	24.6	24.6	24.6	24.6

Relative Humidity (%) of the Room1 at 9.00am , envr. Temp ^{o}C = 20.9, RH = 35.9%

Close to Roof (RH %)

G1	G2	G3	G4	G5	G6
43.4	42.8	41.2	42.3	42.6	41.3
41.3	42.3	43.2	41.3	41.3	41.3
42.3	41.9	41.3	41.9	42.2	44.7
44.7	42.5	43.7	43.4	42.8	42.8
45.9	45.6	43.1	47.5	48.0	49.9

Middle of the Room (RH %)

G1	G2	G3	G4	G5	G6
42.2	42.2	41.3	42.2	42.8	43.1
43.7	43.7	43.1	44.7	44.1	45.0
44.1	44.4	44.1	44.7	44.7	44.7
43.7	44.1	44.7	45.0	44.7	43.7
44.1	44.1	44.7	44.7	44.7	44.4

Close to Floor (RH %)

G1	G2	G3	G4	G5	G6
44.1	43.7	43.7	43.4	44.4	43.7
44.4	44.7	44.7	44.7	45.0	45.0
45.9	45.0	44.1	44.4	44.4	44.4
44.1	44.1	43.7	43.1	43.4	43.7
42.2	43.4	43.7	43.7	43.0	44.7

Walls Temperature(^{o}C) for Room 1(75% shaded against sun rays)

2.00pm, envr temp = 28.4^{o}C, RH = 26.1%

Wall1(Grid(G); 20cm x20cm) Inside, Top to Bottom

G1	G2	G3	G4	G5	G6
24.8	25.2	25.2	25.2	25.2	25.2
24.8	25.2	25.2	25.2	25.2	25.2
24.8	25.2	25.2	25.2	25.2	25.2
25.2	25.2	25.2	25.2	25.2	25.2
25.4	25.6	25.6	25.8	25.8	25.8
25.8	25.8	25.8	25.8	25.8	26.0
26.2	26.2	26.2	26.4	26.4	26.4
26.2	26.8	26.8	26.8	27.2	27.2

Wall1(Grid(G); 20cm x20cm)Outside, Top to Bottom

G1	G2	G3	G4	G5	G6
28.0	27.8	27.8	27.8	27.6	28.8
27.6	27.0	27.6	27.6	28.2	28.6
28.6	28.0	28.4	28.8	27.8	28.6
28.8	28.8	28.4	28.8	28.6	29.6
30.4	30.4	31.2	31.2	32.0	30.4
34.0	34.8	34.8	34.8	34.8	35.4
35.0	36.8	37.2	37.2	37.2	38.2
35.0	37.0	39.0	39.4	39.2	40.2

Wall2 (Grid(G); 20cm x20cm) Inside, Top to Bottom

G1	G2	G3	G4	G5	G6
24.2	24.4	24.4	24.4	24.2	24.2
24.4	24.4	24.4	24.6	24.6	24.6
24.2	24.6	24.4	24.6	24.8	24.6
24.4	24.6	24.8	24.6	24.6	24.6
24.6	24.6	24.6	24.8	25.0	24.8
25.4	25.4	25.4	25.4	25.4	25.6
25.4	25.6	25.6	25.6	25.8	25.6
25.8	25.6	25.8	26.2	26.4	26.8

Wall2 (Grid(G); 20cm x20cm) Outside, Top to Bottom

G1	G2	G3	G4	G5	G6
27.4	27.2	27.2	27.2	28.2	28.2
27.6	27.6	27.6	27.0	27.6	27.6
26.6	26.8	26.5	27.4	27.6	27.6
26.6	27.2	27.2	27.2	27.6	27.8
26.4	27.0	27.4	27.6	27.8	27.8
25.2	25.8	26.2	26.8	26.8	27.8
25.2	26.2	26.6	27.4	28.4	28.4
25.2	26.8	28.6	27.2	28.6	30.4

Wall3 (Grid(G); 20cm x20cm) Inside, Top to Bottom

G1	G2	G3	G4	G5	G6
24.6	24.6	24.6	24.6	24.8	24.8
24.2	24.6	24.6	24.8	24.8	24.8
24.8	24.8	24.8	25.2	25.2	24.8
24.8	24.8	24.8	24.8	25.2	25.0
25.2	25.6	25.6	25.6	25.6	25.6
25.2	25.6	25.4	25.6	25.6	25.6
25.6	25.8	25.8	25.8	25.8	25.8
25.8	25.8	25.8	25.8	25.8	25.8

Wall3(Grid(G); 20cm x20cm) Outside, Top to Bottom

G1	G2	G3	G4	G5	G6
27.0	25.6	25.2	25.6	25.4	28.4
26.8	25.2	25.4	25.6	26.4	27.4
25.6	24.8	24.8	25.0	26.4	25.8
25.8	25.2	25.4	25.4	25.6	25.8
26.2	24.6	24.4	25.2	25.4	26.8
25.6	24.8	24.8	24.8	25.4	25.8
25.6	24.8	24.8	25.4	25.4	26.6
25.6	25.4	24.8	25.6	25.6	25.8

Room 1Roof inside(Grid (G); 20cm x20cm) Inside to Outside

G1	G2	G3	G4	G5	G6
24.6	25.2	25.2	24.8	24.8	24.8
24.8	25.2	25.2	24.8	25.4	25.0
25.0	25.6	25.0	25.6	25.4	25.2
24.8	25.4	25.4	25.4	25.4	25.2
25.0	25.4	25.6	25.4	25.4	25.4
25.2	25.6	25.6	24.8	25.4	25.6
25.2	26.6	25.6	24.6	25.6	25.6
24.6	25.2	25.4	25.4	25.4	25.4

Floor (Grid(G); 20cm x20cm) Inside to Outside

G1	G2	G3	G4	G5	G6
25.8	25.4	26.2	26.4	26.6	26.6
25.8	26.2	26.4	26.6	26.6	26.8
25.8	26.4	26.8	26.4	26.8	26.6
26.2	26.4	26.6	26.6	26.8	27.1
26.2	26.4	26.6	26.6	26.8	27.4
26.4	26.6	26.6	26.8	22.6	27.2
26.2	26.4	26.6	26.4	26.4	27.2
26.4	26.6	26.0	26.4	26.8	27.4

Door Side (Grid(G); 20cm x20cm) Inside, Top to Bottom

	G2	G3	G4
27.8	28.0	28.0	28.0
27.8	28.0	28.0	28.0
28.1	28.2	28.2	28.2
28.2	28.4	28.2	28.2
28.1	28.2	28.2	28.2
28.2	28.2	28.2	28.2
28.2	28.2	28.2	28.2
28.2	28.2	28.2	28.2

Door Side(Grid(G); 20cm x20cm) Outside, Top to Bottom

G1	G2	G3	G4
30.4	30.0	30.4	30.4
31.2	31.2	31.2	30.8
31.2	31.6	31.6	31.8
31.8	33.4	32.6	32.6
33.6	34.4	33.6	33.6
39.0	38.-	34.8	34.0
34.6	34.8	34.2	34.2
35.0	35.2	35.8	35.2

Walls Temperature(^{o}C) for Room 1(75% shaded against sun rays)

12.00mid night, envr temp = 20.3^{o}C, RH = 37.5%

Wall1(Grid(G); 20cm x20cm) Inside, Top to Bottom

G1	G2	G3	G4	G5	G6
25.2	25.2	25.2	25.4	25.6	25.6
25.4	25.8	25.6	25.6	25.6	25.6
25.8	25.8	25.8	25.8	25.6	25.8
25.8	25.8	25.8	25.8	25.8	25.8
26.0	26.0	26.2	26.2	26.2	26.2
26.8	26.4	26.2	26.4	26.4	26.4
26.4	26.4	26.6	26.6	26.6	26.6
26.8	27.2	27.2	27.2	27.2	27.2

Wall1(Grid(G); 20cm x20cm)Outside, Top to Bottom

G1	G2	G3	G4	G5	G6
18.2	18.4	18.6	18.4	18.4	18.4
17.8	18.2	18.4	18.4	18.4	18.4
18.2	18.8	19.0	18.4	18.4	18.4
18.8	19.0	19.2	19.0	18.0	18.0
18.0	18.8	19.2	19.0	18.0	18.6
17.8	19.0	19.2	19.4	19.2	18.4
18.6	19.2	19.4	19.4	19.2	20.2
19.8	19.2	20.4	20.4	20.4	20.4

Wall2(Grid(G); 20cm x20cm) Inside, Top to Bottom

G1	G2	G3	G4	G5	G6
25.2	25.4	25.4	25.2	25.4	25.4
25.4	25.4	25.4	25.4	25.4	25.4
25.4	25.4	25.2	25.4	25.6	25.8
25.4	25.4	25.6	25.8	25.8	25.8
25.8	26.0	20.2	26.2	26.2	26.2
25.8	26.2	26.2	26.4	26.2	26.2
25.8	26.2	26.2	26.4	26.4	26.2
25.8	26.4	26.4	26.4	26.4	26.8

Wall2 (Grid(G); 20cm x20cm) Outside, Top to Bottom

G1	G2	G3	G4	G5	G6
16.8	17.2	17.4	17.4	17.6	17.6
17.2	17.2	18.6	18.2	18.2	18.2
17.2	18.4	18.4	18.4	18.4	18.2
17.6	18.4	18.4	18.4	18.6	18.4
17.6	18.4	18.4	18.4	18.4	18.4
18.6	18.8	18.8	18.8	19.0	19.0
18.8	18.8	19.2	19.2	19.2	19.9
19.2	19.2	19.8	20.0	20.0	20.0

Wall3 (Grid(G); 20cm x20cm) Inside, Top to Bottom

G1	G2	G3	G4	G5	G6
25.2	25.4	25.6	25.8	25.6	25.6
25.6	25.6	25.6	25.6	25.4	25.2
25.6	25.6	25.6	25.4	25.4	25.4
25.6	25.6	25.6	25.6	25.6	25.4
25.8	25.8	26.0	26.0	25.8	25.4
25.8	26.0	26.2	25.8	25.8	25.8
25.8	26.2	26.2	26.2	26.0	25.8
26.2	26.2	26.2	26.2	25.8	25.8

Wall3 (Grid(G); 20cm x20cm) Outside, Top to Bottom

G1	G2	G3	G4	G5	G6
17.8	18.2	18.2	18.2	18.2	18.2
17.8	18.6	18.6	18.8	18.8	18.8
18.4	18.4	18.4	18.8	19.4	19.2
18.4	18.6	19.2	19.2	19.2	19.2
18.6	18.6	18.6	18.6	19.2	19.0
18.6	19.2	19.2	18.4	19.2	19.2
18.4	19.4	19.4	19.6	19.6	19.6
19.3	19.4	19.6	20.4	20.4	20.4

Room 1Roof inside(Grid (G); 20cm x20cm) Inside to Outside

G1	G2	G3	G4	G5	G6
25.2	25.2	25.2	25.6	25.6	25.2
25.4	25.4	25.4	25.8	25.8	25.6
25.2	25.4	25.6	25.6	25.6	25.8
25.2	25.6	25.6	25.6	25.8	25.6
25.4	25.6	25.6	25.8	25.6	25.8
25.2	25.6	25.6	25.6	25.8	25.6
25.2	25.6	25.6	25.8	25.6	25.8
25.4	25.4	25.6	25.6	25.8	25.8

Floor(Grid(G); 20cm x20cm) Inside to Outside

G1	G2	G3	G4	G5	G6
25.4	25.6	25.8	25.8	26.4	27.2
25.4	25.8	25.8	26.0	26.4	27.2
25.8	26.0	26.2	26.4	26.4	27.2
26.0	26.0	26.4	26.4	26.6	27.2
26.2	26.2	26.4	26.6	26.4	27.2
26.2	26.2	26.6	26.4	26.4	27.2
26.2	26.0	25.8	26.4	26.6	27.2
26.0	26.4	25.8	26.4	26.4	27.2

Door Side (Grid(G); 20cm x20cm) Inside, Top to Bottom

G1	G2	G3	G4
23.0	24.2	24.2	25.2
23.8	24.6	24.2	24.2
24.4	24.6	24.6	24.4
24.4	24.4	24.4	24.8
24.6	24.6	24.8	24.6

Door Side(Grid(G); 20cm x20cm) Outside, Top to Bottom

G1	G2	G3	G4
19.6	19.6	19.6	19.4
18.4	18.4	18.4	18.6
18.6	18.4	18.2	18.6
18.4	18.2	18.4	18.8
18.0	18.0	18.2	18.4

Walls Temperature(^{o}C) for Room 1(75% shaded against sun rays)

5.00am, envr temp = 18.9^{o}C, RH = 39.3%

Wall1(Grid(G); 20cm x20cm) Inside, Top to Bottom

G1	G2	G3	G4	G5	G6
24.2	24.4	24.4	24.4	24.8	24.6
24.8	24.8	24.8	24.8	24.8	24.8
24.8	24.8	24.8	25.2	25.4	25.4
25.2	25.2	25.2	25.4	25.4	25.4
25.2	25.2	25.4	25.4	25.8	25.8
25.4	25.4	25.4	25.8	25.4	25.6
25.6	25.4	26.4	26.2	26.2	26.2
25.4	26.2	26.4	26.2	26.6	26.6

Wall1(Grid(G); 20cm x20cm)Outside, Top to Bottom

G1	G2	G3	G4	G5	G6
15.4	16.0	16.2	16.4	16.0	16.0
16.2	16.8	16.2	16.4	16.4	16.2
16.2	16.4	16.4	15.8	15.8	15.8
15.4	15.8	16.2	15.6	15.4	15.6
14.8	15.8	16.2	15.8	15.4	15.8
15.8	16.2	16.8	16.2	16.2	16.2
15.6	16.6	16.6	17.2	17.2	16.6
17.0	18.0	18.0	18.2	18.2	18.2

Wall2(Grid(G); 20cm x20cm) Inside, Top to Bottom

G1	G2	G3	G4	G5	G6
24.0	23.8	24.0	24.2	24.2	24.2
24.4	24.0	23.8	24.4	24.4	24.4
24.4	24.4	23.6	24.6	24.4	24.6
24.8	24.6	24.6	24.8	24.8	24.8
24.8	25.0	25.2	25.2	25.2	25.2
25.2	25.2	25.4	25.4	25.6	25.6
25.0	25.4	25.4	25.4	25.4	25.6
25.4	25.4	25.4	25.4	25.8	26.0

Wall2(Grid(G); 20cm x20cm) Outside, Top to Bottom

G1	G2	G3	G4	G5	G6
14.2	14.8	14.8	14.2	14.2	14.2
14.4	14.6	14.8	14.8	15.0	15.0
13.8	14.4	14.4	14.2	14.4	14.6
15.2	15.2	15.2	13.2	15.2	15.2
14.8	15.2	15.2	15.2	15.4	15.4
14.8	15.2	15.2	15.4	15.4	15.0
14.8	15.2	15.4	15.8	15.8	15.8
15.8	16.2	16.2	17.2	17.2	17.2

Wall3(Grid(G); 20cm x20cm) Inside, Top to Bottom

G1	G2	G3	G4	G5	G6
24.2	24.2	24.6	24.6	24.6	24.6
24.2	24.6	24.6	24.6	24.6	24.6
24.6	24.6	25.0	25.2	25.0	25.0
24.2	25.0	25.6	25.4	25.6	25.6
24.8	25.4	25.6	25.6	25.6	25.6
25.4	25.4	25.6	25.6	25.4	25.6
25.2	2544	25.6	25.8	25.4	25.6
25.2	25.6	25.8	25.8	25.8	25.8

Wall3(Grid(G); 20cm x20cm) Outside, Top to Bottom

G1	G2	G3	G4	G5	G6
14.8	15.2	15.2	15.2	15.2	14.8
14.8	15.2	15.2	15.4	156	15.6
15.2	15.2	15.2	15.6	15.8	15.8
14.8	15.2	15.2	15.6	15.8	15.6
15.2	15.6	16.0	16.0	15.8	15.8
15.2	16.0	16.4	16.4	16.2	16.4
15.4	16.0	16.4	16.2	16.2	16.4
16.2	17.2	17.8	17.8	17.8	17.8

Room 1Roof inside (Grid (G); 20cm x20cm) Inside to Outside

G1	G2	G3	G4	G5	G6
24.4	24.6	24.4	24.4	24.6	24.6
24.6	24.6	24.6	24.8	24.8	24.8
24.6	24.8	25.2	25.6	25.2	24.8
24.6	24.8	24.6	25.0	24.8	24.6
24.6	24.8	24.8	25.2	25.0	24.8
24.8	24.8	25.1	24.8	25.0	25.0
24.8	25.4	25.4	25.4	25.4	25.4
25.0	24.6	25.0	25.2	25.2	25.2

Floor(Grid(G); 20cm x20cm) Inside to Outside

G1	G2	G3	G4	G5	G6
25.6	25.6	25.8	20.6	26.4	26.0
25.8	25.8	25.8	25.8	25.8	26.8
25.8	25.8	26.2	26.2	26.2	26.6
25.8	25.8	25.8	26.2	26.4	26.8
25.8	25.8	25.8	26.4	26.6	26.8
25.8	25.8	25.8	26.2	26.2	26.2
25.8	25.8	25.8	26.4	26.2	26.6
25.8	25.4	25.6	25.8	26.2	26.4

Door Side (Grid(G); 20cm x20cm) Inside, Top to Bottom

G1	G2	G3	G4
22.8	23.2	23.2	23.2
23.4	23.0	23.2	23.2
23.6	23.8	23.2	23.4
23.6	23.2	23.6	23.2
23.8	23.2	23.4	23.6

Door Side(Grid(G); 20cm x20cm) Outside, Top to Bottom

G1	G2	G3	G4
17.2	16.8	16.8	16.2
18.4	18.4	18.4	18.6
15.8	15.8	15.8	16.2
15.6	15.6	15.6	15.6
16.2	16.2	15.6	15.8

Walls Temperature(^{o}C) for Room 2(92% shaded against sun rays)

10.00am, envr temp = 26.1 ^{o}C, RH = 31.8%

Wall1(Grid(G); 20cm x20cm) Inside, Top to Bottom

G1	G2	G3	G4	G5	G6
23.4	23.6	23.6	23.4	23.4	23.4
23.8	23.8	23.8	23.8	24.0	24.0
24.0	24.0	24.0	24.0	24.2	24.2
24.0	24.0	24.0	24.0	23.8	23.8
24.4	24.4	24.4	24.4	24.4	24.4
24.4	24.4	24.6	24.6	24.4	24.4
24.4	24.4	24.4	24.6	24.6	24.6
25.2	25.2	25.2	25.2	25.2	25.2

Wall1(Grid(G); 20cm x20cm)Outside, Top to Bottom

G1	G2	G3	G4	G5	G6
21.4	21.8	21.8	21.8	19.8	19.6
21.2	21.2	21.6	20.8	19.8	19.8
20.6	20.4	20.2	19.8	19.4	18.8
20.8	20.4	20.2	19.8	19.8	18.4
21.2	20.8	20.6	22.4	21.4	21.6
20.8	20.6	20.8	24.0	24.0	24.0
21.2	21.8	21.2	24.6	24.2	24.2
21.4	21.6	22.0	25.2	24.8	24.4

Wall2(Grid(G); 20cm x20cm) Inside, Top to Bottom

G1	G2	G3	G4	G5	G6
24.8	24.6	24.6	24.8	24.8	25.0
24.8	24.8	24.8	28.8	25.2	25.4
25.4	25.4	23.8	24.8	25.4	25.4
25.4	25.4	25.4	24.8	25.4	25.4
25.6	25.6	25.6	25.6	25.8	25.8
25.8	25.8	25.8	25.8	26.0	26.2
25.8	26.2	26.2	26.2	26.2	26.2
25.8	26.4	26.8	26.8	27.0	27.0

Wall2(Grid(G); 20cm x20cm) Outside, Top to Bottom

G1	G2	G3	G4	G5	G6
17.6	17.8	17.8	18.2	18.6	18.6
17.8	17.8	17.8	18.2	18.6	18.6
17.2	17.6	18.4	18.4	19.2	19.2
18.4	18.6	19.2	20.1	20.1	20.1
19.8	19.8	22.2	22.2	23.2	23.6
20.8	22.6	23.2	23.2	24.6	25.6
21.4	23.0	24.0	26.6	27.2	27.4
22.0	24.0	26.0	27.1	24.6	28.0

Wall3(Grid(G); 20cm x20cm) Inside, Top to Bottom

G1	G2	G3	G4	G5	G6
25.2	25.4	25.4	25.4	25.4	25.4
25.4	25.4	25.4	25.4	25.4	25.4
25.4	25.4	25.4	25.4	25.4	25.4
25.4	25.4	25.4	24.8	25.4	25.4
25.8	26.0	26.0	26.0	26.0	25.8
26.0	26.0	26.0	26.0	26.0	26.0
26.2	26.2	26.2	26.2	26.2	25.8
26.4	26.4	26.4	26.2	26.2	25.8

Wall3(Grid(G); 20cm x20cm) Outside, Top to Bottom

G1	G2	G3	G4	G5	G6
17.8	18.2	18.2	18.2	17.8	17.2
18.4	18.4	18.4	18.4	18.4	18.4
18.6	18.6	18.6	18.6	18.4	18.4
18.6	18.8	18.0	19.0	19.0	19.0
19.0	18.8	18.8	19.0	19.2	19.2
18.8	18.6	18.0	19.2	19.4	19.4
19.4	19.4	19.6	19.8	19.8	19.8
19.6	19.8	19.8	20.4	20.0	20.2

Time (day)	Inside Room RH%		Environmental RH%
	Room1	Room2	
0	65	60	58
21	67	67.4	70
42	76.5	74	74
63	87.2	87.5	79
84	88.9	88.3	91.1
105	86.4	92	93

Room 1 02/3/2017 TOP
Time: 11:00am-12:00pm AIR CONDITION
RH-26%
TEMP-30.9^{O}C

T/RH	G1	G2	G3	G4	G5	G6
T	27.2	27.4	26.6	25.8	18.0	20.3
RH	28.5	28.5	29.4	29.5	45.2	44.6
T	20.30	20.70	20.70	20.00	20.90	20.90
RH	44.90	44.0	43.4	43.10	43.10	43.10
T	21.2	21.60	22.40	22.60	22.9	23.0
RH	40.8	40.50	39.40	39.10	38.5	38.0
T	23.40	23.70	23.70	24.50	24.40	24.60
RH	37.40	36.70	36.40	35.80	35.500	35.10
T	25.10	25.10	24.60	23.90	23.90	23.90
RH	34.70	34.70	34.50	34.80	35.1	35.10
T	23.20	22.5	22.3	22.3	22.4	21.60
RH	35.10	35.6	36.00	36.0	36.6	37.00

MIDDLE

T/RH	G1	G2	G3	G4	G5	G6
T	22.2	21.7	21.40	21.1	21.5	21.70
RH	37.2	37.6	38.00	38.3	38.6	38.60
T	22.00	22.00	22.20	22.40	22.6	22.60
RH	39.40	38.50	38.5	38.50	38.50	38.20
T	23.1	23.00	23.10	23.20	23.3	23.4
RH	38.3	38.60	38.00	37.70	38.0	37.7
T	23.80	23.9	23.9	24.1	24.1	24.2
RH	38.6	37.4	36.7	36.7	36.7	36.7
T	24.7	24.5	24.30	24.20	24.20	23.8
RH	36.4	36.4	36.10	36.10	36.10	36.40
T	23.8	22.9	21.8	21.6	21.00	21.1
RH	36.1	36.3	37.00	37.00	37.3	38.2

FLOOR

T/RH	G1	G2	G3	G4	G5	G6
T	21.40	21.7	21.3	21.2	21.2	21.5
RH	38.90	39.9	39.2	39.2	39.2	39.5
T	21.50	21.80	22.00	22.00	22.10	22.4
RH	40.2	39.80	39.80	40.1	40.40	40.1
T	22.70	22.70	22.9	23.00	23.40	23.4
RH	40.40	40.10	39.8	39.6	38.9	38.9
T	23.9	23.9	24.20	24.2	24.3	24.2
RH	38.00	38.00	38.00	37.7	37.4	37.00
T	24.30	23.70	23.4	23.20	22.4	21.8
RH	36.40	36.70	36.7	37.00	37.2	38.00
T	22.3	21.7	21.1	21.2	21.00	20.9
RH	38.5	38.6	38.6	38.9	39.20	39.7

ROOM 1

SOUTH WALL TEMPS

INSIDE						OUTSIDE					
G1	G2	G3	G4	G5	G6	G1	G2	G3	G4	G5	G6
27.3	27.3	26.8	26.8	26.2	25.6	40.4	39.6	39.6	39.4	39.6	40.2
27.6	27.2	27.2	26.8	26.2	25.2	40.4	39.8	39.8	39.6	39.4	39.4
27.2	26.8	26.8	26.4	25.8	23.8	40.2	39.6	39.4	39.4	39.2	39.4
26.0	25.8	26.2	25.8	24.6	24.0	40.2	39.2	39.4	39.00	38.6	38.2
25.6	25.8	26.10	25.6	25.4	24.8	40.4	39.4	39.2	38.6	38.4	38.6
26.6	26.2	26.0	25.6	25.4	25.8	35.8	34.2	33.8	35.6	36.00	35.8

EAST

INSIDE						OUTSIDE					
G1	G2	G3	G4	G5	G6	G1	G2	G3	G4	G5	G6
27.4	26.6	26.0	25.8	26.4	26.6	40.2	40.00	40.2	39.2	38.2	39.00
26.6	26.4	25.0	24.0	25.6	27.2	40.20	39.60	38.2	38.2	38.4	38.40
26.8	26.6	26.6	26.4	27.0	27.2	38.6	38.2	37.8	37.8	37.8	37.4
26.8	26.4	26.4	26.4	26.6	26.8	39.4	38.6	38.6	38.20	37.8	37.4
26.2	26.0	25.8	25.8	26.0	26.4	38.8	38.00	37.8	37.6	37.6	36.6
26.6	26.8	25.8	25.8	26.0	26.2	36.8	36.4	30.4	36.00	35.8	35.4

NORTH

INSIDE						OUTSIDE					
G1	G2	G3	G4	G5	G6	G1	G2	G3	G4	G5	G6
27.2	26.6	26.2	25.0	25.2	24.8	37.2	36.6	37.4	36.4	37.2	38.4
26.6	26.2	26.0	25.8	25.2	24.8	37.00	35.80	36.2	35.6	36.2	36.40
26.4	26.4	26.2	25.6	25.4	25.8	36.4	35.2	35.4	35.4	35.4	35.4
26.4	26.4	26.4	26.2	25.8	26.4	35.6	35.2	35.00	34.8	34.8	35.2
36.4	26.2	26.4	26.2	26.0	25.8	35.6	34.4	34.4	34.4	34.4	34.2
26.4	26.6	26.4	26.4	26.4	26.2	34.8	34.2	34.00	33.6	33.8	34.0

DOOR

INSIDE						OUTSIDE					
G1	G2	G3	G4	G5	G6	G1	G2	G3	G4	G5	G6
27.8	27.4	27.2	27.00	26.8	26.8	40.0	40.4	40.6	40.8	40.8	40.4
26.8	25.8	24.6	24.4	24.0	24.2	39.4	40.8	40.8	40.8	40.8	40.8
26.6	26.2	24.8	24.4	23.8	24.4	39.6	40.2	40.6	40.8	43.8	40.6
24.6	23.6	24.4	24.2	23.6	23.4	37.8	39.6	39.6	39.8	39.8	39.4
25.4	24.8	24.8	25.4	24.8	24.6	37.6	38.2	39.2	39.4	38.4	37.8
25.4	24.4	24.6	24.4	24.8	24.6	36.2	36.2	36.2	36.6	36.8	36.8

ROOF ROOM1

1	2	3	4	5	6
27.6	27.2	26.4	25.8	25.2	25.4
25.8	25.0	25.4	25.6	25.2	24.0
24.6	24.4	25.4	27.6	25.2	25.2
25.2	25.2	25.2	25.2	25.2	25.0
25.2	24.6	24.6	24.4	24.4	24.4
27.2	26.6	26.4	26.6	26.2	25.8

FLOOR ROOM 1

1	2	3	4	5	6
27.4	26.8	26.8	26.8	26.8	27.4
27.00	26.6	26.4	26.4	26.4	26.6
26.8	26.4	26.2	26.2	24.4	26.4
26.4	25.8	25.8	25.8	25.8	25.8
25.8	25.4	25.2	24.8	25.2	24.8
25.2	24.6	24.6	23.8	24.4	24.6

CURTAIN ROOM1

1	2	3	4	5	6
19.8	19.6	18.6	19.6	20.2	20.2
21.8	22.2	22.4	22.4	22.4	22.6
23.4	23.8	24.0	24.0	24.2	24.2
24.6	24.6	24.8	24.8	24.8	24.8
25.4	25.4	25.4	25.5	25.5	25.4
25.6	25.6	25.6	25.6	25.6	25.8

The shade temperature = 51.6^{o}c
The shade temperature = (exposed) = 55.^{o}c
Ambient air temperature = 35.4^{o}c
RH of = 21.8%
Room 1 normal temp = 31
ROOM2
ENVIRONMENTAL TEMPERATURE= 18.9 ^{O}CRELATIVE HUMIDITY =38.4%
INSIDE ROOM MID-TEMP = 21.1 ^{O}C RH=39.5
SHADE MID-TEMP = 15.4 ^{O}C TIME: 6: 26AM B DATE: 26/12/2016

ROOM 2
WALL 1

INSIDE						OUTSIDE					
GI	G2	G3	G4	G5	G6	GI	G2	G3	G4	G5	G6
22.8	22.6	22.6	22.8	22.6	22.6	14.6	14.8	15.0	14.8	14.8	14.8
22.8	23.0	23.2	22.8	23.2	23.2	14.6	14.8	15.0	14.2	14.6	14.6
23.4	23.4	23.4	23.4	23.4	23.4	14.4	14.4	14.2	14.4	14.4	14.4
23.4	23.4	23.4	23.4	23.4	23.4	14.2	14.4	14.8	14.6	14.6	14.6
23.8	23.8	23.8	24.0	23.4	23.6	14.4	14.4	14.4	14.4	14.6	14.6
23.8	23.8	23.8	23.8	23.8	23.8	13.6	14.4	14.4	14.4	14.4	14.2
23.8	24.8	24.2	23.8	23.8	23.8	13.8	14.2	14.2	14.2	14.4	14.4
24.0	24.4	24.6	24.4	24.4	24.4	15.8	15.8	15.8	15.8	16.2	16.2

WALL 2

INSIDE						OUTSIDE					
GI	G2	G3	G4	G5	G6	GI	G2	G3	G4	G5	G6
23.2	22.8	23.6	23.2	23.0	23.0	13.8	14.0	13.8	14.2	14.4	14.4
22.8	23.0	23.0	23.0	23.0	23.0	13.8	13.8	13.8	14.2	14.6	14.8
22.8	22.2	22.2	23.6	23.4	23.4	14.6	15.2	15.2	15.2	15.2	15.2
23.6	23.6	23.2	23.2	23.6	23.6	15.4	15.2	15.5	15.2	15.2	14.8
23.8	23.6	23.8	23.6	23.8	23.8	14.6	15.2	15.2	15.4	15.4	15.4
23.8	23.8	23.8	23.8	23.8	23.8	14.8	15.4	15.4	15.4	15.4	15.4
23.8	23.8	23.8	23.8	23.8	23.8	15.4	15.4	15.8	15.6	16.0	16.0
24.2	24.2	24.6	24.4	24.4	24.4	16.2	16.6	17.2	17.2	17.2	16.4

WALL 3

INSIDE						OUTSIDE					
GI	GI	G3	G4	G5	G6	GI	GI	G3	G4	G5	G6
23.4	23.4	23.4	23.4	23.4	23.4	15.4	15.6	15.8	15.8	15.8	15.8
23.4	23.4	23.4	23.4	23.4	23.4	15.2	15.2	15.4	15.4	15.6	15.6
24.4	23.4	23.4	23.4	23.4	23.4	15.0	15.4	15.6	15.8	15.8	15.8
23.6	23.6	23.6	23.6	23.6	23.6	15.2	15.4	15.6	15.2	15.2	15.2
23.4	23.4	23.2	23.2	22.8	22.8	15.2	15.4	15.6	15.4	15.4	15.4

WALL 3

INSIDE						OUTSIDE					
GI	GI	G3	G4	G5	G6	GI	GI	G3	G4	G5	G6
23.8	23.8	23.8	23.8	23.8	23.8	15.8	15.8	16.0	15.8	15.8	15.8
23.8	23.8	24.0	23.8	23,6	23.6	15.4	16.0	16.4	16.2	16.2	16.2
23.8	23.8	23.8	24.2	24.2	24.2	16.4	17.2	17.2	17.2	17.2	17.6

ROOF INSIDE

23.2	23.4	23.4	23.4	23.4	23.4
23.0	23.4	23.4	23.4	23.4	23.4
23.2	23.2	23.4	23.4	23.4	23.4
23.2	23.2	23.4	23.4	23.4	23.4
23.2	23.2	23.4	23.4	23.4	23.4
23.4	23.6	23.6	23.6	23.6	23.6
23.2	23.6	23.6	23.6	23.6	23.6
23.2	23.4	23.4	23.4	23.4	23.4

ROOF OUTSIDE

15.0	15.4	16.0	16.4	16.4	16.0
14.8	15.0	15.2	15.0	15.0	15..0
15.2	15.4	15.4	15.2	15.2	15.2

DOOR INSIDE

21.8	22.2	21.8	22.2
22.2	22.2	22.1	22.2
21.8	22.2	22.2	22.2
22.2	22.2	22.2	22.2

DOOR OUTSIDE 15.8-16.0

15.6	15.6	15.8	15.8
15.6	15.6	15.6	15.6
15.4	15.2	15.4	15.4
15.4	15.4	15.2	15.2

FLOOR

23.8	24.0	24.0	24.0	24.2	24.2
24.0	24.0	23.8	23.8	24.2	24.2
24.2	24.2	24.2	24.2	24.2	24.2
24.2	24.4	24.2	24.2	24.2	24.2
24.2	24.2	24.2	24.4	24.2	24.2
24.2	24.2	24.2	23.6	23.8	23.8
23.8	23.8	23.8	23.8	23.8	23.8
23.8	23.8	23.2	23.8	23.8	24.2

ROOM 2 TIME: 10:00 Am DATE: 25/12/2016 39 ^{O}C SHADE MID-TEMPS
WALL 2 EAST - WEST

INSIDE						OUTSIDE					
GI	GI	G3	G4	G5	G6	GI	GI	G3	G4	G5	G6
23.4	23.6	23.6	23.4	23.4	23.4	21.8	21.8	21.8	21.8	20.8	22.0
23.8	23.8	23.8	23.8	24.0	24.0	21.2	21.2	21.0	20.8	20.8	21.0
24.0	24.0	24.0	24.0	24.2	24.2	20.6	20.4	20.2	20.2	20.6	21.0
24.0	24.0	24.0	24.0	23.8	23.8	20.8	20.4	20.2	20.2	20.6	21.0
24.4	24.4	24.4	24.4	24.4	24.4	21.2	20.8	20.6	21.2	20.8	23.0
24.4	24.4	24.6	24.6	24.4	24.4	20.8	20.6	20.8	21.0	21.8	23.4
24.4	24.4	24.4	24.6	24.6	24.6	21.2	20.8	21.2	22.2	232	26.0
25.2	25.2	25.2	25.2	25.2	25.2	21.4	21.6	22.0	23.4	23.8	24.0

WALL 2 NORTH – SOUTH
GRID (20x20$_{CM}$)

INSIDE						OUTSIDE					
GI	GI	G3	G4	G5	G6	GI	GI	G3	G4	G5	G6
23.8	23.6	23.2	23.4	24.0	24.2	20.2	20.2	20.4	20.8	20.8	21.0
23.8	23.8	23.8	23.8	24.0	24.0	22.0	21.0	21.2	21.4	21.6	21.8
24.0	24.0	24.0	24.0	24.2	24.2	20.6	21.0	20.8	20.8	21.6	21.6
24.0	24.0	24.0	24.0	23.8	23.8	20.6	21.0	22.0	22.2	22.2	22.2
23.8	24.0	24.2	23.8	24.2	24.4	22.8	21.6	21.6	22.6	21.8	21.8
23.8	24.0	24.0	24.0	24.2	24.4	23.4	23.2	23.2	23.0	22.8	22.6
24.4	24.4	24.4	24.6	24.6	24.6	24.2	23.8	23.8	23.6	23.2	23.2
24.4	24.4	24.4	24.4	24.6	24.6	24.6	4.8	24.6	2.0	23.6	23.6S

ROOM 2 EAST WEST
WALL 3 (20x20)

INSIDE						OUTSIDE					
GI	GI	G3	G4	G5	G6	GI	GI	G3	G4	G5	G6
23.8	23.8	23.8	23.8	24.0	24.0	21.2	21.2	21.2	21.8	21.8	21.8
23.8	23.8	23.8	23.8	24.0	24.2	21.2	21.2	21.2	21.6	21.6	21.6
23.8	23.8	23.8	23.8	24.1	24.2	21.6	21.4	21.4	21.4	21.4	21.6
23.8	23.8	23.8	24.2	24.0	23.8	21.2	21.2	21.4	21.4	21.2	21.4
23.8	23.8	24.0	24.0	24.0	23.8	21.2	20.8	20.8	20.8	20.8	20.8
24.0	24..6	24..6	24..6	24..6	24..6	21.6	21.2	21.2	21.2	21.2	21.2
24.2	24..6	24..6	24..6	24..6	24..6	22.0	21.4	21.4	21.4	21.6	21.8
24..4	24..4	24..6	24..6	24..6	24.6	21.8	22.0	22.0	22.2	22.2	22.2

FLOOR TEMP ROOM 2

24.6	24.6	24.6	24.0	24.6	24.8
24.6	24.4	24.4	24.6	24.6	24.6
24.6	24.6	24.6	24.6	24.6	24.0
24.6	24.6	24.6	24.6	24.6	24.6
24.6	24.6	24.6	24.6	24.8	24.0
24.4	24.4	24.6	24.4	24.6	24.6
24.8	24.8	24.8	24.8	24.8	24.8
24.4	24.4	24.8	24.8	24.8	24.8

ROOM 2 AVERAGE SHADE 39 ^{O}C
OUTSIDE ROOF

23.8	23.8	23.4	23.4	23.8	23.8
25.2	25.2	24.2	24.2	24.2	24.2
25.2	24.8	24.8	24.8	24.2	24.7
25.0	24.8	24.8	24.5	24.2	24.2
24.8	24.8	24.8	24.8	24.6	24.6
24.8	24.8	24.8	24.8	23.8	23.8
24.6	24.6	24.6	24.8	24.8	24.8
24.2	24.8	24.8	24.6	24.6	24.6

ROOM 2 INSIDE

23.4	23.4	23.6	23.6
23.4	23.4	23.4	23.4
23.4	23.4	23.4	23.4
23.4			

ROOF ROOM NORTH – SOUTH INSIDE

23.6	23.6	23.6	23.6	23.6	23.6
23.6	23.6	23.6	23.6	23.6	23.6
23.6	23.6	24.0	24.0	24.0	24.0
23.6	23.6	24.0	24.0	23.6	23.6
23.8	23.8	24.0	24.0	23.8	23.8
24.0	24.0	24.0	24.0	24.0	24.0
23.0	24.0	24.0	23.8	23.8	23.8
23.8	23.8	24.0	23.8	23.8	23.8

ENVIRONMENTAL TEMP 25 ^{O}C
DOOR OUTSIDE ROOM 2

24.6	24.6	24.6	24.6
25.2	25.2	25.2	25.2
25.0	25.0	25.0	25.0
25,4	25.4	25.2	25.2
25.6	25.6	25.6	25.8
25.4	25.4	25.4	25.4
25.2	25.4	25.4	25.8
24.2	24.6	24.0	24.6

ROOM 2 RH PROFILES
ENVIRONMENTAL 21.1 ^{O}C RH 37.3%

T	21.7	21.7	21.9	22.0	22.1	22.2
RH	39.8	39.5	39.8	38.8	38.5	38.8
T	22.6	22.5	22.4	22.4		22.4
RH	28.8	39.1	38.8	38.8	38.8	38.2
T	38.8					
RH	22.6	22.6	22.7	22.7	22.7	22.7
T	39.8	39.4	39.6	39.4	38.8	38.5
RH	22.8	22.8	22.9	22.9	22.9	22.9
T	39.8	38.2	39.1	39.4	39.1	38.8
RH	22.9			23.0	22.6	22.6
T	39.4	39.1	34.8	41.3	38.8	38.5

MIDDLE

T	22.6	22.0	22.6	22.6	22.6	22.6
RH	39.1	39.4	38.8	38.1	38.8	38.8
T	22.7	22.7	22.7	22.7	22.7	22.7
RH	40.1	40.4	40.9	40.1	40.4	40.4
T	22.5	22.5	22.5	22.6	22.6	22.6
RH	41.2	42.2	41.9	41.2	41.2	41.2
T	22.6	27.6	22.7	22.7	22.7	22.7
RH	40.9	41.2	41.2	41.7	41.2	41.2
T	22.6	22.6	22.7	22.7	22.7	22.7
RH	41.5	42.2	41.2	41.2	41.2	41.2
T						

ROOF

T	22.8	22.6	22.9	22.9	22.9	22.9
RH	45.9	45.3	45.4	45.5	45.5	45.5
T	22.9	22.9	22.9	22.9	22.9	22.9
RH	44.5	44.0	44.0	44.0	44.0	44.0
T	23.0	23.0	23.0	23.0	23.0	23.0
RH	43.5	43.8	43.3	44.5	43.6	43.0
T	23.0	23.0	23.0	23.0	23.0	23.0
RH	45.8	44.2	43.8	43.8	43.8	43.8
T	23.1	23.1	23.1	23.1	23.1	23.1
RH	45.8	48.2	47.2	45.5	45.5	45.5

HIGH SPEED ROOM 1 TIME: DATE 10/12/2017
CELLING 3 GRID 20_{CM} x 20_{CM}

WITHOUT DIFUSER(m/s)	WITH DIFUSER(m/s)
0.5	0.5
0.5	0.5
0.4	0.4
0.4	0.4
0.3	0.3
0.3	0.3
0.2	0.2
0.2	0.2
0.1	0.1
0.1S	0.1

AC. AIR THROW SPEED DIFUSER OSCILLATION TIME 4 SECOND
MIDDIUM SPEED

S/no	WITHOUT DIFUSER(m/s)	WITH DIFUSER(m/s)
1.	0.4	0.4 - 0.3
2.	0.3	0.3 – 0.2
3.	0.3	0.3 – 0.2
4.	0.3	0.3 – 0.2
5.	0.3	0.3 – 0.2
6.	0.2	0.3 – 0.2
7.	0.1	0.1
8.	0.1	0.1
9.	0.1	0.1
10.	0.1	0.1
11.	0.1	0.1

AIR FLOW METER
MAKE= AEROVANE PRECISM 0.1_{MLS}
MODEL= EL-3
MEASURING RANGE= 0-30 $_{MLS]}$

Room 2 02/3/2017 CEILING
Time: 11:00am-1:00pm BY AIR CONDITION
RH-26%
TEMP-29.8^{O}C

T/RH	G1	G2	G3	G4	G5	G6
T	29.2	29.2	26.8	26.7	27.6	28.3
RH	28.8	28.7	30.1	30.1	30.2	30.5

T	25.3	25.6	25.8	19.5	20.5	21.6
RH	33.1	33.4	34.0	38.8	38.2	38.6
T	21.3	22.4	22.00	20.9	21.7	22.5
RH	38.8	39.4	39.1	39.8	40.2	39.4
T	22.8	23.2	23.2	23.4	23.8	24.0
RH	38.9	38.9	38.6	38.6	38.3	38.0
T	24.3	24.6	26.4	24.7	24.8	25.0
RH	37.4	37.1	37.1	37.1	37.1	36.6
T	25.2	25.3	25.4	25.5	25.6	25.5
RH	36.6	36.6	36.00	36.00	36.3	36.0

MIDDLE BY AIR CONDITION

T/RH	G1	G2	G3	G4	G5	G6
T	29.2	29.2	26.8	26.7	27.6	28.3
RH	28.8	28.7	30.1	30.1	30.2	30.5
T	25.3	25.6	25.8	19.5	20.5	21.6
RH	33.1	33.4	34.0	38.8	38.2	38.6
T	21.3	22.4	22.00	20.9	21.7	22.5
RH	38.8	39.4	39.1	39.8	40.2	39.4
T	22.8	23.2	23.2	23.4	23.8	24.0
RH	38.9	38.9	38.6	38.6	38.3	38.0
T	24.3	24.6	26.4	24.7	24.8	25.0
RH	37.4	37.1	37.1	37.1	37.1	36.6
T	25.2	25.3	25.4	25.5	25.6	25.5
RH	36.6	36.6	36.00	36.00	36.3	36.0

FLOOR
RH/TEMP BY AIR CONDITION

T/RH	G1	G2	G3	G4	G5	G6
T	23.3	23.7	23.4	23.4	23.2	23.3
RH	33.7	38.00	38.0	38.0	38.0	38
T	23.3	23.2	23.3	23.00	22.9	22.9
RH	38.3	38.6	38.6	38.5	38.5	38.6
T	22.5	22.8	22.7	22.7	22.8	22.7
RH	39.1	39.1	39.4	39.4	39.4	39.4
T	22.9	23.00	23.2	23.3	23.4	23.5
RH	39.4	39.6	39.6	39.9	39.6	39.6
T	23.7	23.7	23.9	22.4	28.2	24.2
RH	39.2	38.9	38.6	38.6	38.6	38.6
T	24.2	24.2	24.2	24.5	24.7	24.6
RH	38.3	38.3	38.3	38.00	38.00	37.7

ROOM 2

SOUTH WITH AIR CONDITION ON WALL TEMP. WALL1

INSIDE						OUTSIDE					
G1	G2	G3	G4	G5	G6	G1	G2	G3	G4	G5	G6
22.0	21.2	20.4	20.8	21.4	20.6	37.6	37.4	36.4	37.0	36.8	36.8
22.6	22.4	22.2	22.2	21.6	21.6	36.6	36.2	35.6	35.8	35.8	36.00
22.6	22.8	23.2	23.0	22.8	22.2	36.2	35.4	35.2	35.0	35.2	35.2

24.0	23.8	24.2	24.2	24.2	23.6	35.4	34.4	34.2	34.4	34.6	35.0
25.4	24.2	24.4	24.6	24.6	24.0	34.4	33.8	34.00	38.8	34.2	34.4
25.2	24.8	24.6	25.0	25.0	24.4	33.8	33.0	33.0	33.0	33.2	33.8

EAST WITH AIR CONDITION ON WALL TEMP. WALL 2

INSIDE						OUTSIDE					
G1	G2	G3	G4	G5	G6	G1	G2	G3	G4	G5	G6
26.4	25.8	25.6	25.2	25.2	24.4	36.6	36.8	37.2	36.6	35.8	35.8
25.0	24.0	23.2	24.2	24.2	24.8	36.4	35.8	36.4	35.8	35.6	35.8
24.8	24.6	24.4	24.4	24.4	25.2	36.00	35.6	35.6	35.6	35.2	35.2
24.2	24.2	24.4	24.4	24.4	24.6	36.00	35.6	35.6	35.6	35.2	35.2
24.4	24.2	24.0	24.2	24.2	24.6	35.6	35.4	35.2	35.7	35.2	34.6
25.0	24.6	24.6	24.6	24.6	24.8	34.8	34.2	34.4	34.4	34.6	34.00

NORTH WITH AIR CONDITION ON WALL TEMP. WALL 3

INSIDE						OUTSIDE					
G1	G2	G3	G4	G5	G6	G1	G2	G3	G4	G5	G6
24.8	24.6	24.6	25.2	25.4	26.0	34.8	34.8	35.2	35.2	35.8	35.8
24.4	24.6	24.8	25.2	25.4	25.4	35.2	34.2	34.6	34.8	35.8	35.00
24.0	24.2	24.4	25.2	25.4	25.6	34.8	34.4	34.4	34.6	34.4	34.4
23.8	24.0	24.4	24.4	24.6	24.4	34.8	33.8	33.8	33.8	33.8	34.2
23.8	24.0	24.4	24.4	24.6	24.6	34.2	33.6	33.6	33.4	33.4	33.8
29.4	23.8	24.0	24.4	24.8	25.2	34.00	32.6	32.4	33.00	32.6	32.8

DOOR OUTSIDE

INSIDE						OUTSIDE					
G1	G2	G3	G4	G5	G6	G1	G2	G3	G4	G5	G6
30.0	29.6	29.2	29.6	28.4	28.4	38.6	38.8	39.2	39.4	38.8	38.2
28.6	27.8	27.6	27.2	27.2	26.6	38.8	38.8	38.8	39.2	39.4	38.2
26.6	26.8	27.2	26.6	24.4	24.4	37.8	38.4	38.2	38.4	38.6	37.8
26.4	25.4	25.0	25.2	25.4	23.8	37.6	37.8	38.2	38.4	37.8	37.4
25.2	25.6	25.6	26.0	25.8	24.0	36.2	37.4	37.4	37.6	37.8	37.0
25.4	24.8	25.2	25.6	25.4	25.2	35.2	35.4	35.6	34.6	35.6	34.2

CURTAIN ROOM2

1	2	3	4	5	6
23.6	24.0	24.6	24.2	24.2	24.0
24.2	24.6	24.6	24.4	24.4	24.4
24.4	24.6	24.8	24.8	24.8	24.6
25.0	25.2	25.2	25.2	25.2	25.2
25.2	25.4	25.4	25.6	25.8	25.8
25.6	25.6	25.8	25.6	25.6	25.4

ROOF ROOM2

1	2	3	4	5	6
26.3	27.0	25.2	25.6	25.2	25.6
26.6	25.8	25.8	25.8	25.2	25.4
26.5	25.4	25.8	25.6	25.4	25.2
25.4	25.4	25.6	26.6	25.6	25.4
24.6	24.2	24.4	24.2	24.4	23.4
24.2	25.6	25.6	25.4	25.2	25.4

FLOOR

1	2	3	4	5	6
25.4	25.00	24.8	25.00	24.88	25.60
25.4	24.8	25.00	25.00	24.80	25.00
25.4	25.00	25.2	25.00	25.00	25.00
25.20	25.20	25.20	25.20	25.00	25.20
25.2	25.00	25.00	24.80	24.08	24.80
24.8	24.4	24.6	24.7	24.2	24.6

Appendix 5 : MICROBIAL QUALITY TEST RESULT

1.0 Tomato

Storage Time (day)	Tomato Sample	Total Bacterial Count Cfu/gm	Total Fungal Count Cfu/gm
0	TD	2.1 X 10^4	7.3 X 10^4
	TF	9.0 X 10^4	1.80 X 10^4
21	TDC	3.2 X 10^4	3.0 X 10^3
	TFC	1.44 X 10^5	1.32 X 10^5
	TD20	2.2 X 10^4	2.8 X 10^4
	TD25	1.85 X 10^5	8.0 X 10^3
	TF20	2.32 X 10^5	1.28 x 10^5
	TF25	3.0 x 10^4	1.75 x 10^5
42	TDC	1.5 x 10^4	1.3 x 10^4
	TFC	1.3 x 10^4	1.7 x 10^4
	TD20	4.1 x 10^4	7.1 x 10^4
	TD25	4.2 x 10^4	4.3 x 10^4
	TF20	3.4 x 10^4	3.0 x 10^4
	TF25	2.8 x 10^4	2.8 x 10^4
63	TDC	5.6 x 10^4	1.5 x 10^4
	TFC	4.44 x 10^5	5.0 x 10^3
	TD20	1.55 x 10^4	6.9 x 10^4
	TD25	1.8 x 10^4	4.1 x 10^4
	TF20	2.4 x 10^4	1.41 x 10^5
	TF25	2.8 x 10^4	7.9 x 10^4

2.0 Okra

Storage Time (day)	Okra Sample	Total Bacterial Count Cfu/gm	Total Fungal Count Cfu/gm
0	KBD	2.30 X 10^5	5.5 X 10^4
	KBF	4.23 X 10^5	1.80 X 10^5
21	KBDC	1.0 X 10^3	3.0 X 10^3
	KBFC	2.0 X 10^3	3.0 X 10^3
	KBD20	5.0 X 10^4	7.1 X 10^4
	KBD25	2.0 X 10^3	6.5 X 10^3

	KBF20	$2.1 \text{ X } 10^4$	$8.0 \text{ x } 10^4$
	KBF25	$3.2 \text{ x } 10^3$	$7.2 \text{ x } 10^3$
42	KBDC	$3.3 \text{ x } 10^4$	$2.1 \text{ x } 10^4$
	KBTFC	$3.5 \text{ x } 10^4$	$4.6 \text{ x } 10^4$
	KBD20	$6.3 \text{ x } 10^4$	$4.1 \text{ x } 10^4$
	KBD25	$5.5 \text{ x } 10^4$	$2.7 \text{ x } 10^4$
	KBF20	$6.6 \text{ x } 10^4$	$6.0 \text{ x } 10^4$
	KBF25	$8.6 \text{ x } 10^4$	$2.8 \text{ x } 10^4$
63	KBDC	$1.6 \text{ x } 10^4$	$2.7 \text{ x } 10^4$
	KBFC	$2.8 \text{ x } 10^4$	$2.1 \text{ x } 10^4$
	KBD20	$2.5 \text{ x } 10^4$	$4.0 \text{ x } 10^4$
	KBD25	$1.12 \text{ x } 10^3$	$8.6 \text{ x } 10^4$
	KBF20	$4.4 \text{ x } 10^3$	$6.2 \text{ x } 10^4$
	KBF25	$1.10 \text{ x } 10^5$	$7.4 \text{ x } 10^4$

3.0 Baobab Leaves

Storage Time (day)	Boabab Leaves Sample	Total Bacterial Count Cfu/gm	Total Fungal Count Cfu/gm
0	KKD	$2.30 \text{ X } 10^6$	$1.1 \text{ X } 10^5$
	KKF	$1.1 \text{ X } 10^4$	$1.90 \text{ X } 10^4$
21	KKDC	$2.0\text{X } 10^3$	$3.0 \text{ X } 10^3$
	KKFC	$1.0 \text{ X } 10^3$	$5.0 \text{ X } 10^3$
	KKD20	$6.4 \text{ X } 10^4$	$7.0 \text{ X } 10^4$
	KKD25	$4.0 \text{ X } 10^3$	$3.0 \text{ X } 10^3$
	KKF20	$1.8 \text{ X } 10^4$	$7.7 \text{ x } 10^4$
	KKF25	$2.0 \text{ x } 10^3$	$8.0 \text{ x } 10^3$
42	KKDC	$1.0 \text{ x } 10^3$	$3.0 \text{ x } 10^3$
	KKFC	$3.0 \text{ x } 10^3$	$4.0 \text{ x } 10^3$
	KKD20	$2.3 \text{ x } 10^4$	$5.5 \text{ x } 10^4$
	KKD25	$7.0 \text{ x } 10^3$	$6.0 \text{ x } 10^3$
	KKF20	$9.0 \text{ x } 10^3$	$1.7 \text{ x } 10^4$
	KKF25	$2.1 \text{ x } 10^4$	$9.0 \text{ x } 10^4$
63	KKDC	$5.9 \text{ x } 10^4$	$3.9 \text{ x } 10^4$
	KKFC	$1.0 \text{ x } 10^3$	$4.0 \text{ x } 10^3$
	KKD20	$8.0 \text{ x } 10^3$	$2.0 \text{ x } 10^3$
	KKD25	$3.6 \text{ x } 10^4$	$3.0 \text{ x } 10^3$
	KKF20	$5.0 \text{ x } 10^3$	$1.1 \text{ x } 10^4$
	KKF25	$8.0 \text{ x } 10^3$	$8.0 \text{ x } 10^3$

Appendix 7: MOISTURE CONTENT AND %SOLID CONTENT RESULT

1.0 Tomato

Storage Time (day)	Tomato Sample	Moisture Content %				Solid Content %			
		R1	R2	R3	Avg	R1	R2	R3	Avg
0	TD	6	6.8	6.4	6.4	94	93.2	93.6	93.6

	TF	6.8	4.4	7.2	6.1	93.2	95.6	92.8	93.9
21	TDC	8	9	7	8	92	91	93	92
	TFC	7	8	7	7.3	93	92	93	92.7
	TD20	8	8	7	7.7	92	92	93	92.3
	TD25	7	7	6	6.7	93	93	94	93.3
	TF20	9	8	8	8.3	91	92	92	91.7
	TF25	6	9	8	7.7	94	91	92	92.3
42	TDC	9	10	8	9	91	90	92	91
	TFC	8	8	8	8	92	92	92	92
	TD20	8	7	7	7.3	92	93	93	92.7
	TD25	7	7	7	7	93	93	93	93
	TF20	8	9	9	8.7	92	91	91	91.3
	TF25	7	8	8	7.7	93	92	92	92.3
63	TDC	10	12	9	10.3	90	88	91	89.7
	TFC	12	12	13	12.3	88	88	87	87.7
	TD20	8	7	8	7.7	92	93	92	92.3
	TD25	7	6	5	6	93	94	95	94
	TF20	10	9	10	9.7	90	91	90	90.3
	TF25	8	8	8	8	92	92	92	92
84	TDC	16	16	17	16.3	84	84	83	83.7
	TFC	12	13	12	12.3	88	87	88	87.7
	TD20	8	8	9	8.3	92	92	91	91.7
	TD25	9	12	10	10.3	91	88	90	89.7

	TF20	8	9	7	8	92	91	93	92
	TF25	7	7	8	7.3	93	93	92	92.7
105	TDC	19	20	20	19.7	81	80	80	80.3
	TFC	18	19	19	18.7	82	81	81	81.3
	TD20	19	8	18	15	81	92	82	85
	TD25	12	13	9	11.3	88	87	91	88.7
	TF20	9	11	11	10.3	91	89	89	89.7
	TF25	8	9	9	8.7	92	91	91	91.3

2.0 Okra

Storage Time (day)	Okra Sample	Moisture Content %				Solid Content %			
		R1	R2	R3	Avg	R1	R2	R3	Avg
0	KBD	8.8	8.5	11.6	9.6	91.2	91.5	88.4	90.4
	KBF	8	6.4	7.2	7.2	92	93.6	92.8	92.8
21	KBDC	12	12	9	11	88	88	91	89
	KBFC	9	9	8	8.7	91	91	92	91.3
	KBD20	13	13	13	13	87	87	87	87
	KBD25	11	11	11	11	89	89	89	89
	KBF20	7	8	7	7.3	93	92	93	93
	KBF25	7	8	8	7.7	93	92	92	92.3
42	KBDC	9	7	6	7.3	91	93	94	92.7
	KBFC	8	8	6	7.3	92	92	94	92.7
	KBD20	8	7	7	7.3	92	93	93	92.7
	KBD25	8	6	9	7.7	92	94	91	92.3
	KBF20	7	6	6	6.3	93	94	94	93.7
	KBF25	7	6	6	6.3	93	94	94	93.7
63	KBDC	13	13	13	13	87	87	87	87
	KBFC	14	11	12	12.3	86	89	88	87.7
	KBD20	11	12	12	11.	89	88	88	88.3

7

Storage Time (days)	Baobab Leaves Samples	Moisture Content(%)wb				Solid Content (%)			
	KBD25	10	10	11	10.3	90	90	89	89.7
	KBF20	8	8	7	7.7	92	92	93	92.3
	KBF25	9	9	8	8.7	91	91	92	91.3
84	KBDC	17	15	17	16.3	83	85	83	83.7
	KBFC	14	13	14	13.7	86	87	86	86.3
	KBD20	13	12	13	12.2	87	88	87	87.3
	KBD25	10	20	11	10.3	90	80	89	86.3
	KBF20	9	8	8	8.3	91	92	92	91.7
	KBF25	8	8	8	8	92	92	92	92
105	KBDC	20	21	21	20.7	80	79	79	79.3
	KBFC	18	18	18	18	82	82	82	82
	KBD20	13	12	11	12	87	88	89	88
	KBD25	9	9	10	9.3	91	91	90	90.7
	KBF20	12	11	10	11	88	89	90	89
	KBF25	8	8	8	8	92	92	92	92

3.0 Baobab leaves (March – August 2017)

		R1	R2	R3	avg	R1	R2	R3	avg
0	KKD	6.8	6.9	6.7	6.8	93.2	93.1	93.3	93.2
	KKF	7.3	6.8	8	7.3	92.7	93.2	92	92.6
21	KKDC	8.5	7.8	9.5	8.6	91.5	92.2	90.5	91.4
	KKFC	9.5	13.4	10	11	90.5	86.6	90	89
	KKD20	8.5	9.3	8.5	8.8	91.5	90.7	91.5	91.2
	KKD25	8.5	8.4	8.3	8.4	91.5	91.6	91.7	91.6
	KKF20	7.7	8.4	8.5	8.2	92.3	91.6	91.5	91.8
	KKF25	8.4	7.4	7.2	7.7	91.6	92.6	92.8	92.3
42	KKDC	11	8	11	10	89	92	89	90
	KKDF	11	9	10	10	89	91	90	90
	KKD20	9	12	8	9.7	91	88	92	90.3
	KKD25	7	7	8	7.3	93	93	92	92.7
	KKF20	8	7	6	7.0	92	93	94	93
	KKF25	7	7	7	7	93	93	93	93
63	KKDC	11	11	11	11	89	89	89	89
	KKFC	11	11	10	10.7	89	89	90	89.3
	KKD20	10	9	5	8	90	91	95	92
	KKD25	9	9	9	9	91	91	91	91
	KKF20	8	8	7	7.7	92	92	93	92.3
	KKF25	11	8	8	9	89	92	92	91

84	KKDC	14	12	13	13	86	88	87	87
	KKFC	14	12	13	13	86	88	87	87
	KKD20	9	9	17	11.7	91	91	83	88.3
	KKD25	9	29	11	13.3	91	71	89	83.7
	KKF20	9	9	9	9	91	91	91	91
	KKF25	9	9	7	8.3	91	91	93	91.7
105	KKDC	12	14	13	13	88	86	87	85.7
	KKFC	14	17	14	15	86	83	86	85
	KKD20	17	13	11	13.7	83	87	89	86.3
	KKD25	10	10	10	10	90	90	90	90
	KKF20	11	10	11	10.7	89	90	89	89.3
	KKF25	11	9	12	10.7	89	91	88	89.3

Appendix 8: REHYDRATION TEST RESULT

Rehydration Ratio Okra

Day	KBFC			KBDC			KBD20			KBD25			KBF20			KBF25		
Time(min)	40	80	120	40	80	120	40	80	120	40	80	120	40	80	120	40	80	120
0	5.8	6.6	7.0	6.9	7.2	7.5	6.9	7.2	7.5	6.9	7.2	7.5	5.8	6.6	7.0	5.8	6.6	7.0
21	7.2	6.6	6.5	6.5	6.6	6.5	7.1	7.6	7.0	6.5	6.4	7.0	7.3	6.4	7.0	6.6	7.6	7.2
42	5.6	5.9	6.0	6.3	6.6	6.0	6.1	6.2	7.3	5.8	6.5	7.3	5.6	6.4	7.6	7.2	6.4	4.2
63	5.7	6.4	6.5	5.8	7.0	6.6	6.2	6.7	7.2	6.2	6.5	6.9	6.1	6.4	6.7	5.9	6.4	5.9
84	5.5	5.7	5.6	5.9	6.3	7.1	5.8	6.9	6.7	6.1	6.9	6.8	6.4	7.2	7.2	6.1	6.1	6.2
105	5.1	5.6	5.9	5.6	6.2	5.9	6.6	6.7	7.4	6.0	6.5	6.7	6.5	7.6	6.2	6.3	6.4	6.5

Rehydration Ratio Baobab

Day	KKFC			KKDC			KKD20			KKD25			KKF20			KKF25		
Time (min)	40	80	120	40	80	120	40	80	120	40	80	120	40	80	120	40	80	120
0	4.7	5.7	7.8	5.0	5.5	7.3	5.0	5.5	7.3	5.0	5.5	7.3	4.7	5.7	7.8	4.7	5.7	7.8
21	5.4	4.9	5.6	3.8	4.0	3.9	4.2	3.9	4.3	5.0	4.1	4.1	5.1	5.8	5.8	6.0	5.1	5.1
42	5.2	5.3	5.5	3.5	3.8	4.3	4.0	3.8	4.1	3.7	4.5	4.4	5.3	5.2	5.2	5.3	5.7	5.9
63	5.1	5.1	5.2	3.6	3.7	3.8	3.9	4.4	3.9	3.8	3.8	4.0	5.2	5.5	5.7	5.5	5.0	6.0
84	4.9	4.9	4.8	3.5	3.5	3.5	3.6	3.9	4.1	3.9	4.4	4.2	5.4	5.6	5.6	4.8	5.0	5.2
105	4.6	4.9	4.7	3.3	3.5	3.5	3.8	4.1	6.3	3.8	4.0	4.2	5.2	5.2	4.0	4.8	5.2	5.4

Storage Time (day)	Tomato Sample	Rehydration Ratio		
Min		40	80	120
0	TD	4.1	4.4	3.7
	TF	2.9	3.6	4.1
21	TDC	3.6	4.0	4.2
	TFC	3.0	3.4	3.7
	TD20	3.5	4.1	4.4
	TD25	4.0	3.8	4.7
	TF20	3.3	3.5	3.6
	TF25	3.4	4.0	4.8
42	TDC	3.3	3.5	3.4
	TFC	3.1	3.1	3.5
	TD20	3.6	3.7	3.8
	TD25	3.6	3.8	3.8
	TF20	2.7	2.4	2.8
	TF25	3.1	2.5	3.5
63	TDC	3.0	3.0	3.5
	TFC	2.7	3.0	3.1
	TD20	3.3	3.7	4.0
	TD25	3.4	3.3	3.5
	TF20	3.0	3.3	3.3
	TF25	3.0	3.2	3.1
84	TDC	2.1	2.4	2.7
	TFC	1.8	1.9	2.0
	TD20	2.8	2.5	3.3

	TD25	2.3	2.4	2.7
	TF20	2.1	3.0	3.0
	TF25	1.8	2.0	2.3
105	TDC	3.2	3.3	3.5
	TFC	2.8	2.6	3.2
	TD20	3.4	3.9	3.9
	TD25	3.5	3.8	4.0
	TF20	2.7	2.9	3.4
	TF25	2.9	3.3	3.1

Appendix 9: WATER ACTIVITY (a_w) RESULT

Baobab (KK)

Time Day	KK_{Fc}	KK_{Dc}	KK_{D20}	KK_{D25}	KK_{F20}	KK_{F25}
0						
21	0.70	0.68	0.48	0.43	0.39	0.41
42	0.80	0.79	0.55	0.50	0.49	0.50
63	0.90	0.90	0.60	0.63	0.59	0.60
84	0.90	0.90	0.66	0.68	0.67	0.65
105	0.89	0.90	0.68	0.69	0.64	0.69

Okra (KB)

Time Day	KB_{Fc}	KB_{Dc}	KB_{D20}	KB_{D25}	KB_{F20}	KB_{F25}
0						
21			0.46	0.50	0.44	0.45
42	0.74	0.72	0.51	0.50	0.45	0.44
63	0.79	0.79	0.55	0.55	0.50	0.49
84	0.86	0.86	0.57	0.57	0.58	0.53

105	0.93	0.93	0.64	0.65	0.52	0.56

TOMATO (T)

Time Day	T_{Fc}	T_{Dc}	T_{D20}	T_{D25}	T_{F20}	T_{F25}
0						
21						
42	0.81	0.81	0.47	0.50	0.50	0.50
63	0.88	0.87	0.48	0.50	0.50	0.53
84	0.91	0.91	0.55	0.57	0.55	0.55
105	0.87	0.89	0.62	0.62	0.61	0.61

Appendix 10: RH% Between Inside Room and Environment(March – August)

Time (day)	Inside Room RH%		Environmental RH%
	Room1	Room2	
0	65	60	58
21	67	67.4	70
42	76.5	74	74
63	87.2	87.5	79
84	88.9	88.3	91.1
105	86.4	92	93

Appendix 11: Power Supply Chain (March – September 2017)

S/No	Month	Mean Daily Supply(Hrs)
01	March	18.0
02	April	23.10
03	May	21.21
04	June	16.0
05	July	20.03
06	August	18.60
07	September	21.87

Appendix 12: Colour measurement values and colour change for the three crops

TD20(virtual)			TD20(real)		
A	B	L	a	B	L
			11.84	-14.1	47
			11.5	-1.1	50.7
130.43	126.11	126.11	2.7576	-1.308	49.455
118.6	115.96	115.88	-8.376	-10.86	45.443
129.11	120.48	122.83	1.5153	-6.607	48.169
123.11	111.47	113.59	-4.132	-15.09	44.545

TD25(virtual)			TD25(real)		
a	B	L	A	b	L
			11.84	-14.1	47
			16.2	-1.1	53
133.04	126.52	128.2	5.2141	-0.922	50.275
125.39	122.67	121.89	-1.986	-4.546	47.8
129.26	112.8	116.47	1.6565	-13.84	45.675
125.66	106.89	112.04	-1.732	-19.4	43.937

Tf20(virtual)			Tf20(real)		
a	b	L	a	B	L
			15.1	4.3	53.9
			14.6	6.2	53.6
141.65	138.58	138.94	13.318	10.428	54.486
113.47	113.42	111.78	-13.2	-13.25	43.835
129.69	114.92	119.89	2.0612	-11.84	47.016
123.02	105.24	111.66	-4.216	-20.95	43.788

Tf25(virtual)			Tf25(real)		
A	b	L	a	b	L
			15.1	4.3	52.9
			15.7	8	54.3
141.86	139.36	139.52	13.515	11.162	54.714
113.57	115.34	113.12	-13.11	-11.44	44.361
123.74	119.16	119.74	-3.539	-7.849	46.957
127.79	103.37	112.51	0.2729	-22.71	44.122

TDC(virtual)			TDC(real)		
a	B	L	a	b	L
			11.8	-14.1	47
			15	-1.9	51.4
134.74	129.48	130.76	6.8141	1.8635	51.278
124.66	126.49	124.63	-2.673	-0.951	48.875
121.78	115.28	116.17	-5.384	-11.5	45.557
119.64	109.8	113.26	-7.398	-16.66	44.416

TfC(virtual)			TfC(real)		
a	b	L	a	B	L
			15.1	4.3	52.9
			15.5	6.4	53.6
136.5	133.12	133.86	8.4706	5.2894	52.494
117.33	116.38	115.66	-9.572	-10.47	45.357
120.55	110.43	113.55	-6.541	-16.07	44.529
121	107.39	112.82	-6.118	-18.93	44.243

Colour change

Days	TD20	TD25	Tf20	Tf25	TDC	TfC
0						
21	13.521	14.967	1.9875	4.0012	13.358	2.2494
42	15.879	15.109	6.409	7.2727	17.263	6.7151
63	20.533	16.825	34.793	33.416	19.644	29.726
84	12.811	10.273	21.861	23.029	17.439	30.874
105	16.189	14.888	33.361	32.039	19.539	32.629

Colour change for kubewa

Kubewa Colour test

Days	KBD20(virtual)			KBD20(real)		
	A	B	L	a	b	L
0				-5.2	-6.1	48
21				-0.3	-1	50
42	144.74	144.45	144.76	16.226	15.953	56.769
63	118.09	115.23	117.84	-8.856	-11.55	46.212
84	120.67	120.68	119.94	-6.428	-6.419	47.035
105	129.84	124.85	129.37	2.2024	-2.494	50.733

KBD25(virtual)			KBD25(real)		
a	b	L	A	b	L
			-5.2	-6.1	48
			4.9	3.8	52
149.76	148.85	149.36	20.951	20.094	58.573
116.95	114.03	116.04	-9.929	-12.68	45.506
123.72	122.79	123.36	-3.558	-4.433	48.376
125.19	118.26	125.28	-2.174	-8.696	49.129

KBf20(virtual)			KBf20(real)		
A	B	L	a	b	L
			12	11.6	55.1
			0.66	-1.4	50.1
148.68	148.06	149.03	19.934	19.351	58.443
108.82	104.94	109.25	-17.58	-21.23	42.843
117.49	115.53	117.19	-9.421	-11.27	45.957
120.99	120.89	127.7	-6.127	-6.221	50.078

KBf25(virtual)			KBf25(real)		
A	B	L	a	b	L
			12	11.6	55.1
			3.4	1.4	51.8
148.44	148.1	148.59	19.708	19.388	58.271
114.27	109.81	114.34	-12.45	-16.65	44.839
119.45	116.47	119.55	-7.576	-10.38	46.882
124.73	117.28	126.13	-2.607	-9.619	49.463

KBDC(virtual)			KBDC(real)		
a	B	L	a	b	L
			-5.2	-6.1	48
			8.91	8.3	53.9
148.16	147.66	148.53	19.445	18.974	58.247
111.41	107.87	111.7	-15.14	-18.48	43.804
116.17	112.21	116.75	-10.66	-14.39	45.784
129.19	122.61	129.84	1.5906	-4.602	50.918

KBfC(virtual)			KBfC(real)		
A	b	L	a	b	L
			12	11.6	55.1
			2.2	-0.25	51.6
149.09	147.78	149.62	20.32	19.087	58.675
108.27	103.43	109.27	-18.1	-22.65	42.851
117.93	113.51	118.66	-9.007	-13.17	46.533
121.18	111.72	122.62	-5.948	-14.85	48.086

Colour change

Days	KBD20	KBD25	KBF20	KBF25	KBDC	KBFC
0						
21	7.3498	14.698	11.584	13.744	21.006	15.771
42	31.973	38.494	45.862	11.407	36.621	11.75
63	6.8008	8.4766	32.639	38.745	16.42	47.216
84	1.594	2.3703	25.911	30.56	10.173	33.587
105	8.6757	4.1441	57.572	26.37	7.5411	32.727

Colour change for Kuka

Kukar Colour test

Days	KKD20(virtual)			KKD20(real)		
	A	B	L	a	b	L
0				-4.3	-8	48.4
21				-3.4	-4.6	48
42	130.38	122.62	128.35	2.7106	-4.593	50.333
63	127.77	114	127.11	0.2541	-12.71	49.847
84	121.91	112.95	121.61	-5.261	-13.69	47.69
105	119.1	110.49	118.39	-7.906	-16.01	46.427

KKD25(virtual)			KKD25(real)		
a	b	L	a	b	L
			-4.3	-8	48.4
			-3.2	-9.8	48
124.86	117.14	123.62	-2.485	-9.751	48.478
123.47	105.23	123.03	-3.793	-20.96	48.247
121.42	104.51	120.97	-5.722	-21.64	47.439
108.93	92.84	107.57	-17.48	-32.62	42.184

KKf20(virtual)			KKf20(real)		
A	B	L	a	b	L
			-5.8	-11.2	47.5
			-2.8	-11.3	48
136.15	125.11	133.7	8.1412	-2.249	52.431
132.55	117.37	131.1	4.7529	-9.534	51.412
131.47	114.35	126.81	3.7365	-12.38	49.729
122.64	112.98	120.93	-4.574	-13.67	47.424

KKf25(virtual)			KKf25(real)		
a	b	L	a	b	L
			-5.8	-11.2	47.5
136.1	123.54	132.2	8.0941	-3.727	51.843
135.36	123.19	132.88	7.3976	-4.056	52.11
132.58	109.92	130.98	4.7812	-16.55	51.365
125.9	103.14	124.06	-1.506	-22.93	48.651
122.24	99.55	120.96	-4.951	-26.31	47.435

Colour change

Days	KKD20	KKD25	KKf20	KKf25	KKDC	KKfC
0						
21	3.5398	2.1471	3.043	16.363	5.9068	10.05
42	8.0308	2.5231	17.285	15.699	3.5353	9.7978
63	6.7067	12.971	11.377	12.469	6.9342	7.7879
84	5.8181	13.745	9.864	12.541	8.8897	6.0384
105	9.0024	28.609	2.7549	15.13	14.286	14.623

KKfC(virtual)			KKfC(real)		
a	B	L	a	B	L
			-5.8	-11.2	47.5
131	118.7	129.1	3.2941	-8.282	50.627
130.92	118.39	128.23	3.2188	-8.574	50.286
128.74	117.81	128.24	1.1671	-9.12	50.29
122.76	109.35	121.79	-4.461	-17.08	47.761
119.86	100.16	118.97	-7.191	-25.73	46.655

KKDC(virtual)			KKDC(real)		
A	B	L	a	b	L
			-4.3	-8	48.4
			-6.6	-13.2	46.8
126.58	119.34	125.4	-0.866	-7.68	49.176
125.83	112.23	123.93	-1.572	-14.37	48.6
122.25	109.6	121.92	-4.941	-16.85	47.812
121.61	104.26	115.32	-5.544	-21.87	45.224

Appendix13: microbial load test results

MICROBIAL QUALITY TEST RESULT

1.0 Tomato

Storage Time (day)	Tomato Sample	Total Bacterial Count Cfu/gm	Total Fungal Count Cfu/gm
0	TD	2.1 X 10^4	7.3 X 10^4
	TF	9.0 X 10^4	1.80 X 10^4
21	TDC	3.2 X 10^4	3.0 X 10^3
	TFC	1.44 X 10^5	1.32 X 10^5
	TD20	2.2 X 10^4	2.8 X 10^4
	TD25	1.85 X 10^5	8.0 X 10^3
	TF20	2.32 X 10^5	1.28 x 10^5
	TF25	3.0 x 10^4	1.75 x 10^5
42	TDC	1.5 x 10^4	1.3 x 10^4
	TFC	1.3 x 10^4	1.7 x 10^4
	TD20	4.1 x 10^4	7.1 x 10^4
	TD25	4.2 x 10^4	4.3 x 10^4
	TF20	3.4 x 10^4	3.0 x 10^4
	TF25	2.8 x 10^4	2.8 x 10^4
63	TDC	5.6 x 10^4	1.5 x 10^4
	TFC	4.44 x 10^5	5.0 x 10^3
	TD20	1.55 x 10^4	6.9 x 10^4
	TD25	1.8 x 10^4	4.1 x 10^4
	TF20	2.4 x 10^4	1.41 x 10^5
	TF25	2.8 x 10^4	7.9 x 10^4

2.0 Okra

Storage Time (day)	Okra Sample	Total Bacterial Count Cfu/gm	Total Fungal Count Cfu/gm
0	KBD	2.30 X 10^5	5.5 X 10^4
	KBF	4.23 X 10^5	1.80 X 10^5
21	KBDC	1.0 X 10^3	3.0 X 10^3
	KBFC	2.0 X 10^3	3.0 X 10^3
	KBD20	5.0 X 10^4	7.1 X 10^4
	KBD25	2.0 X 10^3	6.5 X 10^3
	KBF20	2.1 X 10^4	8.0 x 10^4
	KBF25	3.2 x 10^3	7.2 x 10^3
42	KBDC	3.3 x 10^4	2.1 x 10^4
	KBTFC	3.5 x 10^4	4.6 x 10^4
	KBD20	6.3 x 10^4	4.1 x 10^4
	KBD25	5.5 x 10^4	2.7 x 10^4
	KBF20	6.6 x 10^4	6.0 x 10^4
	KBF25	8.6 x 10^4	2.8 x 10^4
63	KBDC	1.6 x 10^4	2.7 x 10^4
	KBFC	2.8 x 10^4	2.1 x 10^4
	KBD20	2.5 x 10^4	4.0 x 10^4
	KBD25	1.12 x 10^3	8.6 x 10^4
	KBF20	4.4 x 10^3	6.2 x 10^4
	KBF25	1.10 x 10^5	7.4 x 10^4

3.0 Baobab Leaves

Storage Time (day)	Boabab Leaves Sample	Total Bacterial Count Cfu/gm	Total Fungal Count Cfu/gm
0	KKD	2.30 X 10^6	1.1 X 10^5
	KKF	1.1 X 10^4	1.90 X 10^4
21	KKDC	2.0X 10^3	3.0 X 10^3
	KKFC	1.0 X 10^3	5.0 X 10^3
	KKD20	6.4 X 10^4	7.0 X 10^4
	KKD25	4.0 X 10^3	3.0 X 10^3
	KKF20	1.8 X 10^4	7.7 x 10^4
	KKF25	2.0 x 10^3	8.0 x 10^3
42	KKDC	1.0 x 10^3	3.0 x 10^3
	KKFC	3.0 x 10^3	4.0 x 10^3
	KKD20	2.3 x 10^4	5.5 x 10^4
	KKD25	7.0 x 10^3	6.0 x 10^3
	KKF20	9.0 x 10^3	1.7 x 10^4
	KKF25	2.1 x 10^4	9.0 x 10^4
63	KKDC	5.9 x 10^4	3.9 x 10^4
	KKFC	1.0 x 10^3	4.0 x 10^3
	KKD20	8.0 x 10^3	2.0 x 10^3
	KKD25	3.6 x 10^4	3.0 x 10^3
	KKF20	5.0 x 10^3	1.1 x 10^4
	KKF25	8.0 x 10^3	8.0 x 10^3

Appendix14: Experimental layout

Quality Parameter			C	R	S	M	W	B
T1	D1	t1	T1D1t1C1	T1D1t1R1				
		t2						
		t3						
		t4						
		t5						
		t6						
	D2	t1						
		t2						
		t3						
		t4						
		t5						
		t6						
T2	D1	t1						
		t2						
		t3						
		t4						
		t5						
		t6						
	D2	t1						
		t2						
		t3						
		t4						
		t5						

		t6						
Tc	D1	t1						
		t2						
		t3						
		t4						
		t5						
		t6						
	D2	t1						
		t2						
		t3						
		t4						
		t5						
		t6						

Appendix 15 :Group ANOVA table

		Sum of Squares	df	Mean Square	F	Sig.
Baobab	**Between Groups**	504.986	4	126.247	4.241	0.004
	Within Groups	2470.837	83	29.769		
	Total	2975.824	87			
Okra	**Between Groups**	3053.322	4	763.331	3.505	0.011
	Within Groups	18077.054	83	217.796		
	Total	21130.377	87			
Tomato	**Between Groups**	4478.656	4	1119.664	18.331	0.000
	Within Groups	5069.748	83	61.081		
	Total	9548.405	87			