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Designing and experimental testing of solar powered evaporative cooling to store perishable agricultural products

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BAHIR DAR INSTITUTE OF TECHNOLOGY
SCHOOL OF RESEARCH AND POST GRADUATE STUDIES
FACULTY OF MECHANICAL AND INDUSTRIAL
ENGINEERING

DESIGNING AND EXPERIMENTAL TESTING OF SOLAR POWERED
EVAPORATIVE COOLING TO STORE PERISHABLE AGRICULTURAL
PRODUCTS

BY

LIJALEM AYELE ABATE

September, 2018
Bahir Dar, Ethiopia

Designing and experimental testing of solar powered evaporative
cooling to store perishable agricultural products

By

Lijalem Ayele Abate

A thesis submitted to the school of Research and Graduate Studies of Bahir Dar Institute of Technology, Bahir Dar University in partial fulfillment of the requirements for the degree of Master of Science in Thermal Engineering in the Faculty of Mechanical and Industrial Engineering.

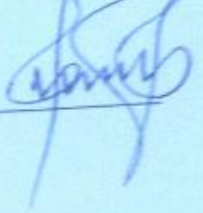
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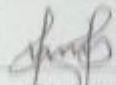

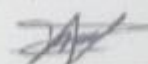

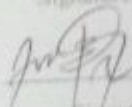
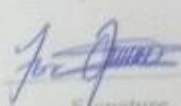
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To my lovely family

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Abstract

This thesis work comprises of designing, manufacturing, and experimental test on solar powered evaporative cooling and is designed to provide an environment which is both lower than ambient temperature and at a higher level of relative humidity for the storage of fresh products.

Evaporative cooling occurs when air, that is not too humid, passes over a wet surface; the faster the rate of evaporation the greater the cooling effect. The efficiency of an evaporative cooling structure depends on the humidity of the surrounding air. Therefore, this thesis will study the theory, advances, principles, methods of solar powered evaporative cooling, and also the optimum storage temperature, relative humidity and shelf life of vegetables.

The experimental setup consists of a rectangular shaped with a specified total storage space, made of galvanized steel for external cover, aluminum for internal cover and internally insulated with fiber glass, a suction axial fan supply volume flow rate of $0.78\text{m}^3/\text{s}$ air at a speed of 0.93m/s to the wet pad, cooling pad remains wet due the recycling of water with axial pump having flow rate of 0.054kg/s and water recirculates inside the cabinet through high conductive copper tube to remove the heat from the commodities and then water stored at the upper water tank coupled with flow controlling valve.

Study is conducted to check the freshness of the agriculture products, and the data is observed hourly and daily. The products shelf life increases when they stored at low temperature and at high relative humidity. Thus, the results of the transient performance tests revealed that the evaporative cooling system temperatures were consistently lower than the ambient air temperatures during the hottest time of the day when insulation was appreciable inside the cooling chamber varied from $16.2 - 22.1^\circ\text{C}$ while in the ambient air temperature varied from $22.6 - 29.8^\circ\text{C}$.and the evaporative cooling chamber relative humidity is 75 - 90% while at outside it was recorded 66 -80%.

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List of abbreviations

A	Ampere
AC	Alternative Current
ACD	Air Change per Day
BIT	Bahir Dar Institute of Technology
DC	Direct Current
DBT	Dry Bulb Temperature
DPT	Dew Point Temperature
Eff	Equipment Efficiency
FUM	Motor Use Factor
Kb	Coefficient of bend
Nu	Nusselt number
Pr	Prandtl number
PV	photovoltaic
Re	Reynolds Number
RH	Relative Humidity
RHS	Rectangular hollow sheet
W	watt
w	Humidity Ratio
V	voltage
Whr	Watt hour
WBT	Wet Bulb Temperature
ϵ	Emissivity

List of symbols

A_p	Heat transfer area of the pad (m^2)
ACL	Air change load (w)
C_p	Specific heat capacity dry air (kJ/KgK)
C_{pu}	Humid specific heat (kJ/KgK)
h_a	Enthalpy of ambient air (kJ/Kg)
h_{fg}	Latent heat of vaporization (kJ/kg)
h_g	Enthalpy of water vapor (kJ/Kg)
h_i	Enthalpy of cold storage (kJ/Kg)
h_o	Enthalpy of ambient air (kJ/Kg)
I	Current (A)
k	Thermal conductivity (w/m.K)
l	Characteristic length (m)
M	mass of the product (kg)
M_a	mass of air (kg)
M_v	mass of water vapor (kg)
P	horse power rating (w)
P_a	partial pressure of dry air (Kpa)
P_b	Bend pressure drop (Kpa)
P_T	Total pressure drop (Kpa)
P_v	Pressure of water vapor (Kpa)
Q	heat transfer rate (w)
Q_l	latent heat (w)
Q_s	Sensible heat (w)

R	heat flow resistance ($\text{m}^2 \text{ }^\circ\text{C}/\text{w}$)
T _i	indoor ambient temperature (K)
T _o	outdoor ambient temperature (K)
T _w	wet bulb temperature (K)
U	over all heat transfer coefficient ($\text{w}/\text{m}^2\text{ }^\circ\text{C}$)
V	Volume of cold storage (m^3)
V	voltage (v)
ε	Direct evaporation effectiveness (%)

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Chapter-one

Introduction

1.1. Back ground

Energy shortages and variable power availability under-privilege society's advancement such as Cold storage, Refrigeration and air conditioning consume enormous energy. In recent years, these sectors have witnessed manifold growth, and become essential not only for human comfort but also for a variety of applications, such as food preservation.

Nearly 35% of all fresh produce, in developing countries like Ethiopia, are lost due to lack of cold storage facilities and unavailability of regular power supply. Providing thermal cooling would minimize post-harvest losses.[1]

The issue of food losses is of paramount importance in pursuit to combat hunger and improve the food security, especially in the poor and developing nations. Such losses not only deprive the under-privileged societies, but also epitomize substantial waste of resources employed during its production. The exact reasons and extent of such losses vary round the globe and are heavily dependent on the specific conditions, as well as indigenous factors prevailing in a specific country. [2]

The post-harvest deterioration contributes towards a significant fraction of the total loss in food grains, especially in the developing countries of the world, owing to poor storage facilities and lack of infrastructure. The hot and humid climate prevailing in the tropical and subtropical countries is also seriously responsible for such enormous decay. Thus, establishment of cold storages is the need of the hour, to reduce the wastage of perishable commodities, as well as, for the economic benefit of both the growers and consumers.

The quality of fruit and vegetables and their related shelf life are reduced by loss of moisture, decay, and physiological breakdown, and such deterioration is directly related to storage temperature, relative humidity, air circulation, mechanical damage, and improper postharvest sanitation.[3]

The present air cooling methods are evaporative coolers, air conditioning, fans and dehumidifiers. But running these products need a source called electricity. The producing of electricity is ultimately responsible for hot and humid conditions, i.e., global warming. Need

of such a source which is abundantly available in nature, which does not impose any bad effects on earth. There is only one thing which can come up with these all problems is solar energy.

Solar energy, radiant light and heat from the sun, is harnessed using a range of technologies such as solar heating, solar photovoltaic. The Earth receives 174 petawatts (PW) of incoming solar radiation.

Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses. Photovoltaic is a method of generating electrical power by converting solar radiation into direct current electricity by photovoltaic effect[4].

Evaporative cooling operates using induced processes of heat and mass transfer, where water and air are the working fluids. It consists, specifically, in water evaporation, induced by the passage of an air flow, thus decreasing the air temperature. When water evaporates into the air to be cooled, simultaneously humidifying it, that is called direct evaporative cooling (DEC) and the thermal process is the adiabatic saturation. The main characteristic of this process is the fact that it is more efficient when the temperatures are higher, that means, when more cooling is necessary for thermal comfort. It has the additional attractiveness of low energy consumption and easy maintenance. Due to use of total airflow renewal, it eliminates the recirculation flow and proliferation of fungi and bacteria, a constant problem in conventional air conditioning systems. Due to its characteristics the evaporative cooling system is more efficient in places where the climate is hot and dry climatic conditions.

In this context, some methods of preserving fruit and vegetables, other than expensive electric powered refrigeration systems, such as storage in a ventilated shed, using zero energy storage based on an evaporative coolant system, waxing and hot water treatment have been found to be an efficient and economical means of reducing postharvest storage loss.[5]

1.2. Statement of the problem

In Ethiopia different types of fruits and vegetables like carrot, peppers, mango and tomato are produced. After the production of fruits and vegetables the farmers and investors stored in high ambient temperature and below the required relative humidity that causes these fruits

and vegetables to be spoiled. The post-harvest deterioration contributes towards a significant fraction of the total loss in food grains, owing to poor storage facilities and lack of infrastructure.

Evaporative cooling system is one of the simplest and least expensive techniques used to delay spoilage of stored fruit and vegetables by lowering the ambient temperature. Therefore, for rural areas and for transportation from harvesting area to the market where main grid power is not available, solar powered evaporative cooling is very important to avoid the upper mentioned problem.

1.3. Significance of the Study

Cold storage is one way of protecting the deterioration agricultural products of fruits and vegetables using evaporative cooling technology. The purpose of the design is creating cold storage by adding cold air to it that increases the shelf life of the perishable agricultural products.

Design of evaporative cooling using solar PV panel energy source provides a service everywhere at which perishable agricultural products are highly produced. This evaporative cooling design benefits for farming for fruits and vegetables such as farmers, merchants, and investors and to consumers.

1.4. Objectives

1.4.1. General objective

The general objective of this thesis is design and experimental testing of solar powered evaporative cooling for perishable agricultural products to increase the shelf life of fruits and vegetables.

1.4.2. Specific objectives

The specific objective of this thesis work is to:

- ✓ design the components of evaporative cooling system
- ✓ prepare evaporative pad from easily available material

- ✓ estimate the power consumption from the solar PV panel to run fan and pump
- ✓ Evaluate the feasibility of the developed project
- ✓ manufacturing and testing of the prototype to get experimental results and comparing with the numerical values

1.5. Scope

The scope of this study is designing and experimental testing of evaporative cooling by using solar PV panel energy source to run the fan that supply air to the system and pump to supply water to the cooling pad to store perishable agricultural products which are highly produced here in Ethiopia.

Agricultural products have different thermo physical properties that needs different storage temperature and relative humidity thus the experiment testing is performed on those fruits which have relatively similar storage temperature and relative humidity.

Chapter-two

Literature reviews

2.1. Introduction of general reviews

The content of this chapter is an overview of the available literature and information on evaporative cooling that will ultimately be used as a foundation throughout the thesis.

The chapter aims at:

- Providing an overview of the history and development of evaporative cooling
- Identifying the gap on the previous work
- Identifying the most effective type of evaporative cooling for the proposed application

This thesis aims to include and further develop the methodologies previously employed in evaporative cooling design to increase the shelf life of agricultural products of perishable fruits and vegetables.

2.2. Previous works on evaporative cooling

Natural losses from fruit and vegetable products stored in cold conditions are investigated using mathematical model and governing equations are solved using Software Mathcad7. When the relative humidity is larger than the equilibrium relative humidity value, an increase in the ventilating air rate reduces the losses of the product during the period of its storage while larger losses occur when the relative humidity values are lower than the equilibrium one [6].

Proposed a system that utilize on zero energy cool chamber (ZECC) consisting of two cooling systems, a solar-driven adsorption refrigerator and an evaporative cooling system, was developed and then evaluated as low-cost and ecofriendly cooling storage for storing fruit with moderate respiration rates. The ice is then used to cool the storage space, which can be done for a long time without the need for electricity. However zero energy evaporative cooler which is limited on wind velocity area otherwise evaporation of water from wet pad may not takes place [7].

Studied on conceptual design of a potato cold storage, along with performance appraisal over a calendar year. The microclimate inside the cold storage is regulated using a water–lithium bromide absorption system. Proposed system utilizes both solar thermal and photovoltaic generated electrical energy for its operation. A suitable operation strategy is devised and the performance of the integrated system is analyzed from energy and exergy point of view to identify the required numbers of thermal collectors and photovoltaic modules [2].

Fresh-cut fruits and vegetables have gained much more attention worldwide in the past decades. Due to the increased awareness of consumers in sensorial and nutritional qualities of fresh-cut fruits and vegetables, as well as the serious concerns towards public health caused by foodborne outbreaks owing to inappropriate handling or preservation of fresh-cut fruits and vegetables, fresh-cut industry is an urgent need of new and improved technologies for shelf life extension [8].

Investigated on direct evaporative cooling methods by changing the air flow rate and pad thickness which are simple but with lower thermal performance and can only be used for short term storage of agricultural product with moderate respiratory rates. but most of the analyses focused on effect of air flow rate and pad thickness on the cooling effectiveness, and the energy efficiency and evaporation loss of these materials in most cases were not evaluated or presented [9].

Investigated on the demand for refrigeration and Air conditioning has been increased during the last decade; the cold storage system can be used to the economic advantage over conventional plants. Energy conservation is required in the cold storage system. So design of experiment is used to optimization of different parameters of cold storage on the bases of performance experiments [10].

Bioclimatic charts are used in assessing the effectiveness and selection of the passive cooling. These charts are based on the typical dry bulb temperature and humidity extracted from the typical meteorological years (TMY) at a given location. TMYs are usually developed for general use and in many situations; they are unavailable due to the lack of

some of the weather parameters, especially solar radiation. Dry bulb temperature and dew point measurements are of the most commonly available parameters [11].

Respiration rate and gas exchange through the package material are the processes involved in creating a modified atmosphere inside a package that will extend shelf life of fresh fruits and vegetables. Thus, modelling respiration rate of the selected produce is crucial to the design of a successful modified atmosphere packaging (MAP) system.

Factors affecting the respiration rate and respiratory quotient are outlined, stressing the importance of temperature, O₂ and CO₂ concentrations, and storage time. Due to the complexity of the respiration process, only empirical models have been developed. The particular variables that influence the O₂ uptake and CO₂ production rate should be identified and quantified for each fruit or vegetable product.[12].

Designed, constructed and evaluated evaporative cooler using locally materials within the study area. The result also showed that maintaining lower temperature and higher relative humidity during storage combined with selecting cultivars having long shelf life could maintain fruit quality and reduce loss. Quality attributes were found to be best which was stored in the evaporative cooler. The effectiveness of the evaporative cooler was higher during the day between the periods of 12 -14 hrs local time when observed. The evaporative cooler was able to preserve freshly harvested tomato and hot pepper for 8 days before color changes and mold spotting appeared and the weight was drastically reduced[13].

Investigated on postharvest losses throughout the world account for significant reductions in food supply which negatively impacts incomes of farmers, prices of food, and food availability. Many of these losses may be mitigated by providing reduced temperature and increased humidity. The result obtained limited temperature reduction (max 2°C) but an acceptable relative humidity increase (to 80%).A similar temperature reduction and relative humidity were obtained as in the second setup however, condensation was limited because the control unit for relative humidity was adjusted to a lower level. The unit was also tested for its effect on produce weight loss[14].

Designed and studied to investigate on post-harvest deterioration and loss in food grains, especially in the developing countries of the world, owing to poor storage facilities and lack

of infrastructure. The construction and test implemented using the two stage evaporative cooling system that reduces the deterioration of commodities that increase the shelf life by five days. Design analysis of the cooling system was limited only on Bahir dar city climatic conditions of the recent five years up to 2016 GC[15].

2.3. Summary of Literature and gaps

The above literatures review reveal different types of evaporative cooling technologies such as direct, indirect and two stage evaporative cooling to increase the shelf life of fruits and vegetables and filled the post-harvest loss gaps.

An overview of the literature provide different appropriate technology based on the evaporative cooling efficiency and the critical gaps found from the literature are the following:

- ✓ Internal heat generation removing mechanism and during loading of fruits and vegetables loads to the cold storage with the ambient temperature that release a high heat after storage.
- ✓ Evaporative cooling technology for rural areas and transportation from harvesting area to the market is not available due to the power source.

Chapter-three

Materials and Methods

3.1. Methodology

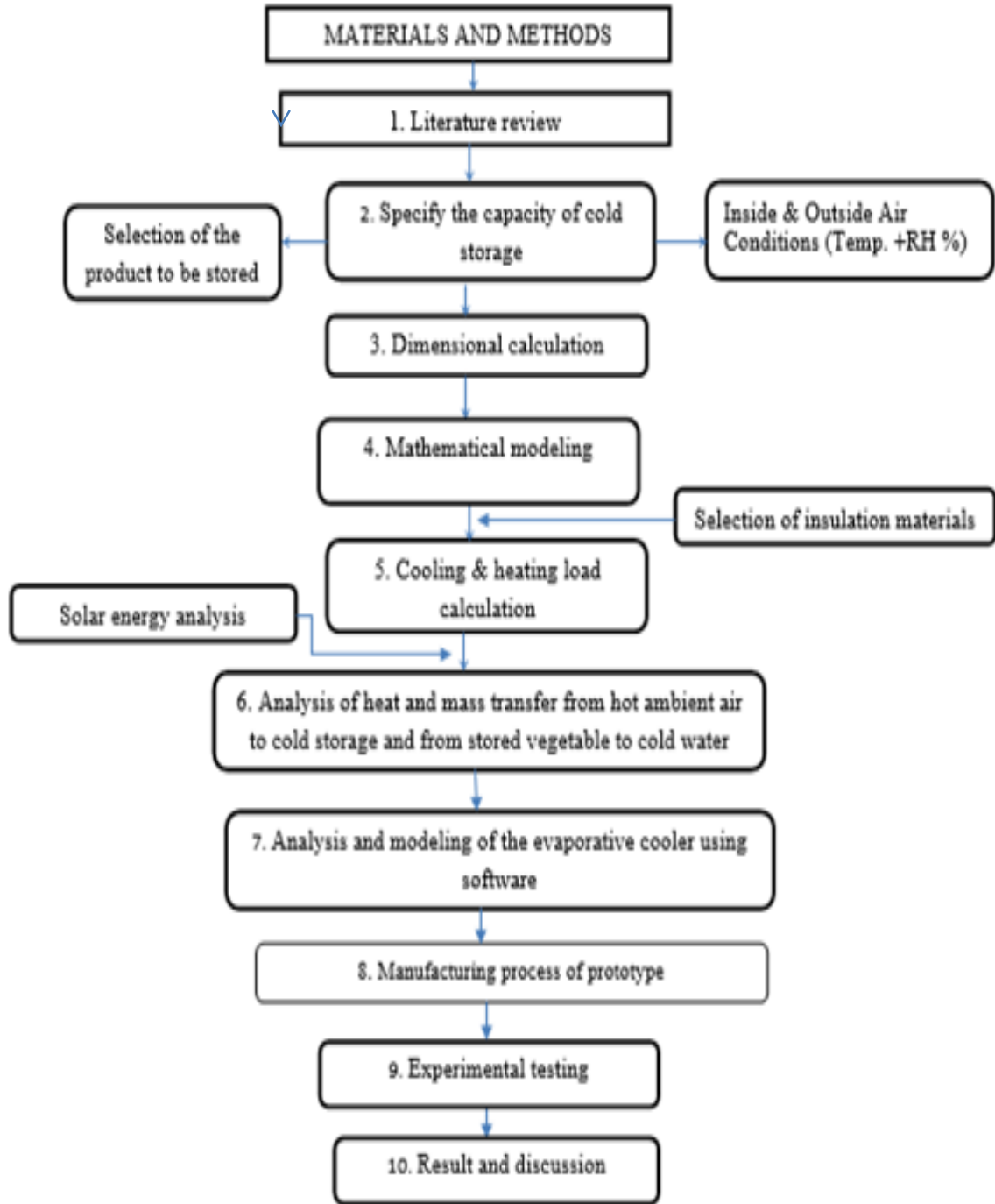


Figure 3. 1: Flow Chart of the thesis methodology

3.2. Materials

In general, the following approaches were used for this thesis work:

- Literature review of key evaporative cooling technology concepts:
 - ✓ Background and theory of evaporative cooling system
 - ✓ The literature review introduces cooling and how it preserves the agricultural products and easily perishable products.
- Review equipment used for evaporative cooling process
 - ✓ The introduction for cooling process equipment introduces the major equipment and items, and some of the challenges in using them.
- An introduction and discussion of evaporative cooler on: Mathematical modelling and creating the system are a major part of this thesis and includes creating and testing a model capable of predicting the result.
- Cold fruit-storage chamber using evaporative cooling system use easily available materials:
 - ✓ Different types of natural fiber used for water retention, evaporative unit, insulation materials, sheet metal, water tubes

3.2.1. Cooling pad material

There is transfer of heat from the pad material during evaporation and during this process water is being evaporated. The cooling capacity of a system is independent on the amount of air flow and its saturation which in turn depends on the characteristics of the pad, air velocity through the pad and the water flow rate. Evaporation from the wetted pad affected by some factors which are wind, temperature, surface area, humidity, air velocity, water flow rate and thickness. The amount of water that the air can evaporate from the pad depends on the rate of saturation and the temperature of the air. The lower the relative humidity the higher the rate of evaporation and thus the more the cooling takes place.[16]

In evaporative cooling pad water flows along the distribution pipe and drains down into the pad material. The sump should be large enough to hold all run-off when the pump is turned off.

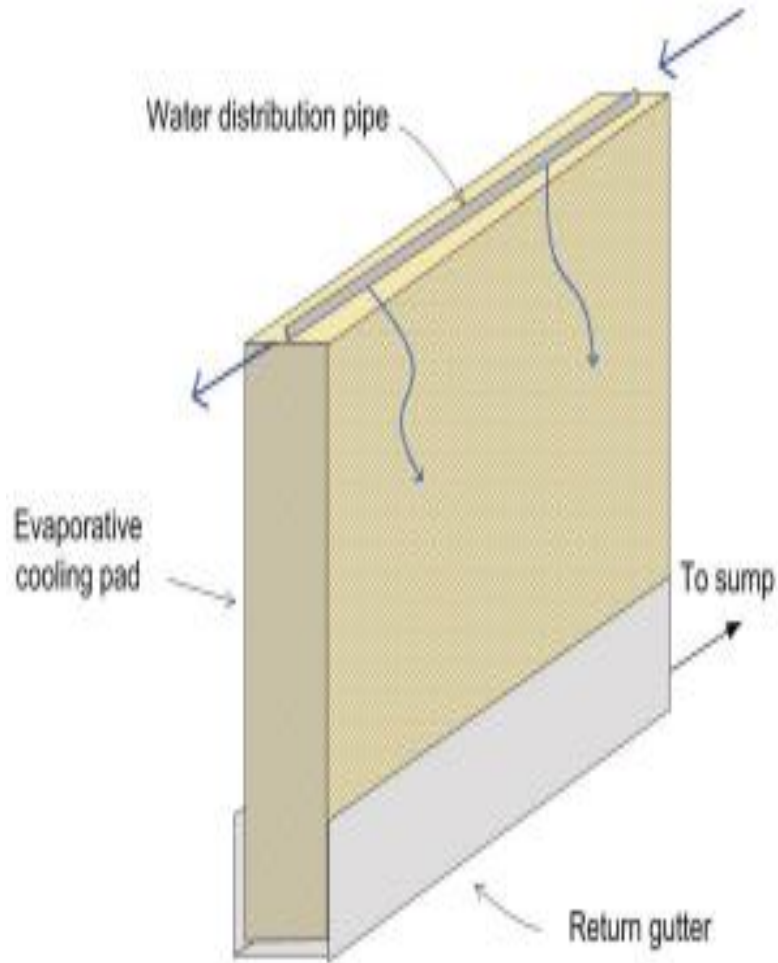


Figure 3. 2: Water circulation diagram of evaporative media pad[17],

Fan and pad systems consist of exhaust fans at one end of the greenhouse and a pump circulating water through and over a porous pad (Figure 3.2) installed at the opposite end of the cold storage.

Various materials have been used as pad ranging like palm tree leaves, hessian cloths, aspen wood, jute, cotton materials, perforated clay blocks mad some other materials based on the functionality, costing and availability. Easily available material natural fiber local name of Kusha which is found everywhere in the rural area of the country. Which is also used to prepare as package for different applications and has a high-water absorbing properties for a certain time.



Figure 3. 3: Kusha and its mat

Kusha is a raw material used to prepare the mat and the mat is used to prepare pad in different thickness to measure the effectiveness of the cooling system.

3.2.2. Insulation materials

Insulation materials are very basic and important in evaporative cooling dealing with various heat transfer unit operations. It is very important in cold storage industry to maintain the temperature of chilled water and steam supply, store the products at low temperature either in cold storages or in tanks and transportation of the products at lower temperature[18].

The key properties of an insulating material to be considered are:

- ✓ Compressive strength
- ✓ Service temperature range
- ✓ Thermal conductivity
- ✓ Water absorption and thickness tolerance

The compressive strength of most insulating materials decreases as temperature increases and therefore it is necessary to consider the compressive strength at the service temperature. The service temperature is the highest temperature at which the insulation material can perform reliably in long-term application. Thermal conductivity (K) is the most important parameter in determining a material's ability to resist the flow of heat. The absorption of water in insulating material increases conductivity of the material and causes swelling of the material. Thickness tolerance is important for achieving alignments and product quality. A low value of thermal expansion at operating temperatures is required for the insulation.

In order to minimize the heat gained through the walls via conduction, the R-value must be optimized. However, there will be a point where the cost of materials no longer justifies the additional gains in R-value. Additionally, the practical requirements of the cold storage design need to be taken into consideration[19].

The materials reviewed for insulation were fiberglass, stainless steel sheet metal, and aluminum sheet metal. Fiberglass was chosen as it has a very high thermal resistance at a low cost. Aluminum sheet metal was chosen because it is cheap and readily available for internal face wall. Stainless steel sheet metal was chosen for exterior face wall of cold storage. Fiberglass insulation works best in construction with walls and ceilings.

The skeleton of the cold storage was constructed from RHS metal that carries the body of the cold storage and fruits and vegetables to be stored in.

Table 3. 1: Thermo-physical properties of some common constructing and insulating materials[20]

Insulating Materials	Specific heat KJ/KgK	Density Kg/m ³	Thermal conductivity W/m.K
Mineral or glass wool	0.67	24 -64	0.038
Fiberglass	0.7	64 - 144	0.04
Cork board	1.884	104-128	0.038
Cork granulated	1.88	45-120	0.045
Thermocouple (EPS)	-	30	0.037
Stainless steel	-	-	19
Steel Carbon 1%	-	-	43
Aluminum	-	-	143

3.2.3. Equipment's used for measuring and power supply unit

- ✓ Temperature and relative humidity measuring devices
- ✓ Fan
- ✓ Solar panel
- ✓ battery
- ✓ Invertor
- ✓ Wire and water tube

i. Fan

A standalone fan is typically powered with an electric motor. Fans are often attached directly to the motor's output, with no need for gears or belts. Smaller fans are often powered by shaded pole AC motors or brushed or brushless DC motors [15]. In this case it is powered by ac motor having three blades attached with small inverter which convert DC to AC power

ii. Solar panel

A solar panel is a device that collects and converts solar energy into electricity or heat. It is known as Photovoltaic panels, used to generate electricity directly from sunlight. A solar power technology that uses solar cells or solar photovoltaic arrays to convert light from the sun directly into electricity. Photovoltaic, is in which light is converted into electrical power. It is best known as a method for generating solar power by using solar cells packaged in photovoltaic modules, often electrically connected in multiples as solar photovoltaic arrays to convert energy from the sun into electricity. The photovoltaic solar panel is photons from sunlight knock electrons into a higher state of energy, creating electricity.

In this project, 70watt (2 fan 35 watt each) for the fan and 50 watt for the pump and the fan engaged with the system in to two areas based on the porosity area of the pad. Thus, total solar power becomes 120 watts.

iii. Battery

Batteries designed to capture surplus electricity generated by the solar PV system. This guide sets out the main features need to take into account when deciding if a battery storage system is suitable for solar PV system[21].

Potentially batteries can help to use more of the electricity generated by PV system. It is also important to note that, contrary to expectations, some battery storage systems are not designed to work during power-cuts. In addition, they are not cheap: at today's prices, poorly designed systems may not repay their initial investment (in what they save on electricity bills). But prices continue to fall and the technology is also improving, meaning that battery storage is becoming a viable economic option for some households and businesses[22].

Battery can be categorized in to primary and secondary. In this case secondary battery choose due to rechargeable batteries can be charged and discharged many times before wearing out.

iv. Pump

A pump is a device used to move gases, liquids or slurries. A pump moves liquids or gases from lower pressure to higher pressure and overcomes this difference in pressure by adding energy to the system such as a water system. A gas pump is generally called a compressor, except in very low pressure-rise applications, such as in heating, ventilating, and air-conditioning, where the operative equipment consists of fans or blowers. Pumps work by using mechanical forces to push the material, either by physically lifting, or by the force of compression. Hand-operated, reciprocating, positive displacement, water pump[22].

For this thesis axial pump is selected based on the flow rate calculated in section 3.4.6. And delivers water in to water circulating pipe to exchange thermal energy from stored fruit and vegetable to cold water and then add it on wet pad continuously.

v. Inverter

Power obtained from PV panel DC power in solar energy the Power Inverter is the heart of the system. It makes 220 volts AC from the 12 volts DC stored in the batteries. It can also

charge the batteries if connected to a generator or the AC line. For 12v applications an inverter is not required.

An inverter should only be required when it is necessary to convert the 12v input to power a 220v standard application[23].

Inverter supply AC power to fan that supply air from the surrounding air to wet pad and the pump which deliver water into circulated tube and then drip it on pad.

3.3. Design procedure and cold storage development

Systems consisting of dry air and water vapor essential for the design and analysis of cold storage, air conditioning devices, cooling towers, and industrial processes requiring close control of the vapor content in air. Air moisture and heat interactions are rather complex[24].

3.3.1. Types of Evaporative Cooling Systems

Two working principles of evaporative cooling are

1. **Direct cooling:** In direct cooling water evaporates directly into the airstream, thus reducing the air's dry-bulb temperature while humidifying the air.

In direct evaporative cooling, the dry bulb temperature is lowered but the wet bulb temperature remains unchanged.

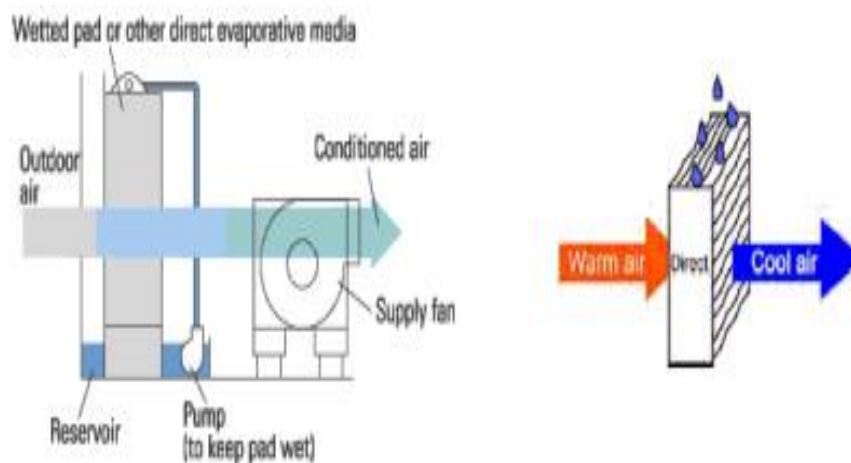


Figure 3. 4: Direct evaporative cooling system [18].

The efficiency of direct cooling depends on the pad media. A good quality rigid cellulose pad can provide up to 90% efficiency while the loosely pen wood fiber pad shall result in 50 to 60% contact efficiencies.

2. **Indirect cooling:** In indirect cooling, one stream of air called primary air is cooled sensibly (without addition of moisture) with a heat exchanger, while the secondary air carries away the heat energy from the primary air.

In indirect evaporative cooling system both the dry bulb and wet bulb temperatures are reduced.

Indirect evaporative coolers do not add humidity to the air but cost more than direct coolers and operate at a lower efficiency. The efficiency of indirect cooling is in the range of 60-70%.

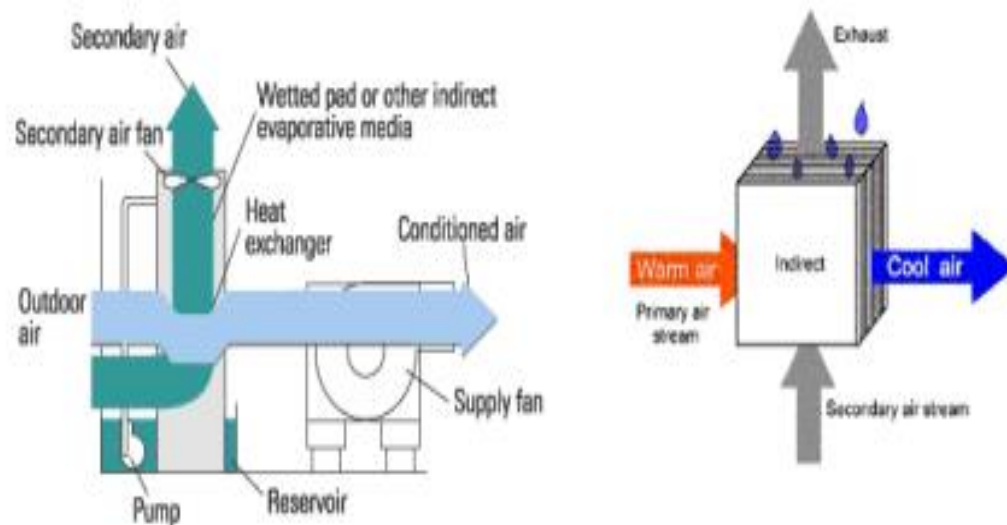
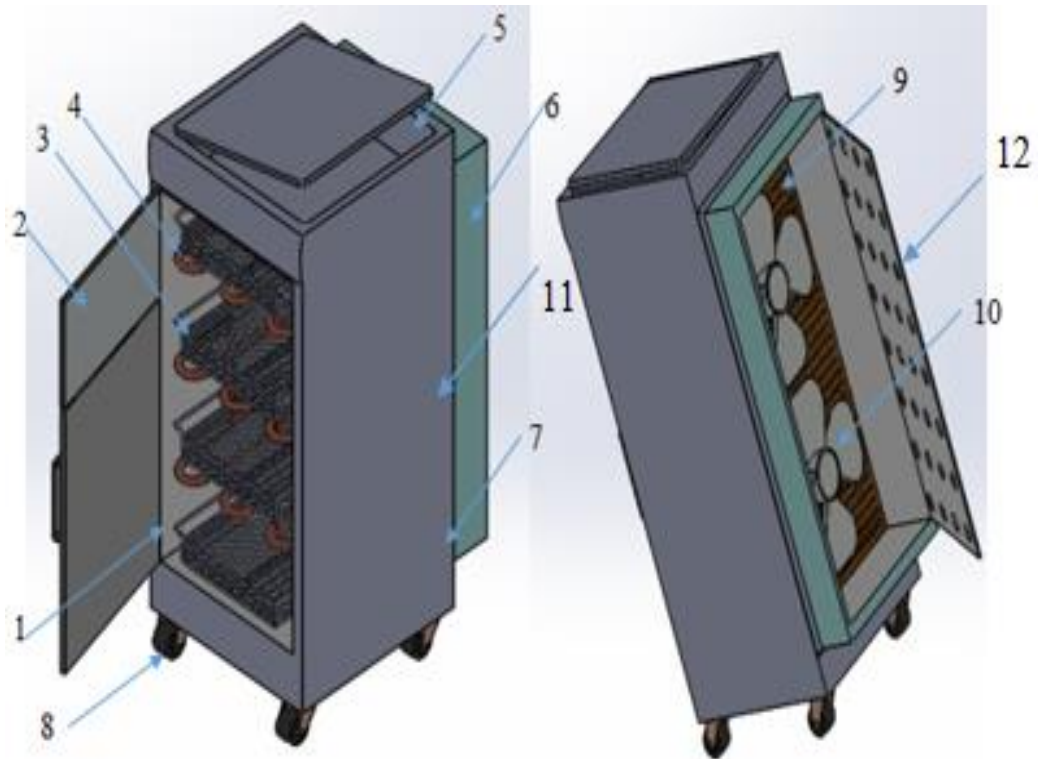


Figure 3. 5: Indirect evaporative cooling system [18].

Based on the cooling efficiency and cost, it is going to be designed direct evaporative cooling system for a better cold storage. Direct and indirect processes can also be combined (indirect/direct). The effectiveness of either of these methods is directly dependent on the low wet bulb temperature in the supply airstream.

Direct Evaporative cooling systems consist basically of the cabinet, the cooling fan, and transmitting medium (cooling pad).



- | | |
|---------------------------|-------------------------------|
| 1. cold storage | 7. pump and bottom water tank |
| 2. door | 8. wheel |
| 3. shelf | 9. Cooling pad |
| 4. water circulating tube | 10. air supply fan |
| 5. top water tank | 11. body of cold storage |
| 6. evaporative unit | 12. pad cover with air filter |

Figure 3. 6: components of the cold storage.

As shown in the figure 3.6 the evaporative unit consists of transmitting medium/cooling pad, cooling fan and water distributor and gutter.

One of the important components of the evaporative cooling system is the cabinet, which houses the insulating materials and their components. The resistance that a wall or a material offers to the flow of heat is inversely proportional to the ability of the wall or material to transmit heat, that is, the overall thermal resistance is inversely proportional to the overall heat transfer.[25]

3.3.2. Cooling Load Methodology – Considerations & Assumptions

Design cooling load takes into considerations all the loads experienced by a cold storage under a specific set of assumed conditions. The assumptions behind design cooling load are as follows:

- ✓ Weather conditions are selected from a long-term statistical database. The conditions will not necessary represent any actual year but are representative of the location of the cold storage.
- ✓ The solar loads on the housing are assumed to be those that would occur on a clear day in the month chosen for the calculations
- ✓ The ventilation rates are either assumed on air changes or based on maximum occupancy expected
- ✓ Latent as well as sensible loads are considered
- ✓ Heat flow is analyzed assuming dynamic conditions, which means that heat storage in cold storage envelope and interior materials is considered
- ✓ The latent heat gain is assumed to become cooling load instantly, whereas the sensible heat gain is partially delayed depending on the characteristics of the conditioned space. According to the ASHRAE regulations.

3.3.3. Cooling versus heating load calculations

Heating load calculations are carried out to estimate the heat loss from the building in winter so as to arrive at required heating capacities. Normally during winter months, the peak heating load occurs before sunrise and the outdoor conditions do not vary significantly throughout the winter season. In addition, internal heat sources such as occupants or appliances are beneficial as they compensate some of the heat losses[20].

As a result, normally, the heat load calculations are carried out assuming steady state conditions (no solar radiation and steady outdoor conditions) and neglecting internal heat sources. This is a simple but conservative approach that leads to slight overestimation of the heating capacity [7].

For estimating cooling loads, one has to consider the unsteady state processes, as the peak cooling load occurs during the day time and the outside conditions also vary significantly throughout the day due to solar radiation. In addition, all internal sources add on to the cooling loads and neglecting them would lead to underestimation of the required cooling capacity and the possibility of not being able to maintain the required indoor conditions. Thus cooling load calculations are inherently more complicated as it involves solving unsteady equations with unsteady boundary conditions and internal heat sources[20].

For cold storage there exists a balance point at which the solar radiation (Q_{solar}) and internal heat generation rate (Q_{int}) exactly balance the heat losses from the cold storage building. Thus, from sensible heat balance equation, at balanced condition:

$$(Q_{solar} + Q_{int})_{sensible} = UA (T_i - T_o) \quad (3.1)$$

Where

UA - the product of overall heat transfer coefficient and heat transfer area of the housing,

T_i - the required indoor temperature and

T_o - the outdoor temperature

From the above equation, the outside temperature at balanced condition (T_o, b) is given by:

$$T_{o, balance} = T_i - \frac{(Q_{solar} + Q_{int})}{UA} \quad (3.2)$$

If the outdoor temperature is greater than the balanced outdoor temperature given by the above equation, i.e.:

- ✓ When $T_o > T_{o,b}$, then there is a need for cooling the cold storage
- ✓ When the outdoor temperature is less than the balanced outdoor temperature, i.e., when $T_o < T_{o,b}$, then there is a need for heating the cold storage.
- ✓ When the outdoor temperature exactly equals the balanced outdoor temperature, i.e., when $T_o = T_{o,b}$, then there is no need for either cooling or heating the cold storage.

In this case the average minimum temperature of the selected area above the required indoor temperature, thus no need of heating load calculation for reheating the cold storage to avoid over chilled deterioration and spoilage of fruits and vegetables.

3.3.4. Sizing the evaporative cooling chamber

The size of the cold chamber depends on air change per hour and sensible heat load removal as well as the budget to manufacture the prototype of the cold storage.

The "Air Change" method is a practical approach to assist in the determination of the size of evaporative cooling equipment. The principle behind this method is to determine two factors [24].

- i. Leaving air temperature from the evaporator cooler
- ii. Difference between the inside temperature of the space, when evaporative cooling is not in use and the outside ambient temperature during its highest condition

Determine the Cubic Capacity of the cold storage or that portion of the structure to be evaporative cooled from Appendix B.

$$\text{Width} \times \text{Length} \times \text{Effective Cooling Height} = \text{Capacity in Cubic meter} \quad (3.3)$$

Based on air change per hour and sensible heat load removal as well as the budget to manufacture the prototype of the cold storage let's take total amount in kilogram that the cold storage can hold is 200kg and the overall dimension based on air change and the budget become 0.7 m*0.7m * 1.5m.

The volume of the cold storage become

$$V = 0.7m * 0.7m * 1.5m \quad (3.4)$$
$$V = 0.735m^3$$

Fruits and vegetables which are taken for experiment carrot, peppers and tomatoes'. The kg of fruits and vegetables for experiment taken based on the total kg stored in the cabinet and the volume of commodities is 40% of total volume and remaining 60% which is necessary for the air circulation and loading and unloading of fruits and vegetables[26]. Thus 40% of the total kg becomes 80kg.

$$\text{volume carrot} = \frac{\text{mass}}{\text{density of carrot}} \quad (3.5)$$
$$= \frac{80kg}{320kg / m^3} = 0.25m^3$$

$$\text{Volume for pepper} = \frac{\text{mass}}{\text{density of lemon}} \quad (3.6)$$

$$= \frac{80\text{kg}}{1032\text{kg} / \text{m}^3} = 0.0775\text{m}^3$$

$$\text{Volume for tomato} = \frac{\text{mass}}{\text{density of tomato}} \quad (3.7)$$

$$= \frac{80\text{kg}}{970\text{kg} / \text{m}^3} = 0.1 \text{m}^3$$

$$\text{Volume for mango} = \frac{\text{mass}}{\text{density mango}} \quad (3.8)$$

$$= \frac{80\text{kg}}{1069\text{kg} / \text{m}^3} = 0.073\text{m}^3$$

From the volumetric calculation above 50% of the volume become free which is used for air circulation and loading and unloading of fruits and vegetables.

Table 3. 2: Selected engineering properties of some fruits and vegetables [27].

Fruit and vegetable	Specific gravity	Solid density (kg/m ³)	Specific heat capacity (KJ/kg)
Lemon	1.032	1032	3.93
Tomato	1.02	970	3.67
Mango	1.068	1068	3.78
Banana	0.964	964	3.45
Carrot	0.32	320	3.24
Orange	1.04	1040	3.91

3.3.5. Data collection and data analysis

Data collection and analysis are divided into two types. These are for basic design and commodity storage requirements.

3.3.5.1. Basic design data

Basic design data which give information about location of plants their capacity, atmospheric condition around cold storage plants, product temperature and there loading rate. All type of basic design data are as follows:

Table 3. 3: Basic atmospheric condition data

i. DBT	+29°C (Average.)
ii. WBT	+16°C
iii. Product Temperature	20 °C to 30°C (At the loading Time)
iv. Total Storage Capacity	80kg
v. No of Chambers & Capacity	1 & 80kg
vi. Chamber Size	0.7* 0.7* 1.5 (L x W x H)
vii. Cross sectional area for each wall and chamber	

Table 3. 4: Cross section area for each wall and each chamber

Parts	Area
Front	$0.7 \times 1.5 = 1.05 \text{ m}^2$
Right side	$0.8 \times 1.5 = 1.2 \text{ m}^2$
Left side	$0.8 \times 1.5 = 1.2 \text{ m}^2$
Rear	$0.7 \times 1.5 - (0.5 \times 0.8) = 0.65 \text{ m}^2$

3.3.5.2. Commodity storage requirements data

Data regarding the product which is to be stored inside the cold store that has to maintain inside the cold store.

Table 3. 5: Basic inside cold storage condition data

i.	Type of Commodities/Produce:	lemon, tomato, carrot
ii.	Ventilation (Air Changes/hour)	0.5-2
iii.	Max Storage period (months)	1-2
iv.	Daily loading rate (kg/day):	80
v.	Cold Chamber Dry bulb (DB in °C):	8-22 degree centigrade
vi.	Cold Chamber RH (%):	85-98

Table 3. 6: Temperature and relevant humidity and storage life for fruits, vegetables & root crops [28].

Product	Temperature °C	Relative Humidity (Percent)	Approximate Storage Life
Pepper	7-13	90-95	6-8 weeks
Avocados	13	85-90	2 week
Bananas, green	13-14	90-95	14 weeks
Tomatoes, mature-green	18-22	90-95	1-3 weeks
Mamey	13-15	90-95	2-3 weeks
Mangoes	13	85-90	2-4 weeks
Casaba	10	90-95	3 weeks
Sweet Potatoes	13-15	85-90	4-7 months
Papayas	7-13	85-90	1-3 weeks
Persian	7	90-95	2 weeks

3.3.6. Selection of cooling pad thickness

As part of the general requirements, the efficiency of an active evaporative cooler depends on the rate and amount of evaporation of water from the cooling pad. This is dependent upon the air velocity through the fan, pad thickness and the degree of saturation of the pad, which

is a function of the water flow rate wetting the cooling pad. An effective cooling thickness pad depending on the amount of supply air from the fan and the amount of water rate the effective thickness of pad 20mm – 60mm[25].

In this work, natural fiber local name of kusha type of cooling pad of 0.03 m thickness was selected for an efficient performance of the evaporative cooling system as it has good water holding capacity and high moisture content.

3.3.7. The total cooling load calculation

The air inside a cabinet receives heat from a number of sources if the temperature and humidity of the air are to be maintained at a desired level this heat must be removed. The amount of heat must be removed is called the cooling load. The cooling load must be determined because it is the basis for selection of the proper size of cold storage equipment and distribution system.

3.3.7.1. Heat transmission through walls

The conduction heat transfer through the wall or roof will depend on the thickness and thermal conductivity of the material used. In addition, there will be convection and radiation from both the outside and inside surfaces. Hence steady state heat transfer is expressed in terms of an overall heat transfer coefficient U and the overall temperature difference between the outside and inside $\Delta T=(T_o-T_i)$. A wall is composite, consisting of many sections of different construction and insulating material.

Heat transfer coefficient U is the reciprocal of the total thermal resistance. The heat transfer through the cold storage building is the total amount of heat that gain through the walls, windows, ceiling, and floor of the cabinet room per unit of time [26].

$$\text{Heat Gain} = (U) \times (A) \times (T_o - T_i) \text{ (W)} \quad (3.9)$$

Where:

A = The outside surface area of cold storage (m^2)

U = The overall heat transfer coefficient ($W/m^2\text{ }^\circ C$)

T_i = The inside air temperature of cold storage ($^\circ C$)

T_o = Outside atmosphere air temperature ($^\circ C$)

Determination of overall heat transfer coefficient (U)

$$(R) = R_0 + ((R_1) + (R_2) + \dots + (R_n)) \quad (3.10)$$

$$U = \frac{1}{R} \quad (3.11)$$

Where:

U = The overall heat transfer coefficient (W/m²oC)

R = Total thermal resistance of wall (m²oC/W)

R_i = Thermal resistance through the inside layer of air (m²oC/W)

R_o = Thermal resistance through the outside layer of air (m²oC/W)

R_1 = Thermal resistance layer 1 (m²oC/W)

R_2 = Thermal resistance layer 2 (m²oC/W)

The cold storage walls consisting of 10 mm thick sheet metal at outer side then 40 mm thick of fiber glass as insulation and 4 mm thick Aluminum sheet metal at inner side based on the availability. For all front, left side, right side and rear walls.

For this project the experiment tested at Bahir Dar, the ambient temperature of Bahir Dar from four year average meteorology data 29°C, the wet bulb temperature depends of the speed of fan 1440 rpm and the temperature of cold storage which is obtained from the standard Table 3.5 take the average 15°C [28].

The total resistance from equation (3.10)

$$R = R_1 + R_2 + R_3 \quad (3.12)$$

$$R = \frac{l_1}{A_1 k_1} + \frac{l_2}{A_2 k_2} + \frac{l_3}{A_3 k_3} \quad (3.13)$$

Where l is thickness of insulation materials, A area of material k thermal conductivity of the material

$$R = 6.82 \times 10^{-6} + 0.244 + 5.67 \times 10^{-5}$$

$$R = 0.2441$$

$$U = 1/R$$

$$U = 4.1 \text{ W / m}^2\text{oC}$$

Heat transfer through the front face having the area of 1.05 m²

$$Q = 4.1 \times 1.05 \times (29 - 15)$$

$$Q = 60.27 \text{ W}$$

Heat transfer through the front right side having the area of 1.2 m²

$$\begin{aligned}
 U &= 1/R = 4.1 \text{ W / m}^2\text{C} \\
 Q &= 4.1 \times 1.2 \times (29 - 15) \\
 Q &= 68.88 \text{ W}
 \end{aligned}$$

Heat transfer through the left side having the area of 1.2 m²

$$\begin{aligned}
 U &= 1/R = 4.1 \text{ W / m}^2\text{C} \\
 Q &= 4.1 \times 1.2 \times (29 - 15) \\
 Q &= 68.88 \text{ W}
 \end{aligned}$$

Heat transfer through the rear having the area of 0.65 m²

$$\begin{aligned}
 U &= 1/R = 4.1 \text{ W / m}^2\text{C} \\
 Q &= 4.1 \times 0.65 \times (29 - 15) \\
 Q &= 37.31 \text{ W}
 \end{aligned}$$

Heat transmission through all the cabinet walls is the sum of total heat gain

$$\begin{aligned}
 Q &= (60.27 + 68.88 + 68.88 + 37.31) \text{ W} \\
 Q &= 235.34 \text{ W}
 \end{aligned}$$

3.3.7.2. Heat transmission through ceiling

The cold storage chamber ceiling is consisting of different layer of material so that overall heat transfer coefficient is calculated on the basis of given criteria and then heat transfer in equation (3.14) is calculated as [29].

$$Q = UA (T_o - T_i) \text{ W} \tag{3.14}$$

Where

- A = Surface area of the cabinet (m²)
- U = Over all heat transfer coefficient (W/m² °C)
- T_i = Inside temperature of cold storage air (°C)
- T_o = Outside temperature of atmosphere air (°C)

Heat transfer through the ceil having the area of 0.56 m²

$$\begin{aligned}
 U &= 1/R = 4.1 \text{ W / m}^2\text{C} \\
 Q &= 4.1 \times 0.56 \times (29 - 15) \\
 Q &= 32.144 \text{ W}
 \end{aligned}$$

3.3.7.3. Fruit and vegetable load

Commodity warmer than the conditioned space. When loaded at the cold storage space where it will cool up to the required temperature. Specific heat multiplied by mass and temperature difference gives potatoes cooling load [17].

$$Q = (M) \times (C) \times (\Delta T) \quad (3.15)$$

Where

Q = The quantity of heat in W

M = The mass of the product in kg/day from section 3.3.4

C = The specific heat of vegetables above freezing kJ/kg.K from table (3.2)

ΔT = Temperature difference ($^{\circ}\text{C}$)

Cooling load of carrot

$$M = 80 \text{ kg / day}$$

$$C = 3.24 \text{ kJ / kg K}$$

$$Q = (M) \times (C) \times (\Delta T)$$

$$Q = 80 \times 3.24 \times (29 - 15)$$

$$Q = 42 \text{ W}$$

Cooling load of pepper

$$M = 80 \text{ kg / day}$$

$$C = 3.93 \text{ kJ / kg K}$$

$$Q = (M) \times (C) \times (\Delta T)$$

$$Q = 80 \times 3.93 \times (29 - 15)$$

$$Q = 51 \text{ W}$$

Cooling load of tomato

$$M = 80 \text{ kg}$$

$$C = 3.78 \text{ kJ / kg K}$$

$$Q = (M) \times (C) \times (\Delta T)$$

$$Q = 80 \times 3.78 \times (29 - 15)$$

$$Q = 49 \text{ W}$$

Selected the maximum load from the commodity load to calculate the total cooling load.

3.3.7.4. Respiration load

Fruits and vegetables are still alive after harvesting and continue to undergo changes while in storage the more important of these changes are produced by respiration, a process during which oxygen from the air combine with the carbohydrates in the plant tissue and results in the release of CO_2 and heat. The heat release called respiration heat. In such case heat gain is compute by the following equation[26].

$$Q = (M) \times (\text{Respiration heat}) \quad (3.16)$$

Where

Q = Quantity heat in W

M = Mass the product in kg

Take the average heat of respiration which is obtained from the standard table 3.7

Cooling load of carrot

$$M = 80\text{kg}$$

$$\text{Heat of respiration} = 0.0905\text{W / kg}$$

$$Q = 80\text{kg} \times 0.0905\text{W / kg}$$

$$Q = 7.24 \text{ W}$$

Table 3. 7: Heat of respiration of products [30]

Product	5°C (mW/kg)	25°C(mW/kg)
peppers	13–36	44–167
Strawberries	48–98	303–581
Broccoli	102–475	825–1011
Cabbage	22–87	121–437
Carrots	20–58	64–117
Cherries	28–42	83–95
Lettuce	39–87	169–298
Watermelon	*	51–74
Mushrooms	211	782–939
Onions	10–20	50
Peaches	19–27	176–304
Plums	12–27	53–77
Potatoes	11–35	13–92
Tomatoes	*	71–120
Mango	10-22	75-151
Lemon	7-10	20-28

Cooling load of pepper

$$M = 80\text{kg}$$

$$\text{Heat of respiration} = 0.024\text{W / kg}$$

$$Q = 80 \times 0.024\text{W / kg}$$

$$Q = 1.92\text{W}$$

Cooling load of tomato

$$M = 80\text{kg}$$

$$\text{Heat of respiration} = 0.0955\text{W / kg}$$

$$Q = 80 \times 0.0955\text{W / kg}$$

$$Q = 7.64\text{W}$$

3.3.7.5. Air change load

Air that enters a storage space must be cooled. Air needs to be renewed, and consequently there is a need for ventilation. When air enters the refrigerated space, heat must be removed from it.

$$ACL = (V) \times (ACH) \times (h_o - h_i) \times (\rho) \quad (3.17)$$

Where

ACL = Air change load due to door opening infiltration and ventilation etc. (W)

V = Volume of cold chamber

ρ = Density of commodity

ACH = Air change per hour

Subscripts o and i denote out and in, respectively.

The ACH value varies from 0.5 ACH for tight and well-sealed cold storage buildings to about 2.0 for loose and poorly sealed buildings. For modern buildings the ACH value may be as low as 0.2 ACD[20]. For this take the average of ACH 1.2. Corresponding to $T_0 = 15$ degree centigrade and 92% RH value of $h_i = 41$ kJ/kg same as $T_i = 29$ degree centigrade and 57% RH value of $h_o = 62$ kJ/kg

Air change load of carrot

$$\begin{aligned}
V &= 0.735 \text{ m}^3 \\
\rho &= 320 \text{ kg / m}^3 \\
ACD &= 1.25 \\
(h_o - h_i) &= 26 \text{ kJ / kg} \\
ACL &= (V) \times (ACD) \times (h_o - h_i) \times (\rho) \\
ACL &= 0.735 \times 1.25 \times (62 - 41) \times 320 \\
ACL &= 71.45 \text{ W}
\end{aligned}$$

Air change load of pepper

$$\begin{aligned}
V &= 0.735 \text{ m}^3 \\
\rho &= 1032 \text{ kg / m}^3 \\
ACH &= 1.25 \\
(h_0 - h_i) &= 26 \text{ kJ / kg} \\
ACL &= (V) \times (ACH) \times (h_o - h_i) \times (\rho) \\
ACL &= 0.735 \times 1.25 \times (62 - 41) \times 342 \\
ACL &= 76.4 \text{ W}
\end{aligned}$$

Air change load of tomato

$$\begin{aligned}
V &= 0.84 \text{ m}^3 \\
\rho &= 970 \\
ACD &= 1.25 \\
(h_o - h_i) &= 26 \text{ kJ / kg} \\
ACL &= (V) \times (ACH) \times (h_o - h_i) \times (\rho) \\
ACL &= 0.735 \times 1.25 \times (62 - 41) \times 970 \\
ACL &= 216.6 \text{ W}
\end{aligned}$$

3.3.7.6. Power Loads

In cold storage applications use various equipment's such as fans and pump which add significantly to the heat gain[29].

$$Q = 2545 * (P / Eff) * FUM * FLM \quad (3.18)$$

Where

P =Horsepower rating from electrical power plans or manufacturer's data

Eff =Equipment motor efficiency, as decimal fraction

FUM =Motor use factor (normally =1.0)

FLM =Motor load factor (normally =1.0)

Note: FUM =1.0, if operation 24 hours

In this situation the total power is transferred as heat to the room

Power Loads of Fan

$$Eff = 0.75$$

$$P = 35W$$

$$Q = 2545 * (P / Eff) * FUM * FLM$$

$$Q = 2545 * (P / Eff) * 1 * 1$$

$$Q = 1.06W$$

For two fan $Q = 2.12W$

Power loads of pump

$$Eff = 0.85$$

$$P = 50W$$

$$Q = 2545 * (P / Eff) * FUM * FLM$$

$$Q = 2545 * (P / Eff) * 1 * 1$$

$$Q = 1.8W$$

$$Total\ equipment\ load = 3.16W$$

3.3.7.7. Convection heat transfer effect on cold storage

Heat transferred from the wall of cold storage to the cabinet air, it led to Newton's cooling law equation.

$$Q = hA(T_w - T_c) \tag{3.19}$$

Where

h- Convective heat transfer coefficient obtained from dimensionless number using film temperature calculated in section 3.4.4

A- area of the cabinet

T_w- wall temperature of cold storage

T_c- cabinet temperature

Convective heat transfer from the wall of cold storage to cabinet becomes

$$Q = hA(T_w - T_c)$$

$$Q = 63.84w$$

3.3.7.8. Effect of solar radiation

Radiation is the energy emitted from a surface as particles or waves. The rate of radiative emission per unit time and per unit surface area, or radiative flux, is represented as Q . Note that this " Q " is actually power per unit area, or P/A ; it has different units than the " Q " for conduction.

Radiative flux on the 4th power temperature of the emitting surface:

$$Q = \epsilon \sigma (T_1^4 - T_2^4) \quad (3.20)$$

Where T is measured in Kelvins, ϵ emissivity and σ Stefan-Boltzmann constant
Emissivity (ϵ) is the ratio of a surface's ability to emit radiant energy compared with the ability of a perfect black body of the same area at the same temperature. Emissivity is a dimensionless constant having values between 0 and 1.

$$Q \propto \epsilon, 0 < \epsilon < 1$$

Table 3. 8: Emissivity of Some Common Materials [27]

Materials	Emissivity Values (no unit, dimensionless)
Carbon	0.85-0.95
Aluminum	0.11
Fiberglass	0.75
Stainless Plate	0.34
Stainless Steel	0.59
Steel: galvanized	0.28
Water: snow	0.85
Wood: planed	0.90
Wood: paneling, light finish	0.87

A constant to balance the equation Stefan's constant (σ) [also known as the Stefan-Boltzmann constant]

$$\sigma = 5.67 \times 10^{-8} \text{ W / (m}^2 \cdot \text{K}^4)$$

Putting this all together, Stefan's law (or the Stefan-Boltzmann law), which states that the radiative flux (Q) is equal to the emissivity times the fourth power of temperature in Kelvins times Stefan's constant:

$$Q = \epsilon \sigma (T_1^4 - T_2^4) \quad (3.20)$$

Where T_1 and T_2 are the ambient air temperature and cold storage temperature respectively.

The radiative flux (Q) calculated from equation (3.12)

$$\begin{aligned} Q &= \epsilon \sigma (T_1^4 - T_2^4) \\ Q &= 0.38 \times 5.67 \times 10^{-8} (302^4 - 289^4) \\ Q &= 29 \text{ w} \end{aligned}$$

Heat gain to cold storage due to radiation effect 29 w.

Cooling load = heat transfer through cold storage cabinet wall + air change load + product load + respiration load + equipment load + convective heat transfer effect + effect of radiation (3.21)

$$\begin{aligned} \text{Cooling Load} &= (267.5 + 29.5 + 51 + 216.6 + 3.16 + 63.8 + 29) \text{ w} \\ \text{Cooling Load} &= 660.56 \text{ w} \end{aligned}$$

This much amount of heat must be removed from cold storage to cool the stored fruits and vegetables based on the storage capacity.

3.4. Methods for estimating properties of moist air

In order to perform cold storage calculations, it is essential first to estimate various properties of air. It is difficult to estimate the exact property values of moist air as it is a mixture of several permanent gases and water vapor. However, moist air up to 3 atm. pressure is found to obey perfect gas law with accuracy sufficient for engineering calculations[20].

For higher accuracy Goff and Gratch tables can be used for estimating moist air properties. These tables are obtained using mixture models based on fundamental principles of statistical mechanics that take into account the real gas behavior of dry air and water vapor.

However, these tables are valid for a barometric pressure of 1 atm only. Even though the calculation procedure is quite complex, using the mixture models it is possible to estimate moist air properties at other pressures also. However, since in most cases the pressures involved are low, one can apply the perfect gas model to estimate psychrometric properties [22].

3.4.1. Important psychrometric properties

i. Dry bulb temperature

DBT the temperature of the moist air as measured by a standard thermometer or other temperature measuring instruments.

ii. Wet-bulb temperature (WBT)

It is the temperature a parcel of air would have if it were cooled to saturation (100% relative humidity) by the evaporation of water into it, with the latent heat being supplied by the parcel.

iii. Relative humidity

Relative humidity (RH), expressed in percent, is the ratio of actual partial pressure exerted by the water vapour in any volume of air to the partial pressure that would be exerted by the water vapour if the water vapour in the air is saturated at the temperature of the air, that is [26],

$$RH = \frac{\text{actual partial pressure}}{\text{partial pressure at saturation}} \times 100\% \quad (3.22)$$

iv. Enthalpy

The enthalpy of moist air is the sum of the enthalpy of the dry air and the enthalpy of the water vapour. Enthalpy values are always based on some reference value. For moist air, the enthalpy of dry air is given a zero value at 0°C, and for water vapour the enthalpy of saturated water is taken as zero at 0°C [20].

The enthalpy of moist air is given by

$$h = h_a + wh_g = c_p T + w (h_{fg} + c_{pw} T) \quad (3.23)$$

Where

C_p = Specific heat of dry air at constant pressure, kJ/kg.K

C_{pw} = Specific heat of water vapor/ kJ/kg.K

T = Dry bulb temperature of air-vapor mixture, °C

W = Humidity ratio, kg of water vapor/kg of dry air

h_a = Enthalpy of dry air at temperature T , kJ/kg

h_g = Enthalpy of water vapor at temperature T , kJ/kg

h_{fg} = Latent heat of vaporization at 0°C, kJ/kg

The unit of h is kJ/kg of dry air. Substituting the approximate values of c_p and h_g , we obtain:

$$h = 1.005T + w (2501 + 1.88T) \quad (3.24)$$

Water vapor in air behaves as if it existed alone and obeys the ideal-gas relation $PV = RT$. Then the atmospheric air can be treated as an ideal-gas mixture whose pressure is the sum of the partial pressure of dry air P_a and that of water vapor P_v [31]:

$$P = P_a + P_v \text{ (Kpa)} \quad (3.25)$$

v. Specific humidity (w)

The mass of water vapor present in a unit mass of dry air. This is called absolute or specific humidity (also called humidity ratio) and is denoted by w [31]:

$$w = \frac{\text{mass of vapor}}{\text{mass of air}} = \frac{m_v}{m_a} \text{ (Kg water vapor/kg dry air)} \quad (3.26)$$

vi. Dew-Point Temperature

The dew-point temperature T_{dp} is defined as the temperature at which condensation begins when the air is cooled at constant pressure. In other words, T_{dp} is the saturation temperature of water corresponding to the vapor pressure:

$$TDP = T_{sat} @ P_v \quad (3.27)$$

vii. Sensible Heat:

The heat used to change the temperature of the air. Sensible heat will always cause a change in the temperature of the substance.

viii. Latent heat:

Latent heat is the heat energy involved in the phase change of water. The heat will only change the structure or phase of the material without change to temperature.

3.4.2. Fan selection based on the cold storage size

Select a fan using the required air flow. The air flow of a mounted fan can be found from the fan's air flow vs. static pressure characteristics and the pressure loss of the object to be cooled. It is difficult to calculate the device's pressure loss, so an estimation for the maximum air flow of 1.3 to 2 times the required air flow may be used.

3.4.2.1. Fan selection details

Table 3. 9: fan selection specifications

Items		Letter	Specification
cabinet	Size	H	1.5m
		W	0.7m
		D	0.7m
	Total surface area	A	4.1 m ²
Materials			Steel, Aluminum & fiber glass
Over all heat transfer coefficient		U	4.1 W / m ² °C
Temperature difference		ΔT	14°C
Total heat generation/cooling load		Q	711.42w
Safety factor		S.f	1.15

Total cooling load, surface area and the overall heat transfer coefficient were calculate during cooling load calculation in section 3.3.7 and ΔT temperature difference of the ambient and cabinet temperature.

The volume of air flow required to cool the cold storage [32]can be determined from equation (3.28)

$$\dot{V} = k \left(\frac{Q}{\Delta T} - UxA \right)_{xs.f} \quad (3.28)$$

Where k coefficient factor take k = 0.02,[32]

$$\dot{V} = 0.02 \left(\frac{660.56w}{14} - 4.1 \times 4.1 \right) \times 1.15$$

$$\dot{V} = 0.78 \frac{m^3}{s}$$

This amount of flow rate of air required to cool the specified cabinet.

Based on the flow rate of the air fan selected from standard Appendix A Table A.4 with 2850 rpm and the diameter of fan blade 350mm.

The required air velocity (v)

$$v = \frac{\text{flow rate}}{\text{area of the pad}} \quad (3.29)$$

$$v = \frac{0.78 \frac{m^3}{s}}{0.84m^2} = 0.93 \frac{m}{s}$$

This amount of air velocity required which passes through wet surface of the pad

3.4.2.2. Fan power consumption

Fan power consumption is directly proportional to system flow rate and static pressure. For theoretically perfect efficiency, the minimum power required to move air against resistance is defined as[33]:

$$P = \frac{\dot{V} \times p}{6356} \quad (3.30)$$

Where

P = Horse power of fan

\dot{V} = volumetric flow rate (cubic meter per minute)

P = max static pressure of air created by fan from standard Appendix A Table A.4

From equation (19) fan power consumption becomes

$$P = \frac{\dot{V} \times p}{6356}$$

$$P = \frac{0.78 \frac{m^3}{s} \times 196 \text{ pa}}{6356} = 0.024$$

This is minimum horse power needed to run the fan, but market available fan 0.047hp (35w) and the cooling pad area required two fan the total watt become 70w

3.4.3. Heat and mass transfer analysis on cooling pad

Basic Mathematical Model assumptions

- ✓ Cooler is insulated from the surrounding
- ✓ The system is adiabatic
- ✓ Specific heats are constant
- ✓ The cooling pad is a plain porous wall bounded by two convective fluids (air) at different temperature.
- ✓ Bulk water and air/water interface have the same temperature
- ✓ The surface of the pad is completely wet
- ✓ The cooling pad is rigid

On the assumption that the cooling pad is a plain porous wall bounded by two convective fluids (air) outside the pad surface and inside the cooler, each at different temperature, the elementary sensible heat flux in terms of overall temperature and thermal properties of the pad as shown in the figure below.

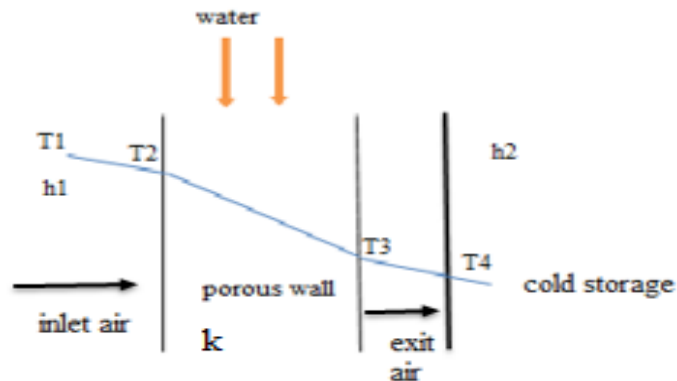


Figure 3. 7: Scheme of the heat transfer process across the porous evaporative cooling pad

Basic model equations

$$Q = h_1 A (T_1 - T_2) \quad (3.31)$$

$$Q = \frac{A(T_2 - T_3)}{X/K} \quad (3.32)$$

$$Q = h_2 A (T_3 - T_4) \quad (3.33)$$

The heat balance for the three equations gave

$$Q = \frac{A(T_1 - T_4)}{\frac{1}{h_1} + \frac{X}{K} + \frac{1}{h_2}} \quad (3.34)$$

Where h_1 and h_2 are the convective heat transfer coefficient, A is the area of the pad, k is the thermal conductivity of the pad, x is the thickness and T is the temperature.

Based on the atmospheric pressure 101.325kpa and the average temperature of Bahir dar 29°C with the flow velocity of 0.93m/s which is delivered by the fan over the area of the pad 1.5m x 0.7m flat surface whose temperature is the wet bulb temperature of the pad.

The heat transfer coefficient h determined from the Nusselt number (Nu) expressed as a function of the Reynolds number (Re) and Prandtl number (Pr).

The convective heat transfer coefficient is calculated from the Nusselt number as follows[34]

$$Nu = \frac{hl}{K} \quad (3.35)$$

Where k is the thermal conductivity of air, l is the characteristic length and is given by as

$$l = v/A \quad (3.36)$$

Where v is the volume occupied by the pad

Correlation to determine the heat transfer coefficient for a rigid evaporative media as

$$Nu = 0.1\left(\frac{l}{X}\right)^{0.12} Re^{0.8} Pr^{0.33} \quad (3.37)$$

Where the Reynolds number Re is given by[34]

$$Re = \frac{Vl}{\nu} \quad (3.38)$$

Where V is the air speed, ν is the kinematic viscosity also the Prandtl number Pr l thickness of the pad

The critical Reynolds number for flat plat surface $Re_{cr} = 5 \times 10^5$

The film temperature of the air the average of the dry bulb temperature and wet bulb temperature

$$T_f = \frac{T_{db} + T_{wb}}{2} \quad (3.39)$$

$$T_f = \frac{29+16}{2} = 23^{\circ}C$$

The properties of air at 23°C[35]

$$k = 0.02613 \frac{w}{mK} \quad \nu = 15.12 \times 10^{-6} \frac{m^2}{s} \quad pr = 0.702$$

Reynolds number from equation (3.38)

$$Re = \frac{V l}{\nu}$$

$$Re = \frac{0.93 \times 0.03}{15.12 \times 10^{-6}} = 1845.3$$

Thus, the flow is laminar

Nusselt number from equation (3.37)

$$Nu = 0.1 \left(\frac{l}{X} \right)^{0.12} Re^{0.8} Pr^{0.33}$$

$$Nu = 36.5$$

Then the convective heat transfer coefficient is calculated from the Nusselt number

$$Nu = \frac{h l}{K}$$

$$h = \frac{Nu \times k}{l} = \frac{36.5 \times 0.02613}{0.03} = 31.8 \frac{w}{m^2 \cdot ^{\circ}C}$$

Which is the exterior heat transfer coefficient of air at the outside of the cold storage

In similar way the internal side film temperature to calculate h₂ the properties of air at the film temperature of wet bulb temperature and cold storage dry bulb temperature from equation (3.39).

$$T_f = \frac{T_{db} + T_{wb}}{2}$$

$$T_f = \frac{18+16}{2} = 17^{\circ}C$$

The properties of air at 17 °C[35]

$$k = 0.02487 \frac{w}{mK} \quad \nu = 14.43 \times 10^{-6} \frac{m^2}{s} \quad pr = 0.704$$

Reynolds number

$$Re = \frac{Vl}{\nu}$$

$$Re = \frac{0.93 \times 0.03}{14.43 \times 10^{-6}} = 1933.5$$

Thus the flow is laminar

$$Nu = 0.1 \left(\frac{l}{X} \right)^{0.12} Re^{0.8} Pr^{0.33}$$

$$Nu = 38$$

Then the convective heat transfer coefficient is calculated from the Nusselt number

$$Nu = \frac{hl}{K}$$

$$h = \frac{Nu \times k}{l} = \frac{38 \times 0.02613}{0.03} = 33 \frac{w}{m^2 \cdot ^\circ C}$$

The exterior heat transfer coefficient of air at the outside of the cold storage

Then the amount of heat transfer from the cooling pad from equation (3.34)

$$Q = \frac{A(T_1 - T_4)}{\frac{1}{h_1} + \frac{X}{K} + \frac{1}{h_2}}$$

$$Q = \frac{1.05(29 - 15)}{\frac{1}{31.8} + \frac{0.03}{0.12} + \frac{1}{33}}$$

$$Q = 49w$$

The total heat transfer through the given area of cooling pad

3.4.4. Mass balance on the cooling pad

An overall mass balance on water gives the water mass flow rate in terms of the humidity ratios of the entering and leaving air, w_1 and w_2 respectively, given by

$$m_{a1} + m_{v1} + m_v = m_{a2} + m_{v2} \quad (3.40)$$

$$\text{Dry air } m_{a1} = m_{a2} = m_a$$

$$\text{Humidity ratio } w = \frac{m_v}{m_a} \quad (3.41)$$

$$m_{v1} = w_1 m_{a1} \quad \& \quad m_{v2} = w_2 m_{a2}$$

Thus

$$m_v = m_a (w_2 - w_1) \quad (3.42)$$

Where M_a – mass of air and M_v mass water vapor

$$m_a = \rho_a VA \quad (3.43)$$

Where A- the area of the pad covered by each of the fan

V - Velocity of air delivered by fan

ρ - Density of air

The specific value of moist air varies appreciably, all calculation made on the basis of mass, not volume the flow rate of air. However the volume flow rates are often required for the selection of heating and cooling coil and fan. In those cases volume values based on measurements at standard conditions may be used for accurate results.

The value specified by ASHRAE for the density of standard air

$$\rho = 1.204 \text{ kg} / \text{m}^3$$

The mass flow rate air from equation (3.43)

$$m_a = \rho_a VA$$

$$m_a = 1.204 \text{ kg} / \text{m}^3 \times 0.93 \text{ m} / \text{s} \times 0.84 \text{ m}^2$$

$$m_a = 0.94 \text{ kg} / \text{s}$$

Thus the mass flow rate water vapor in terms of specific humidity determined using equation (3.42)

$$m_v = m_a (w_2 - w_1)$$

Specific humidity obtained from psychometric chart using the cabinet and ambient temperature and relative humidity from Appendix A , figure1.

$$m_v = 0.94 \text{ kg} / \text{s} (0.013 - 0.009)$$

$$m_v = 0.00376 \text{ kg} / \text{s}$$

3.4.5. Energy balance on the cooling pad

Simultaneous heat and mass transfer take place at the air–water interface. Analyzed the interface of air – liquid of direct evaporative cooling system, by energy conservation and gave the heat passing through the air -water interface.

Considering the flow of humid air close to a wet surface, the heat transfer will occur if the surface temperature T_1 is different from the draft temperature T_4 . If the absolute humidity (concentration) of the air close the surface w_s is different from the humidity of the draft w_a a mass transfer will also occur.

3.4.3.1. sensible heat

The quantity of heat loss by draft air and the cooling pad is equal to heat passing through air water interface. The overall energy balance on the process fluid and the cooling pad[36].

$$Q_s = hA(T_1 - T_4) \quad (3.44)$$

$$Q = Q_l + Q_s \quad (3.45)$$

Where Q - Total heat transfer in the pad

T_1 - Ambient average temperature

T_4 - Cabinet storage temperature

h - Convective heat transfer coefficient, calculated in equation (3.38)

A - Area of the pad

Thus from equation (3.44) sensible heat becomes

$$Q_s = hA(T_1 - T_4)$$

$$Q_s = 38w / m^2 c (1.4m \times 0.7m) (29^\circ c - 15^\circ c)$$

$$Q_s = 521.4w$$

The quantity of heat loss by draft air and the cooling pad 521.4w, thus this amount of heat loosed during mixing of water and air in cooling pad.

3.4.3.2. Latent heat analysis

By analysis of the interface air-liquid, the latent heat Q_L is determined by the energy conservation law from equation (3.44)

$$Q_l = Q - Q_s = h_v m_v \quad (3.46)$$

Where Q is the flow of total heat and h_v is the specific enthalpy of vaporization of the water at surface temperature, then substitute rearrange the above equation.

$$Q = hA(T_1 - T_4) + h_v m_a (w_2 - w_1) \quad (3.47)$$

h_v Obtained from the equation (3.34)

$$h_v = 1.005T + w(2501 + 1.88T) \quad (3.48)$$

Where T – Temperature of moist air

W = Specific humidity moist air

$$h_v = 1.005 \times 16 + 0.013 (2501 + 1.88 \times 16)$$

$$h_v = 48.98 \text{ kJ / kg}$$

$$QL = h_v m_v$$

$$QL = 48.98 \text{ kJ / kg} \times 0.00376 \text{ kg / s}$$

$$QL = 184.2 \text{ w}$$

The total heat flow rate become

$$Q = Q_s + QL \tag{3.49}$$

$$Q = (521.4 + 184.2) \text{ w}$$

$$Q = 705.6 \text{ w}$$

The total quantity of heat loss by draft air and the cooling pad 705.6w, thus this amounts of heat loosed during mixing of water and air in cooling pad to evaporate water and deliver to cold storage.

3.4.6. Energy exchanging analysis from stored vegetables to circulating water

Liquid flow through the pipes is commonly used in heating and cooling applications. The fluid in such applications is forced to flow by using fan and pump through a tube and pad that is sufficiently long to accomplish to the desired heat transfer.

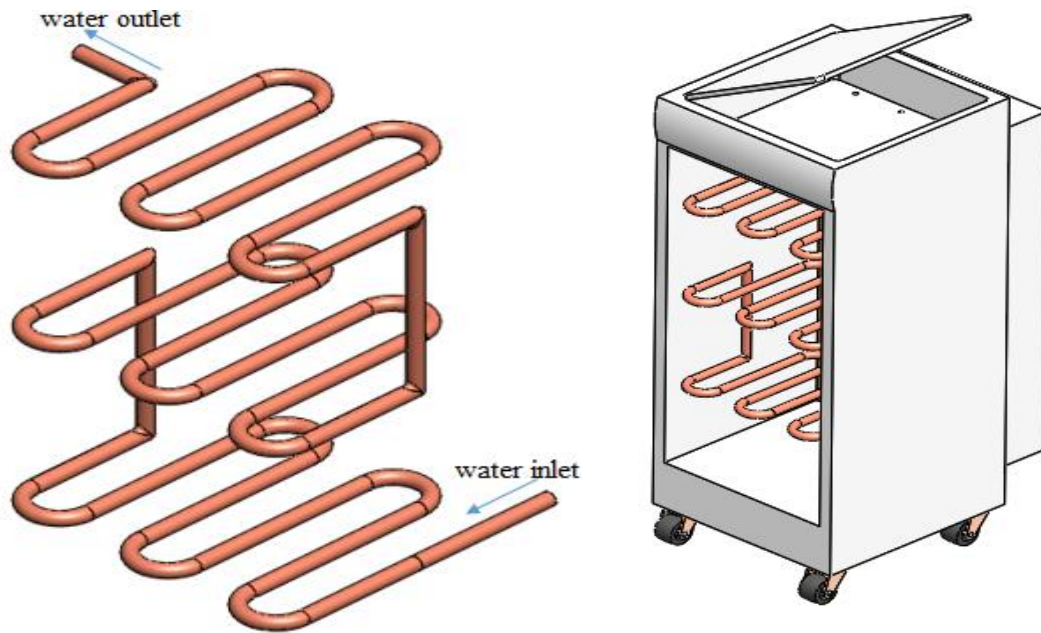


Figure 3. 8: water circulation pipe and its arrangement inside cold storage

As shown in figure 3.8 water circulate in a pipe inside the cold storage with a specified height gap at the flow rate which is delivered by the pump the length the pipe depends on the capacity of cold storage area.

Diameter of copper pipe

Using small diameter pipes instead of one large diameter pipe will provide high heat transfer area and copper has high thermal conductivity. For this heat exchanger 10mm outer diameter and 0.61mm thick commercially available copper tube is selected.

$$d_o = 10mm \quad (3.50)$$

$$d_i = 9.39mm$$

Required length of copper tube

The required length of the coil depends on capacity of the cold storage area from equation (3.3) the height of cabinet 1.4m the coiled tube started from 0.3m bottom and end 1.1m, thus the required area becomes

$$A = \text{usage height} \times \text{Depth} \quad (3.51)$$

$$A = 0.8m \times 0.7m$$

$$A = 0.56m^2$$

Length (L)

$$L = \frac{A}{\pi d_i}$$

$$(3.52)$$

$$L = \frac{0.56m^2}{\pi \times 0.00939}$$

$$L = 18.98m \approx 20m$$

The conservation of energy equation for the steady flow of a fluid in a tube can be expressed

$$Q = mc_p (T_e - T_i) \quad (3.53)$$

Where T_i and T_e are the mean fluid temperatures at the inlet and exit of the tube, respectively, and Q is the rate of heat transfer to or from the fluid. Note that the temperature of a fluid flowing in a tube varies along the length of tube due to energy interactions through the wall of the tube.

The thermal conditions at the surface can usually be approximated with reasonable accuracy to be constant surface temperature ($T_s = \text{constant}$) or constant surface heat flux ($q_s = \text{constant}$). The thermal conditions at the surface can usually be approximated with reasonable accuracy to be constant surface temperature ($T_s = \text{constant}$) or constant surface heat flux ($q_s = \text{constant}$). For example, the constant surface temperature condition is realized when a phase change process such as boiling or condensation occurs at the outer surface of a tube[37]. For this case the constant surface heat flux condition is realized when the tube is subjected to radiation and cooling uniformly from all directions. Constant surface heat flux ($q_s = \text{constant}$) can be calculated as:

$$Q = A_s q_s = mc_p (T_e - T_i) \quad (3.54)$$

Note that the mean fluid temperature increases linearly in the flow direction in the case of constant surface heat flux, since the surface area increases linearly in the flow direction (A_s is equal to the perimeter, which is constant, times the tube length). Then, the mean fluid temperature at the tube exit becomes

$$T_e = T_i + \frac{Q}{mc_p} \quad (3.55)$$

Where Q heat transfer through cooling pad 49w from equation (3.12) plus total cooling load 660.56w from equation (3.34) already calculated during cooling load calculation and m is mass flow rate of water $Q = 709.56\text{w}$.

3.4.6.1. Pumping energy requirements analysis

The energy of a pump for a particular day can be determined in equation (3.56)

$$E = \frac{mgh}{\eta} \quad (3.56)$$

Where

m – Mass of water needed

g – Acceleration due to gravity (m/s^2)

h – The height from the pump to top water tank (m)

η – Efficiency of the system

E will be in joules, $1\text{joule} = 2.77778 \times 10^{-7} \text{ kWhr}$, since the fluid is water (density 1000 kg/m^3), m can replace by $1000V$ (where V is the volume of the water in m^3), $g = 9.81\text{m/s}^2$ and thus equation (3.41) becomes:

$$E = \frac{Vh}{367\eta} \text{ kWhr} \quad (3.57)$$

From equation (3.33) based on the mass flow rate of water vapor from the cooling pad, the amount of water needed per day becomes $m = 679\text{kg/day} = 679\text{litter/day}$ to keep the cooling pad wet and to create evaporation from the pad by supplying forced air.

The flow rate of the pump can be calculated as in equation (3.58)

$$\dot{Q} = \frac{24}{PSH} \times m_{\text{day}} \quad (3.58)$$

Where

\dot{Q} = water flow rate

m = amount of water per day

PSH = peak sunshine hour

PSH available and this can be obtained from weather data, the PSH is 6, then the real pump capacity should be from equation (3.58):

$$\dot{Q} = \frac{24}{6} \times 679\text{litter / day}, 1\text{litter / day} = 1.2 \times 10^{-8} \text{ m}^3 / \text{s}$$

$$\dot{Q} = 5.4 \times 10^{-5} \text{ m}^3 / \text{s}$$

Velocity of fluid (V)

$$Q = V \times A \quad (3.59)$$

$$V = \frac{Q}{A} \quad (3.60)$$

Where A area of the pipe, $D = 0.01\text{m}$

$$V = \frac{Q}{A}$$

$$V = \frac{5.4 \times 10^{-5} \text{ m}^3 / \text{s}}{\pi / 4 \times 0.01^2}$$

$$V = 0.69 \text{ m} / \text{s}$$

Mass flow rate m

$$\dot{m} = \rho v A \quad (3.61)$$

Where ρ density of water, v velocity of water and A area of pipe

$$m = \rho v A$$

$$m = 1000 \times 0.69 \times \pi \times \frac{0.01^2}{4}$$

$$m = 0.054 \text{ kg / s}$$

The mean fluid temperature at the tube exit becomes from equation (3.55)

$$T_e = T_i + \frac{Q}{m c_p}$$

$$T_e = 16 + \frac{711.42}{0.054 \times 4184} = 19^\circ \text{C}$$

The exit temperature become rise 2°C which is depends on environmental condition from the inlet water temperature.

Flow type

To determine the flow regime, the critical Reynolds number for tube surface $Re < 2300$ laminar, $Re > 4000$ turbulent [27].

The properties of water at the film temperature of inlet temperature and outlet temperature from equation (3.39).

$$T_f = \frac{T_e + T_i}{2}$$

$$T_f = \frac{16 + 18}{2} = 17^\circ \text{C}$$

The kinematic viscosity of water at film temperature 17 °C, $\nu = 1.006 \times 10^{-6} \text{ m}^2/\text{s}$
Reynolds number from equation (3.38)

$$Re = \frac{VD}{\nu}$$

Where ν kinematic viscosity

$$Re = \frac{0.69 \times 0.01}{1.006 \times 10^{-6}} = 6858.9$$

The flow is turbulent

3.4.6.2. Power requirements from solar panel

The amount of power required from the solar panel can be calculated from equation (3.57) by changing kWhr to kW.

$$P = \frac{E}{hr} = \frac{V}{hr} \frac{xh}{367\eta} \text{ kW} \quad (3.62)$$

$$P = \frac{Q_{hr} x h}{367\eta} \quad (3.63)$$

Where h length of coiled pipe, η efficiency of the pump

$$P = \frac{5.4 \times 10^{-5} \frac{m^3}{hr} \times 20m}{367 \times 0.3} = 35.3 \text{ watt}$$

3.4.6.3. Selection of PV array

The size of PV array has to have a relationship to the pump requirements. The depreciation of the panel due to ageing and environmental features (dust, etc). Take the depreciation of 40 percent is allowed for:

$$\begin{aligned} P_{array} &= 1.4 \times P \\ &= 1.4 \times 35.3W = 50W \end{aligned} \quad (3.64)$$

The pump required 50W power from PV panel to deliver the required amount of water to the coil.

3.4.6.4. Pressure Drop in water circulating tube

The analysis of tube flow is the pressure drop ΔP since it is directly related to the power requirements of the fan or pump to maintain flow. The pressure drops for all types of internal flows (laminar or turbulent flows, circular or noncircular tubes, smooth or rough surfaces)

Pressure drop due to friction

$$\Delta P = f \frac{L}{D} \frac{\rho v^2}{2} \quad (3.65)$$

Where f dimensionless quantity is the friction factor

L -height of from bottom to top tanker

D -Diameter of pipe

v -Velocity of water and ρ density of water

For f gives the friction factor for the fully developed laminar flow in a circular tube to be

$$f = (0.790 \ln Re - 1.64)^{-2} \quad (3.66)$$

$$f = (0.790 \ln 6858.9 - 1.64)^{-2}$$

$$f = 0.03$$

The pressure drop from equation (3.65)

$$\Delta P = f \frac{L}{D} \frac{\rho v^2}{2}$$

$$\Delta P = 0.03 \times \frac{1.9}{0.01} \times \frac{1000 \times 0.69^2}{2} = 1357 \text{ pa}$$



Figure 3. 9: Top view of water circulating copper tube

The pressure loss due to bend of pipe in this boiler is the sum of the pressure drop in 180° and 90° pipe bend. There are 3 shelf's each has 5 bends of 180° and 4 bends of 90° for one pipe line.

$$\Delta P_b = \frac{k_b \rho v^2}{2} \quad (3.67)$$

Where k_b – coefficient of bend

The value of k depends on:

- i. Angle of bend
- ii. Radius of curvature of bend
- iii. Diameter of the pipe

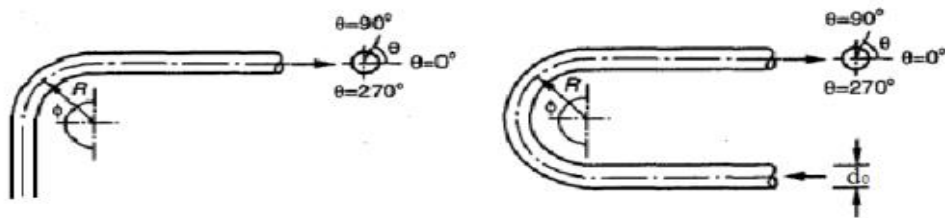


Figure 3. 10: 90° and 180° pipe bends [38]

Pressure loss due to 180° pipe bend

Centerline radius of bend = 0.12m

Internal diameter of pipe = 0.0939

Angle of pipe bend = 180°

Coefficient of bend from figure 3.11 $k_b = 0.45$, pressure loss due 180° bend from equation (3.67) becomes

$$\Delta P_{b,180^\circ} = \frac{k_b \rho v^2}{2}$$
$$\Delta P_{b,180^\circ} = \frac{0.45 \times 1000 \times 0.69^2}{2} = 107.122 \text{ pa}$$

Since there are 15 bends with 180° angle of bend for two stoves the total pressure drops becomes the sum of all bends.

$$\Delta P_{b,180^\circ} = 15 \times 107.122 \text{ pa}$$
$$\Delta P_{b,180^\circ} = 1,606.83 \text{ pa}$$

Pressure loss due to 90° pipes bend

Centerline radius of bend = 0.12m

Internal diameter of pipe = 0.0939

Angle of pipe bend = 90°

Coefficient of bend from figure 3.11, $k_b = 0.45$

$$\Delta P_{b,90^\circ} = \frac{k_b \rho v^2}{2}$$
$$\Delta P_{b,90^\circ} = \frac{0.4 \times 1000 \times 0.69^2}{2} = 95.22 \text{ pa}$$

There are 4 bends of 90°. The total pressure drop is the sum of all 90° bends

$$\Delta P_{b,90^\circ} = 4 \times 95.22 \text{ pa}$$
$$\Delta P_{b,90^\circ} = 380.88 \text{ pa}$$

The total pipe bend pressure drop becomes the sum of the pressure drops in 90° and 180° bends.

$$\Delta P_{b,T} = \Delta P_{b,90^\circ} + \Delta P_{b,180^\circ} \tag{3.68}$$
$$\Delta P_{b,T} = 380.88 \text{ pa} + 1606.83 \text{ pa}$$
$$\Delta P_{b,T} = 1,987.71 \text{ pa}$$

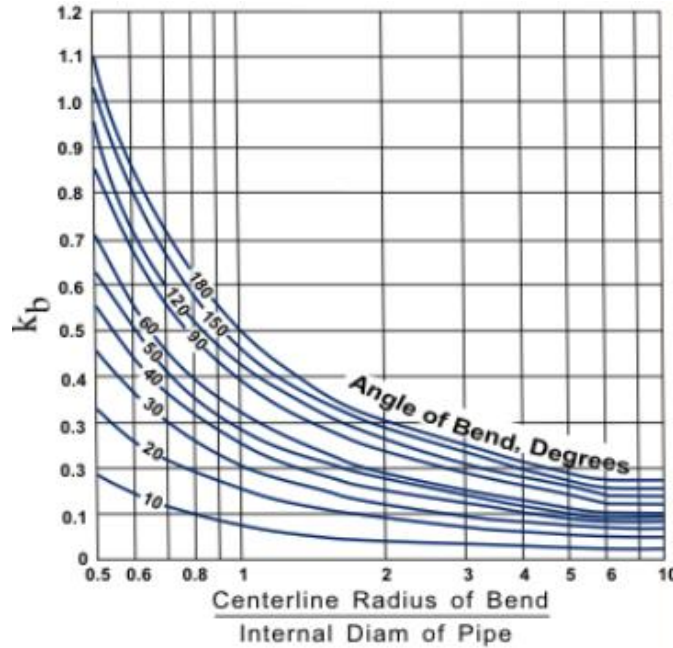


Figure 3. 11: coefficient of pipe bends [39]

The total pipe pressure drop becomes the sum of friction and the pressure drops in 90° and 180°

pipe bends

$$\Delta P_T = \Delta P_{b,90^\circ} + \Delta P_{b,180^\circ} + \Delta P_f \quad (3.69)$$

$$\Delta P_T = 380.88 \text{ pa} + 1606.83 \text{ pa} + 18,283 \text{ pa}$$

$$\Delta P_T = 20270.71 \text{ pa}$$

The minimum required power to circulate water through a coil is determined from the product of flow rate of water and pressure drop.

$$P = \dot{Q} \times \Delta P \quad (3.70)$$

The volume flow rate of flow (\dot{Q}) = $5.4 \times 10^{-5} \text{ kg/s}$, obtained from the equation (3.58)

The minimum required pumping power (P) from equation (3.70)

$$P = \dot{Q} \times \Delta P$$

$$P = 5.4 \times 10^{-5} \text{ kg / s} \times 20270.71 \text{ pa}$$

$$P = 1.2 \text{ w} \approx 50 \text{ w}$$

From the result it is clear that the inlet pressure of the water is higher than the total pressure drop. Then the water can easily flow throughout the cold storage circulating pipe system.

3.4.7. Efficiency of evaporative cooling

The efficiency of direct evaporative cooling can be calculated based on the mathematical value obtained.

From the overall energy balance on the process fluid and the cooling pad will be

$$Q = \left(\frac{(T_1 - T_4)}{\frac{1}{h_1} + \frac{X}{K} + \frac{1}{h_2}} \right) dA = m_a c_{pu} dT \quad (3.71)$$

The above equation can be integrated resulting in

$$\frac{1}{m_a c_{pu} \left(\frac{1}{h_1} + \frac{X}{K} + \frac{1}{h_2} \right)} \int_0^A dA = \int_{T_1}^{T_4} \frac{dT}{T_1 - T_4} \quad (3.72)$$

The integration will yield

$$-\left[\frac{1}{m_a c_{pu} \left(\frac{1}{h_1} + \frac{X}{K} + \frac{1}{h_2} \right)} \right] = \ln \left[1 - \frac{T_1 - T_4}{T_1 - T_w} \right] \quad (3.73)$$

In equation (3.73) $\frac{T_1 - T_4}{T_1 - T_w}$ is the evaporative cooling efficiency and is represented by ε

$$\varepsilon = \frac{T_1 - T_4}{T_1 - T_w} \quad (3.74)$$

Where ε - direct evaporative efficiency, %

T_1 - dry-bulb temperature of entering air, °C

T_4 - dry-bulb temperature of leaving air (cabinet temperature), °C

T_w - wet-bulb temperature of entering air, °C

The dry-bulb temperature of entering air obtained from weather data from appendix A –five year average data $T_1 = 29^\circ\text{C}$, dry-bulb temperature of leaving air (cabinet temperature) obtained from the standards fruit and vegetable storage temperature appendix A table 1, $T_4 = 18.4^\circ\text{C}$ and the wet bulb temperature obtained by using average dry-bulb temperature of entering air and the average relative humidity of the entering air, the read from psychometric table from appendix A figure 1, $T_w = 16.5^\circ\text{C}$.

Efficiency of evaporative cooling become

$$\varepsilon = \frac{29^{\circ}c - 18.4^{\circ}c}{29^{\circ}c - 16.5^{\circ}c}$$

$$\varepsilon = 84\%$$

Theoretical efficiency of the direct evaporative cooling using theoretical values become 84%, it will be compared with the experimental value.

3.5. Solar energy conversion

Solar energy conversion is done by using battery, inverter and charge controller. As sun light falls on solar panel, which converts into electrical energy by photoelectric effect. This electrical energy stored in battery in the form of chemical energy. Charge controller is employed in between solar panel and battery which prevents overcharging and may protect against overvoltage, which can reduce battery performance or lifespan, and may pose a safety risk. The stored energy directly can used for DC loads or else need to be converted AC (alternate current) by the help of inverter. Below shown figure explains solar energy conversion[4].

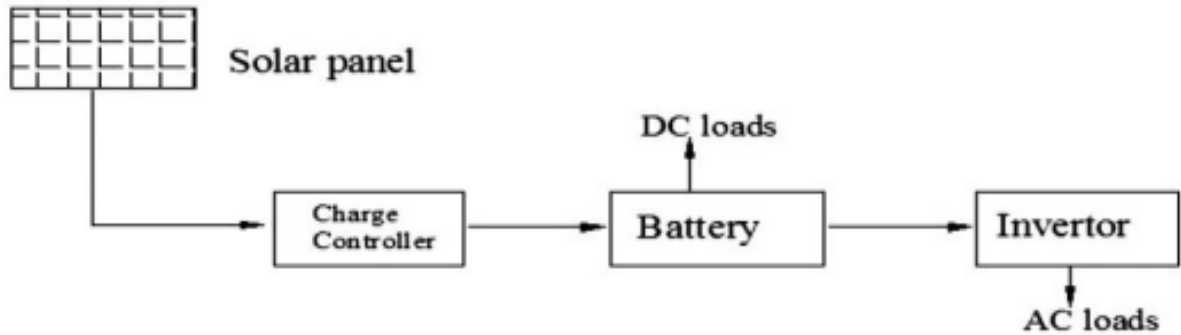


Figure 3. 12: Solar energy conversion process.

The converted energy is used to run the fan to deliver air on wet pad and pump deliver water to pad and circulating the water inside the cabinet and the fan covered with cooling pads, through which water is passed at a specific rate. As the fan sucks the hot air through cooling pads, heat transfer occurs between air and water thus generated cool air enters into the cold storage room.

The circulating water inside the cold storage carries heat from the stored fruits and vegetables and water circulate in a high thermal conductive coil to exchange energy from the stored vegetables and vice versa.

3.5.1. Solar energy analysis

The system was designed to provide 120 W, enough to power the cold storage unit with additional capacity to run cold storage room appliances such as to hot water during the cooling process. To generate this much power, the farm would need 120 W Sun Module solar panels, available from Solar World. These panels would be arranged on the best orientation. Additionally, there is the need for Emphases micro-inverters to quickly convert the DC current to AC, greatly reducing power loss. Both the panels and inverters come with many year warranty, and the panels are virtually indestructible.

Base condition: 2 fans (35 watts each) for a day, 1 micro pump (50watt) for recirculating water through the cabinet.

✓ The total energy requirement of the system (total load) i.e. Total connected load to PV panel system.

$$= \text{No. of units} \times \text{rating of equipment} = 2 \times 35 + 50 = 120 \text{ watts}$$

For safety factor due to cloud and night take the total amount of needed 200 watt

3.5.2. Capacity solar panel and battery required

Total watt-hours rating of the system

$$= \text{Total connected load (watts)} \times \text{Operating hours, take the operating hour 10 hr}$$

$$= 200 \times 10 = 2000 \text{ watt-hours}$$

Energy generating capacity of solar panel over a period of time:

To calculate the energy it can supply to the battery, multiply watts by the hours exposed to sunlight, then multiply the result by 0.85 (This factor allows for natural system losses).

For the solar 200 W panel in 10 hours exposed to sunlight:

$$P = 200 \times 10 \times 0.85$$

$$P = 1700 \text{ Whr}$$

The battery required based on the operating hour and the voltage obtained from the solar panel which is 12V the battery current becomes

$$I = \frac{\text{power}}{\text{voltage}}$$

$$I = \frac{1700Whr}{12V}$$

$$I = 141.667Ahr$$

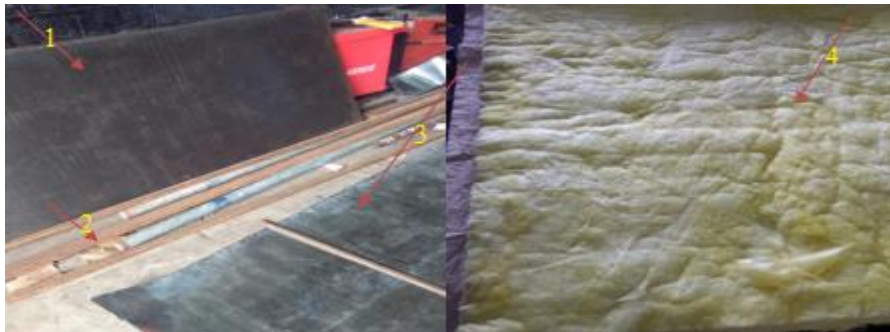
The available battery in a market 12V and 50, 100, 150,200A etc battery, based on the calculation value of current 150A and 12V battery selected.

Inverter size is to be selected as:

- ✓ Total connected load to PV panel system = 200 watts
- ✓ Inverter are available with rating of 600, 1000, 1500W etc.
- ✓ Therefore, the choice of the inverter should be 1000 W.

3.6. Prototype manufacturing process

To manufacture the cold storage used to different raw materials such as galvanized sheet metals for internal and external cover, rectangular hallow sheet metal for the Skelton of prototype, copper tube, fiberglass for insulation purpose.



- | | |
|------------------------------------|--------------------------------------|
| 1. Galvanized steel sheet metal | 3. Galvanized aluminum sheet |
| 2. Rectangular hallow sheet) metal | 4. Insulation material (fiber glass) |

Figure 3. 13: raw materials to construct prototype.

3.6.1. Equipment's/hand tools used to construct the prototype

Hand tools used in machine shop work are those tools which use hand power as their driving or turning force. Those tools fall into two categories'; cutting and non-cutting. The cutting tools are generally used to remove metal or cut special forms into metal. The non-cutting tools are generally used to hold or turn the work pieces.

i. Non-cutting tools

- ✓ *Bench vise*: is a work holding device used to hold work for such operations as sawing, filing chips, tapping and threading, etc.
- ✓ *Ball-peen hammer*: used for shaping the work materials.
- ✓ *Screw driver*: is used to tightening or loosening slotted head screws.
- ✓ *Wrench*: is used to tightening or loosening hexagonal bolt head or nut.
- ✓ *Plier*: are one of a hand tools, used to grip or hold various parts for assembly or adjustment.
- ✓ *Rivet gun*: is used to assemble two or more than two sheet metals by a rivet.

ii. **Cutting tools**

- ✓ Hack saw: is used to cut or separating work pieces to rough lengths for preparing grooves to be chiseled off and for making notches and incisions.
 - ✓ Files: is a process of removing and smoothing surplus materials to produce finished surfaces.
 - ✓ Snips: are scissor like devices with sharp blades used to cut sheet metals.
- Threading dies by hand: are used to cut external threads on round work

3.6.2. Measuring tools

- ✓ Tap rule: is the most common measuring tool used in machine shop, it is used where a fast measurement, which do not require a high degree of accuracy.
- ✓ Steel rule: is used to measure short length.
- ✓ Vernier caliper: are a precision measuring instruments used to measure inside outside and depth with a great accuracy.

3.6.3. Personal protective equipment

- ✓ Goggle: is used to protect our eyes from flying particles, and foreign Martials.
- ✓ Helmet: is used to cover our face, hairs from ultra violet and infra-red rays during the welding.
- ✓ Glove: is used to protect our hands
- ✓ Apron: is made from leather to protect our body from ultra violet ray and heat.
- ✓ Coverall: is used to protect all of our body except the face from dusts, grease, and oils.

- ✓ Safety shoe: is a protective reinforcement in the toe which protects the foot from falling objects or compression, usually combined with a mid-sole plate to protect against punctures from below.

3.6.4. Painting tools

- ✓ Mobile compressor
- ✓ Enamel paint (Anti-rust and White)
- ✓ Thinner: adding a suitable thinner will allow more viscous paint to flow freely through the siphon tube, metering valve (fluid) assembly, and nozzle.

3.6.5. Layout tools

- ✓ Scriber: is a tool used for marking layout lines on metal surface.
- ✓ Center punch: are used to mark holes that are used as a guide for drilling.
- ✓ Try square: is used to checking and layout lines parallel and at right angles to an edge and 45 degrees.

3.6.6. Machine used to construct prototype

- ✓ Portable Drilling machine,
- ✓ Manual Arc Welding machine,
- ✓ Circular cut off machine,
- ✓ Grinding machine,
- ✓ Sheet metal Rolling machine,
- ✓ Sheet metal circular saw machine, and
- ✓ Sheet metal bending machine.



1. Portable drilling machine
2. Grinding machine

3. Circular cut off machine

4. Manual arc welding machine

5. Sheet metal bending machine

Figure 3. 14: Some of machines used for constructing prototype.

Final subassembly and assemble of the prototype



a. Before painting

b. After painting

Figure 3. 15: before and after painting of assembly of the prototype

3.7. Feasibility of the developed project

Determining the economic feasibility of a cold storage unit requires analysis of the construction expenses and usage solar power to increase its affordability of cold storage. The total cost to the cold storage unit will be composed of three main categories;

- ✓ Materials for construction
- ✓ Solar panel with its accessories and
- ✓ Machine cost

All savings generated derive from the unit's reduction in electricity and increase affordability of cold storage used as refrigeration.

i. Materials cost for construction

Table 3. 10: List of material and their cost for construction

Item/Activity		Unit	Quantity	specification	Cost		
Materials					Unit	Total	
1	Sheet metal	Galvanized steel	Piece	6	2x1m, 0.8mm thickness	750	3500
		Galvanized aluminum	Piece		6x1m, 0.2mm thickness		700
2	Fiber glass		Piece	3	1x1m	400	600
3	RHS sheet metal		Piece	6	20x40cm, 1.5mm thick	250	1100
4	Copper tube				Diameter 10mm, length 20m		2000
5	Pump		Piece	1	50watt, 220V, and 3.5litter/min	1000	1000
6	Fan		Piece	2	35watt, 1440 rpm and blade of Ø350mm	750	1500
7	Caster wheel		Piece	4	Height of wheel 0.15m, dia 0.1m	100	400
8	Evaporative unit and its accessory						200
9	Revit		Packet	1	Diameter 4mm	100	100
10	Electrode		Packet	1	Diameter 2.5mm	180	180
11	Cutter disc, small		Piece	2	180x22.5mm	80	80
12	Cutter disc, large		Piece	1	340x22.5mm	170	170
13	Paint, antirust and white		packet	2		150	300
Total cost						11,830 birr	

ii. Solar panel with its accessories cost

Table 3. 11: Solar panel and its accessories cost

Item/Activity Unit	Unit	Quantity	specification	Cost	
				unit	Total
Materials				unit	Total
1	Solar panel (PV)	Piece	1	200W	4500
2	Battery	Piece	1	12V, 150A	6500
3	Invertor	Piece	1	1000W invertor, 12V to A.C	1500
4	Charge controller	Piece	1	50A, 12V	1000
5	Adapter	Piece	1		200
Total cost					13,500

iii. Machine cost

Table 3. 12: machine cost

Activities	Cost
Arc welding	100
Bending machine	50
Grinding machine	50
Drilling machine	100
Circular cut of machine	50
Total cost	350birr

iv. Labor cost

Table 3. 13: Labor cost

Labor	Cost per day	Days	Total cost
1	200	10	2000

3.7.1. Electricity power reduction/salvage

The solar panel system provides from section 3.5 solar energy analysis 612KWh per year, enough to power the cold storage unit based on the calculation of fan and pump power consumption. The solar system consists of solar panel, control system, battery and inverter,

both the inverter and solar panel come with a 20-year warranty, and the panels are virtually indestructible.

The cost to buy this much electricity at the current rate of a country (\$0.06/kWh) for 20 years was calculated. This cost is 12,096birr.

This means that the solar panel will save a minimum of 12,096birr on electricity over the 20-year warranty period, or 640.8birr/yr. additionally, the price of electricity from the grid is very likely to rise in the next 20 years, and, the equipment may last well beyond 20 years.

3.7.2. Salvage from fruits and vegetables

Total amount that the cold storage can hold is 80kg of fruits and vegetables and maximum period waited in a cold storage one month. Its obtained information by interview of consumers and merchants at the market 40-50% the product becomes spoiled specially on a hot season.



Figure 3.16: Pictures taken from market.

At the current market condition, the price of fruits and vegetables varies from 20-30 birr/kg, based on the capacity of the cold storage in a month total capacity 80kg out which 40-50% becomes spoiled. The total loss becomes 40kg, it becomes in birr 1200birr/month.

After installed the cold storage farmers, consumers, merchants, and investors will save 14400birr/year based on 80kg capacity of cold storage.

3.7.3. Payback period

The time in which the initial cost out flow of a cold storage is expected to recovered from the cash inflows generated by the cold storage, which means the cost reduced by PV panel from grid power payment and cost by avoiding the spoilage of fruits and vegetables.

$$\text{payback period} = \frac{\text{initial cost}}{\text{cash inflow / year}}$$

$$\text{payback period} = \frac{27,680\text{birr}}{15040.8\text{birr / year}}$$

$$\text{payback period} = 1.8\text{yrs}$$

From this solar powered evaporative cooling, reducing the spoilage of fruits and vegetables and also avoid grid power payment will pay back the total cost of the cold storage within 1.8yrs.

Chapter-four

Result and discussion

4.1. Model validation

An experimental test was conducted with natural fiber as the cooling pad material with inlet air velocities of 0.93m/s. The characteristic length of the pad is 30mm, height 1.4m and width of 0.7m. The pad was divided into two equal areas and an axial fan delivering 0.00376kg/s of water vapor at a pad face was mounted. The experiment was performed as shown in Figure 4.1.



Figure 4. 1: Pictures of experimental test set up of evaporative cooling.



Figure 4. 2: Experimental sample fruits and vegetables.



Figure 4. 3: Temperature and relative humidity measuring devices.



Figure 4. 4: picture taken during experimental result measurement.

4.2. Temperature and relative humidity variation

The performance of evaporative cooling system with a sample load to be cooled was evaluated daily at intervals of two hours from 8:00 am and 12:00 pm for 7 days as shown in Table 4.1.

Table 4. 1: temperature and relative humidity variation for ambient and cabinet

	hours	ambient		cabinet		
		temperature	RH%	temperature	RH%	WBT
day 1	2	23.7	71	17.8	75	16.5
	4	25.2	70	18.6	79	17
	6	28.9	69	19.9	83	18.4
	8	28.2	69	21.5	85	19
	10	26.5	70	20.7	88	19.5
	12	23	75	19.9	88	19.2

	hours	ambient		cabinet		
		temperature	RH%	temperature	RH%	WBT
day 2	2	22.5	73	17.3	83	17.2
	4	25.9	71	19	83	18.1
	6	27.9	69	20.2	85	19.2
	8	28.8	68	20.7	84	19
	10	24.6	72	19.2	87	19.1
	12	22.7	80	19.6	89	19.2
	day 3	2	24.2	72	18.4	82
4		26.5	71	19.1	85	18.7
6		29.8	66	22.7	86	19.8
8		27.2	70	21.2	85	19.2
10		25.6	73	19.3	89	17.8
12		25.1	77	19.2	89	17.7
day 4		2	18.9	79	16.8	84
	4	25.5	72	19.7	86	19.1
	6	28.2	69	22.1	86	20.3
	8	26.8	71	21.2	84	19.5
	10	24.9	78	19.9	87	19.2
	12	23.8	81	20.7	88	19.1
	day 5	2	20.2	79	16.5	82
4		23.6	75	18.2	85	17.6
6		24.5	71	19.3	88	18.9
8		24	76	20	87	19.2
10		23.9	80	19.7	90	19.2
12		23.8	82	19.6	91	19.3
day 6		2	21.5	78	16.3	83
	4	25.7	75	18.3	86	18.2
	6	27.4	69	20.1	86	19.3
	8	27.2	70	19.5	87	19.1
	10	24.3	76	18.7	85	18.4
	12	22.6	77	18.6	87	18.2

	hours	ambient		cabinet		
		temperature	RH%	temperature	RH%	WBT
day 7	2	19.6	73	16.2	81	15.8
	4	24.2	71	18.7	83	17.8
	6	26.7	69	20.2	83	19.8
	8	28.3	65	21.1	85	20.2
	10	25.2	70	19.8	84	19.3
	12	22.9	78	19.2	86	18.8

Within these periods of evaluating the performance of the cooling system, the ambient temperature kept on increasing with time changing, the cabinet temperature dropped and thereafter maintained an appreciable average low temperature value of about 17°C with time for the remaining testing period. However, the average temperature inside the cooling chamber varied from 16.2 – 22.1°C while in the ambient air temperature varied from 22.6 – 29.8°C.

As it is observed in Table 4.1 the evaporative cooling system temperatures were consistently lower than the ambient air temperatures during the hottest time of the day when insulation was appreciable and the evaporative cooling chamber relative humidity is 75 - 90% while at outside it was recorded 66 -80%.

The transient responses of the evaporative cooling system loaded for 7 days with fresh peppers, carrots and tomatoes during the testing period and the test results like relative humidity and the average temperature are shown in Table 4.2. Low temperatures are necessary to maintain the products in fresh conditions for a significantly longer period. These results clearly demonstrate that the evaporative cooling system can help to preserve perishable farm products for short term preservation especially, during the hottest times of the day when cooling is most needed.

4.3. Physiological weight loss during storage

It was observed that the weight loss of peppers, carrots and tomatoes was minimum when the commodities were stored in the evaporative cooling system chamber while it was maximum in ambient storage as presented in Figures 4.5 - 4.9. In Figure 4.6 it is observed that the shelf life of the vegetables used in the experiment increased by seven days by using the cabinet.



a. Cabinet

b. Ambient

Figure 4. 5: Physiological weight loss difference on a two days interval cabinet and ambient.



a. Cabinet

b. Ambient

Figure 4. 6: weight loss difference on a seven days of cabinet and four days of ambient.

Table 4. 2: Physiological weight loss peppers, carrot and tomatoes

Day	Cabinet		
	Carrot(kg)	Tomatoes(kg)	Peppers(kg)
1	0.75	1	0.5
2	0.75	1	0.45
3	0.73	0.98	0.43
4	0.71	0.9	0.43
5	0.69	0.92	0.42
6	0.69	0.9	
Day	Ambient		
	Carrot(kg)	Tomatoes(kg)	Peppers(kg)
1	0.75	1	0.5
2	0.71	0.91	0.35
3	0.65	0.79	0.3
4	0.5	0.73	0.25
5	0.43	0.65	0.25
6	0.37	0.62	

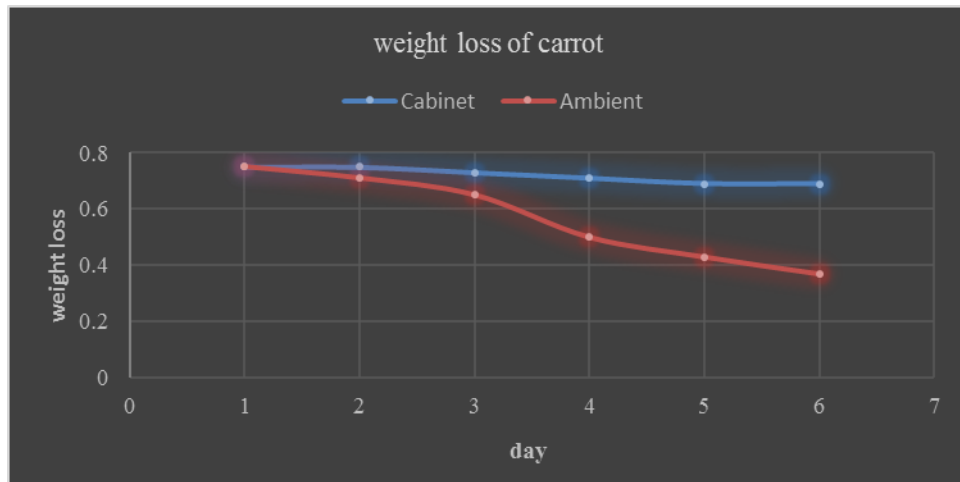


Figure 4. 7: Experimental result weight loss of carrot.

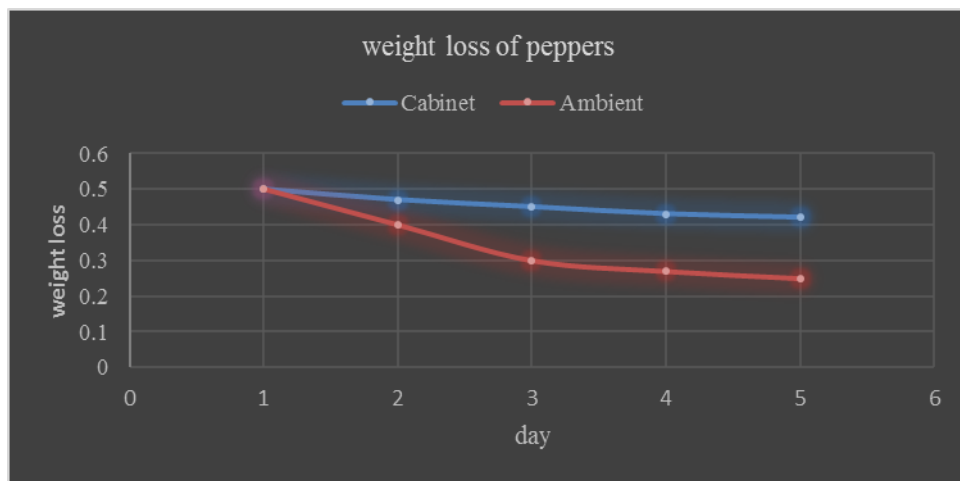


Figure 4. 8: Experimental result weight loss of peppers.

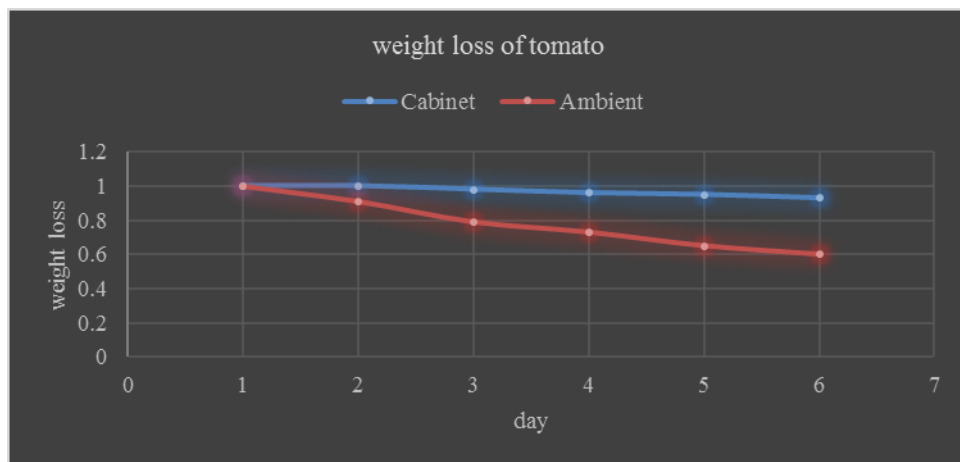


Figure 4. 9: Experimental result weight loss of tomatoes.

4.4. Evaporative cooling efficiency from experimental output

The evaporative efficiency and is represented by from equation (3.74)

$$\varepsilon = \frac{T_1 - T_4}{T_1 - T_w}$$

Where ε - direct evaporation efficiency, %

T_1 – ambient temperature, °C

T_4 - cabinet temperature, °C

T_w - wet-bulb temperature on pad, °C

From table 4.1 the average ambient temperature, cabinet temperature and wet bulb temperature becomes 25 °C, 19.6 °C and 18.4 °C respectively. Thus, the experimental cooling efficiency becomes

$$\varepsilon = \frac{25^\circ C - 19.6^\circ C}{25^\circ C - 18.4^\circ C}$$

$$\varepsilon = 82\%$$

The theoretical cooling efficiency from portion 3.4.7 had been calculated 84% and the experimental cooling efficiency 82% less than theoretical cooling efficiency, the difference might be due to air linkage.

Chapter-five

Conclusion and recommendation

5.1. Conclusion

This thesis work comprises of design, manufacturing, and experimental testing on solar powered evaporative cooling to create a comfort zone for fruits and vegetables to extend their shelf life. It is also affordable and can be used everywhere since its power source solar energy. The extension of shelf life of fruits and vegetables could be obtained by reducing the ambient temperature and at a higher level of relative humidity. In the present thesis, the shelf life of the vegetables used in the experiment was increased by seven days by using the cabinet.

Based on the quality of the stored items (vegetable samples) results obtained show that, the solar powered evaporative cooling system developed maintained a higher quality of preservation when compared to the mechanical multipurpose refrigerating system. Hence, the excessive chilling or freezing effects normally causes the spoilage of fruits and vegetables.

From the transient experimental test, the required storage temperature and relative humidity for the preservation of the selected vegetable samples was achieved a minimum temperature 16.2°C and the maximum relative humidity 90%.

In this solar power evaporative cooling system, as the stored products were exposed to their required storage temperatures and relative humidity's this system can be used for preservation of fresh vegetables with their quality still maintained for at least seven days.

From the economic feasibility of a cold storage unit requires analysis of the construction expenses and usage solar powered evaporative cooling, reducing the spoilage of fruits and vegetables and also avoid grid power payment will pay back the total cost of the cold storage within 1.8yrs.

The developed system is easy to operate, efficient and affordable most especially for farmers in developing countries like Ethiopia may find other methods of preservation quite unaffordable. It can preserve fresh vegetables, which if adopted will reduce post-harvest losses, and hence increase income generated from agricultural produce.

5.2. Recommendation

To increase its system efficiency and to generate the agricultural income the following points are recommended.

- ✓ The cold storage evaporative unit or pad needs to be replaced by new pad in 5 months, if possible, design of permanent pad is preferable and check with a variable pad thickness the experiment implemented only with a single pad thickness.
- ✓ It is better to install automatic control systems for the cold storage using different sensors to regulate the cabinet temperature and relative humidity.
- ✓ The recirculating water in a cold storage carries a heat from the stored fruits and vegetables and then stored at top tanker, to remove this heat from the water it is necessary to add heat exchanging unit.
- ✓ The components of cold storage could be constructed by costly sheet metals for internal and external cover. To reduce the cost it will be better to replace by cheap materials like different types of treated woods.

REFERENCES

- [1]. L.A. Chidambarama, A.S.R., G. Kamaraja, R. Velraj *Review of solar cooling methods and thermal storage options*. solar energy, 5 April 2011.
- [2]. Dipankar N. Basu a, A.G., *Solar thermal–photovoltaic powered potato cold storage – Conceptual design and performance analyses*. 4 January 2016.
- [3]. Camargo, J.R., *The use of fiber wood as evaporative pad packaging material*. August 18 – 21, 2010.
- [4]. Prakash¹, V.K.a.R., *MODELLING AND FABRICATION OF SOLAR POWERED AIR COOLER WITH COOLING CABIN FOR HOUSEHOLD FOOD ITEMS* International journal of Mechanical Engineering and Robotic Research 2014. **3**(3).
- [5]. M.P. Islam, T.M., *Evaluation of a new heat transfer and evaporative design for a zero energy storage structure*. 23 June 2015.
- [6]. Tashtoush, B., *Natural losses from vegetable and fruit products in cold storage*. 28 February 2000.
- [7]. Md. Parvez Islam, T.M., *A new zero energy cool chamber with a solar-driven adsorption refrigerator*. 2014. **72**.
- [8]. Liang Ma , M.Z.a., Bhesh Bhandari c, Zhongxue Gao, *Recent developments in novel shelf life extension technologies of fresh-cut fruits and vegetables*. 2017.
- [9]. M. C. Ndukwu, S.I.M., *Review of research and application of evaporative cooling in preservation of fresh agricultural produce*. 2014. **Vol. 7**(85).
- [10]. Amit M Patel, P.R.I.P., *Optimization of Different Parameter of Cold Storage for Energy Conservation*. 2012. **03**(02).
- [11]. Al-Azri, N.A., *Development of a typical meteorological year based on dry bulb temperature and dew point for passive cooling applications*. Energy for Sustainable Development, 2016(33).
- [12]. Susana C. Fonseca , F.A.R.O., Jeffrey K. Brecht *Modelling respiration rate of fresh fruits and vegetables for modified atmosphere packages: a review*.
- [13]. B.G Jahun¹, S.A.A., S. M. Musa³, Huzaifa Umar, *Assessment of Evaporative Cooling System for Storage of Vegetables*. International Journal of Science and Research, 2014.

- [14]. Kael Eggie, G.S.V.R., *DESIGN AND TESTING OF AN EVAPORATIVE COOLING SYSTEM USING AN ULTRASONIC HUMIDIFIER*. 2008.
- [15]. Tewodros, Y., *DESIGN AND FABRICATION OF A SMALL-SCALE EVAPORATIVE COOLING SYSTEM FOR PERISHABLE COMMODITIES* 2017.
- [16]. J.T. Libertya*, B.O.U., S.A Pukumab and C.E Odoc, *Principles and Application of Evaporative Cooling Systems for Fruits and Vegetables Preservation*. August 2013. **Vol.3**(No.3).
- [17]. R. A. Bucklin, J.D.L., D. B. McConnell, and E. G. Wilkerson, *Fan and Pad Greenhouse Evaporative Cooling Systems*. 2016.
- [18]. Gajanan Deshmukh*, P.B., Rupesh Datir and Saurabh Patel, *Thermal Insulation Materials: A Tool for Energy Conservation*. Journal of Food Processing & Technology 2017. **8**(4).
- [19]. Robert Kraemer, A.P., John Venn, *Design of a Small-Scale, Low-Cost Cold Storage System*. Biosystems Design Project, (BE 487).
- [20]. KHARAGPUR, F.I., *REFRIGERATION AND AIR CONDITIONING, USEFUL TRAINING MATERIAL FOR MECHANICAL ENGINEERING STUDENTS/COLLEGE, OR AS REFERENCE FOR ENGINEER*.
- [21]. Sue Bloomfield, R., *Batteries and Solar Power: Guidance for domestic and small commercial consumers*. BRE National solar centre, 2016.
- [22]. Vipin Das, N.M., Midhun Unnikrishnan, Nygin Jose, Rishikesh P, Suneeth Sukumaran, *Fabrication and Analysis of Solar Powered Air Cooler*. The International Journal Of Engineering And Science (IJES), 2016. **5**(1).
- [23]. B1 Stellenhof, V.R., *solar panel technical information guidelines solar flex*.
- [24]. A. Bhatia, B.E., *Principles of Evaporative Cooling System*. An Approved Continuing Education Provider, 2012.
- [25]. Taye S. Mogaji, a.O.P.F., *Development of an evaporative cooling system for the preservation of fresh vegetables*. African Journal of Food Science, 2011. **5**(4).
- [26]. Jitendra Jayant, A.S., *COOLING LOAD CALCULATION FOR A POTATO COLD STORAGE PLANT*. International Journal of Innovative Research in Engineering & Science, 2016. **3**(5).

- [27]. Ekwu, O.J.I.a.F.C., *thermal and physical properties of some tropical fruits and their juices in Nigeria*. Journal of Food Technology, 2009. 7(2).
- [28]. Paltrinieri, G., *HANDLING OF FRESH FRUITS, VEGETABLES AND ROOT CROPS*. FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS.
- [29]. Bhatia, A., *Cooling Load Calculations and Principles*. Continuing Education and Development, Inc.
- [30]. Kenneth C. Gross, C.Y.W., and Mikal Saltveit, *The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks*. Agricultural Research Service, 2016.
- [31]. edition, Y.A.C.M.A.B.T., *Thermodynamics An Engineering Approach*
- [32]. MLEZIVA, B., *Basic methods of fan selecting typical ventilation and cooling products based on their use*. 2012.
- [33]. BRIAN MLEZIV Greenheck Fan Corp. Schofeld, W., *Reducing power consumption by minimizing system pressure loss and choosing the right equipment*. Fan Selection and Energy Savings, August 2010.
- [34]. John Olukunle, N.m.c., S. I. Manuwa, saac B Oluwalana., *MATHEMATICAL MODEL FOR DIRECT EVAPORATIVE SPACE COOLING SYSTEMS*. 2013.
- [35]. C.P Kothandaraman, S.s., *Heat and Mass transfer data book*.
- [36]. C. D. Ebinuma, J.R.C., S. Cardoso, *A MATHEMATICAL MODEL FOR DIRECT EVAPORATIVE COOLING AIR CONDITIONING SYSTEM*.
- [37]. Incropera, F.p., *Fundamental of Heat and Mass transfer* 2007.
- [38]. Kakac, S., *Heat exchangers, selection, rating and thermal design. (2nded)*. Department of mechanical engineering. University of Miami. CRC press LLC., 2002.
- [39]. Ranaware, N.D.a.K.N.M., *A Review on Comparison Between Shell and Tube Heat Exchanger. India : IJIERT*. 2015. 2(2): p. 2394-3696.
- [40]. REGAL-BELOIT, *Axial Flow Fan And Centrifugal Fan selection*. 2015.

Appendix A

Table A. 1: Recommended temperature and relevant humidity and storage life for fruits, vegetables and root crops [28].

Product		Temperature °C	Relative Humidity (Percent)	Approximate Storage Life
Lime		9-10	85-90	6-8 weeks
Avocados		13	85-90	2 week
Bananas, green		13-14	90-95	14 weeks
Malanga		7	70-80	3 months
Mamey		13-15	90-95	2-3 weeks
Mangoes		13	85-90	2-4 weeks
Casaba		10	90-95	3 weeks
Crenshaw		7	90-95	2 weeks
Honeydew		7	90-95	3 weeks
Persian		7	90-95	2 weeks
Okra		7-10	90-95	7-10 weeks
Onion, green		0	95-100	34 weeks
Onion, dry		0	65-70	1-8 months
Onion set		0	65-70	6-8 months
Oranges, Calif. & Ariz		3-9	85-90	3-8 weeks
Oranges, Fla. & Texas		0-1	85-90	8-12 weeks
Papayas		7-13	85-90	1-3 weeks
Passion fruit		7-10	85-90	3-5 weeks
Pears		-1.5 to 0.5	90-95	1-2 weeks
Peas, green		0	95-98	6-8 weeks
Peppers, Chill (dry)		0-10	60-70	6 months
Peppers, Sweet		7-13	90-95	2-3 weeks
Pineapples		7-13	85-90	24 weeks
Plantain		13-14	90-95	1-5 weeks
Pummelo		7-9	85-90	12 weeks
Pumpkins		10-13	50-70	2-3 months
Sapodilla		16-20	85-90	2-3 weeks
Snow peas		0-1	90-95	1-2 weeks
Soursop		13	82-90	1-2 weeks
Spinach		0	95-100	10-14 days

Squashes, Summer		5-10	95	1-2 weeks
Squashes, winter		10	50-70	2-3 months
Sugar apples		7	85-90	4 weeks
Sweet Potatoes		13-15	85-90	4-7 months
Tamarinds		7	90-95	3-4 weeks
Tangerines, mandarins, & related citrus fruits		4	90-95	24 weeks
Taro root		7-10	85-90	4-5 months
Tomatoes, mature- green		18-22	90-95	1-3 weeks
Tomatoes, firm-ripe		13-15	90-95	4-7 days
Watermelons		10-15	90	2-3 weeks
White Sapote		19-21	85-90	2-3 weeks
Yams		16	70-80	6-7 months

Table A. 2: property values of metals at 20°C [27]

<i>Metal</i>	<i>Density</i> ρ <i>kg/m³</i>	<i>Thermal Diffusivity</i> $\alpha = k/\rho c$ <i>m²/s</i>	<i>Specific Heat</i> <i>c</i> <i>J/kg K</i>	<i>Thermal Conductivity</i> <i>k</i> <i>W/mK</i>
Lead	11393	23.43×10^{-6}	130	34.7
Magnesium, Pure	1746	97.08×10^{-6}	1013	171.3
Mg-Al (Electrolytic) (6-8% Al, 1.2% Zn)	1810	36.05×10^{-6}	1005	65.7
Manganese Steel (5% Mn)	7849	4.83×10^{-6}	460	22.0
Molybdenum	10220	47.90×10^{-6}	251	122.8
Nickel ; Pure (99.9%)	8906	22.66×10^{-6}	446	90.0
Nickel-Chrome (90% Ni, 10% Cr)	8666	4.44×10^{-6}	444	17.2
Nikrome (80% Ni, 20% Cr)	8314	3.43×10^{-6}	444	12.6
Nickel Steel (20% Ni)	7993	5.26×10^{-6}	461	19.1
Nickel Steel (40% Ni)	8169	2.79×10^{-6}	461	10.4
Nickel Steel (80% Ni)	8618	8.72×10^{-6}	461	34.7
Platinum, Pure at 27°C	21450	25.10×10^{-6}	133	71.6
Platinum-Rhodium alloy, (60% Pt, 40% Rh) at 27°C	16630	17.40×10^{-6}	162	47.0
Silver, Purest	10524	170.04×10^{-6}	234	419.0
Silver, Pure (99.9%)	10525	165.63×10^{-6}	234	406.8
Silicon Steel (5% Si)	7417	5.55×10^{-6}	460	19.0
Stainless Steels, AISI 302 at 27°C	8055	3.91×10^{-6}	480	15.1
Stainless Steels, AISI 304 at 27°C	7900	3.95×10^{-6}	477	14.9
Stainless Steel AISI 316 at 27°C	8238	3.48×10^{-6}	468	13.4
Stainless Steel AISI 347 at 27°C	7978	3.71×10^{-6}	480	14.2
Tin, Pure	7304	38.84×10^{-6}	226	64.1
Tungsten	19350	62.71×10^{-6}	134	162.7
Tungsten Steel, (1% W)	7913	18.58×10^{-6}	448	65.7
Tungsten Steel, (5% W)	8073	15.25×10^{-6}	435	53.6
Tungsten Steel, (10% W)	8314	13.91×10^{-6}	419	48.5
Wrought Iron (C < 0.5%)	7849	16.26×10^{-6}	461	58.9
Zinc, Pure	7144	41.06×10^{-6}	385	112.1

$1 \text{ W/mK} = 0.86 \text{ kcal/m hr}^\circ\text{C}$

$1 \text{ J/kgK} = 238.9 \times 10^{-6} \text{ kcal/kg}^\circ\text{C}$

Table A. 3: Thermal diffusivity of foods [2]

Food	Thermal Diffusivity, mm ² /s	Water Content, % by mass	Fat Content, % by mass	Apparent Density, kg/m ³	Temperature, °C	Reference
Fruits and Vegetables						
Apple, Red Delicious, whole ^a	0.14	85	—	840	0 to 30	Bennett et al. (1969)
dried	0.096	42	—	856	23	Sweat (1985)
Applesauce	0.11	37	—	—	5	Riedel (1969)
	0.11	37	—	—	65	Riedel (1969)
	0.12	30	—	—	5	Riedel (1969)
	0.14	30	—	—	65	Riedel (1969)
Apricots, dried	0.11	44	—	1323	23	Sweat (1985)
Bananas, flesh	0.12	76	—	—	5	Riedel (1969)
	0.14	76	—	—	65	Riedel (1969)
Cherries, flesh ^b	0.13	—	—	1050	0 to 30	Parker and Stout (1967)
Dates	0.10	35	—	1319	23	Sweat (1985)
Figs	0.096	40	—	1241	23	Sweat (1985)
Jam, strawberry	0.12	41	—	1310	20	Sweat (1985)
Jelly, grape	0.12	42	—	1320	20	Sweat (1985)
Peaches ^b	0.14	—	—	960	2 to 32	Bennett (1963)
dried	0.12	43	—	1259	23	Sweat (1985)
Potatoes, whole	0.13	—	—	1040 to 1070	0 to 70	Mathews and Hall (1968), Minh et al. (1969)
mashed, cooked	0.12	78	—	—	5	Riedel (1969)
	0.15	78	—	—	65	Riedel (1969)
Prunes	0.12	43	—	1219	23	Sweat (1985)
Raisins	0.11	32	—	1380	23	Sweat (1985)
Strawberries, flesh	0.13	92	—	—	5	Riedel (1969)
Sugar beets	0.13	—	—	—	0 to 60	Slavicek et al. (1962)
Meats						
Codfish	0.12	81	—	—	5	Riedel (1969)
	0.14	81	—	—	65	Riedel (1969)
Halibut ^c	0.15	76	1	1070	40 to 65	Dickerson and Read (1975)
Beef, chuck ^d	0.12	66	16	1060	40 to 65	Dickerson and Read (1975)
round ^d	0.13	71	4	1090	40 to 65	Dickerson and Read (1975)
tongue ^d	0.13	68	13	1060	40 to 65	Dickerson and Read (1975)
Beefstick	0.11	37	—	1050	20	Sweat (1985)
Bologna	0.13	65	—	1000	20	Sweat (1985)
Corned beef	0.11	65	—	—	5	Riedel (1969)
	0.13	65	—	—	65	Riedel (1969)
Ham, country	0.14	72	—	1030	20	Sweat (1985)
smoked	0.12	64	—	—	5	Riedel (1969)
smoked ^d	0.13	64	14	1090	40 to 65	Dickerson and Read (1975)
Pepperoni	0.093	32	—	1060	20	Sweat (1985)
Salami	0.13	36	—	960	20	Sweat (1985)
Cakes						
Angel food	0.26	36	—	147	23	Sweat (1985)
Applesauce	0.12	24	—	300	23	Sweat (1985)
Carrot	0.12	22	—	320	23	Sweat (1985)
Chocolate	0.12	32	—	340	23	Sweat (1985)
Pound	0.12	23	—	480	23	Sweat (1985)
Yellow	0.12	25	—	300	23	Sweat (1985)
White	0.10	32	—	446	23	Sweat (1985)

^aData apply only to raw whole apple.

^bFreshly harvested.

^cStored frozen and thawed before test.

^dData apply only where juices exuded during heating remain in food samples.

Table A. 4: Standard Axial Flow Fan [40]

Model		Voltage VAC	Frequency Hz	Current A	Input W	Speed r/min	Max. Air Flow		Max. Static Pressure Pa	Noise Level dB (A)	Capacitor μ F
Type	Terminal Box						m ³ /min	m ³ /h			
Low-Speed Alarm, Electronic Alarm Type (Alarm specifications: ②)	MRS18-ETM	Single-Phase 220	50	0.4	53	2850	11.0	660	196	56	6.0
		Single-Phase 220	60	0.5	70	3300	12.5	750	245	60	
		Single-Phase 230	50	0.4	57	2850	11.0	660	196	56	
		Single-Phase 230	60	0.5	73	3350	12.5	750	245	60	
	MRS18-BTM	Single-Phase 100	50	0.8	54.5	2850	11.0	660	196	56	6.0
		Single-Phase 100	60	1.0	76	3300	12.8	768	245	60	
		Single-Phase 110	60	1.0	81	3350	12.8	768	245	61	
		Single-Phase 115	60	1.0	84	3350	12.8	768	245	61	
Standard Type	MRS18-E	Single-Phase 220	50	0.4	53	2850	11.0	660	196	56	6.0
		Single-Phase 220	60	0.5	70	3300	12.5	750	245	60	
		Single-Phase 230	50	0.4	57	2850	11.0	660	196	56	
		Single-Phase 230	60	0.5	73	3350	12.5	750	245	60	
	MRS18-BUL	Single-Phase 100	50	0.8	54.5	2850	11.0	660	196	56	6.0
		Single-Phase 100	60	1.0	76	3300	12.8	768	245	60	
		Single-Phase 110	60	1.0	81	3350	12.8	768	245	61	
		Single-Phase 115	60	1.0	84	3350	12.8	768	245	61	

Table A. 5: Thermal conductivity of some come materials at 25oC[31]

Material	k	Material	k
Acetone	0.16	Foam Glass	0.045
Acrylic	0.2	Gasoline	0.15
Alcohol	0.17	Glycerol	0.28
Aluminium 2024, temper 351	143	Hard board-high density	0.15
Aluminium 2024, temper T4	121	Hard woods (oak, maple)	0.16
Aluminium 5052, temper H32	138	Kapak insulation	0.034
Aluminium 5052, temper O	144	Kovar (54% Fe, 29% Ni, 17% Co)	16.3
Aluminium 6061, temper O	144	Lime stone	1.26-1.33
Aluminium 6061, temper T4	154	Magnesite	4.15
Aluminium 6061, temper T6	167	Mercury	8
Aluminium 775, temper T6	128	Methane	0.030
Aluminium A356, temper T6	128	Methanol	0.21
Antimony	18.5	Monel	26
Argon	0.016	Nylon 6	0.25
Asbestos-cement board	0.744	SAE 50, Oil	0.15
Asbestos-cement sheets	0.166	Olive Oil	0.17
Asbestos-cement	2.07	Perlite, Atm. Pressure	0.031
Asbestos loosely packed	0.15	Plywood	0.13
Asbestos mill board	0.14	Polyethylene HD	0.42-0.51
Bitumin	0.17	Polypropylene	0.1-0.22
Benzene	0.18	PTFE	0.25
Brick-dense	1.31	PVC	0.19
Brick work	0.69	Rock solid	2-7
Clay-Dry to Moist	0.15-0.18	Rock porous, volcanic, (TuffD)	0.5-2.5
Clay saturated	0.6-2.5	Sand stone	1.7
Corian (ceramic filled)	1.06	Silica aerogel	0.02
Cork	0.07	Silicone oil	0.1
Cotton	0.03	Snow (<0°C)	0.05-0.25
Cotton wool insulation	0.029	Solder soft (95% Pb, 5% Sn)	32.3
Diatomaceous earth (Si-o-cel)	0.06	Solder hard (80% Au, 20% Sn)	57
Ether	0.14	Straw insulation	0.09
Epoxy	0.36	Tissue, human skin, at 27°C	0.37
Fiber glass	0.04	Fat layer, at 27°C	0.2
		Muscle, at 27°C	0.41
		Urithane foam	0.021
		Vinyl ether	0.25

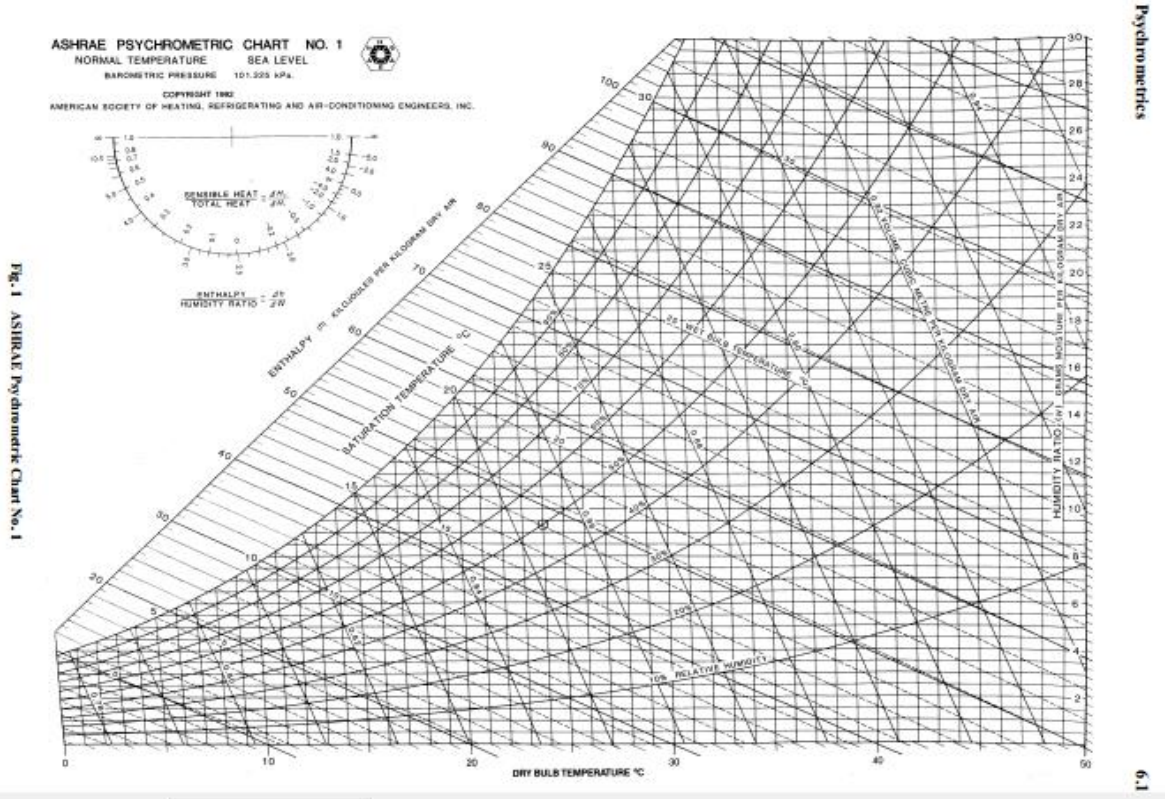


Figure A-1: Psychrometric chart[31]

Figure B. 1: Manufacturing drawing of body of prototype

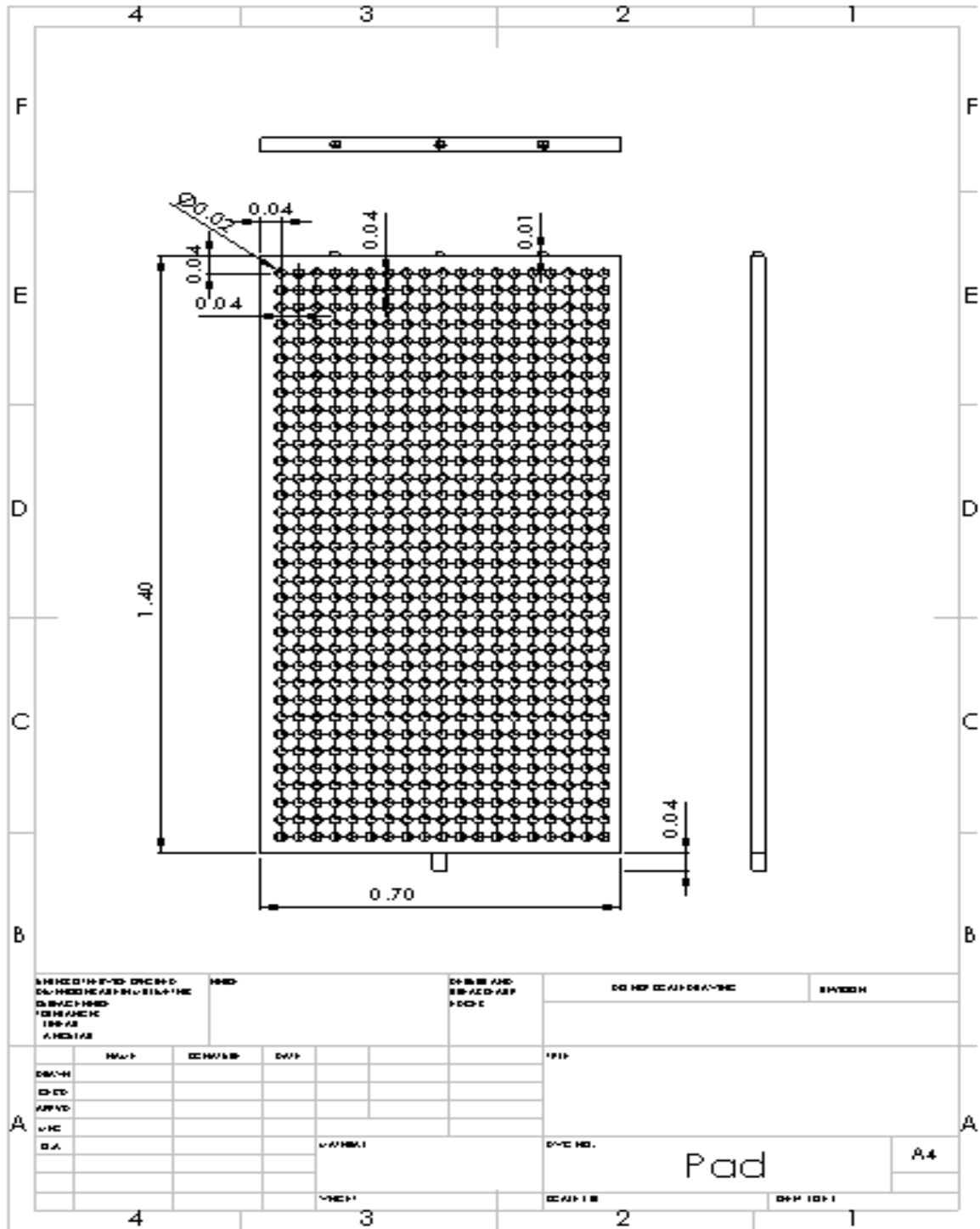


Figure B. 2: Manufacturing drawing for evaporative cooling pad

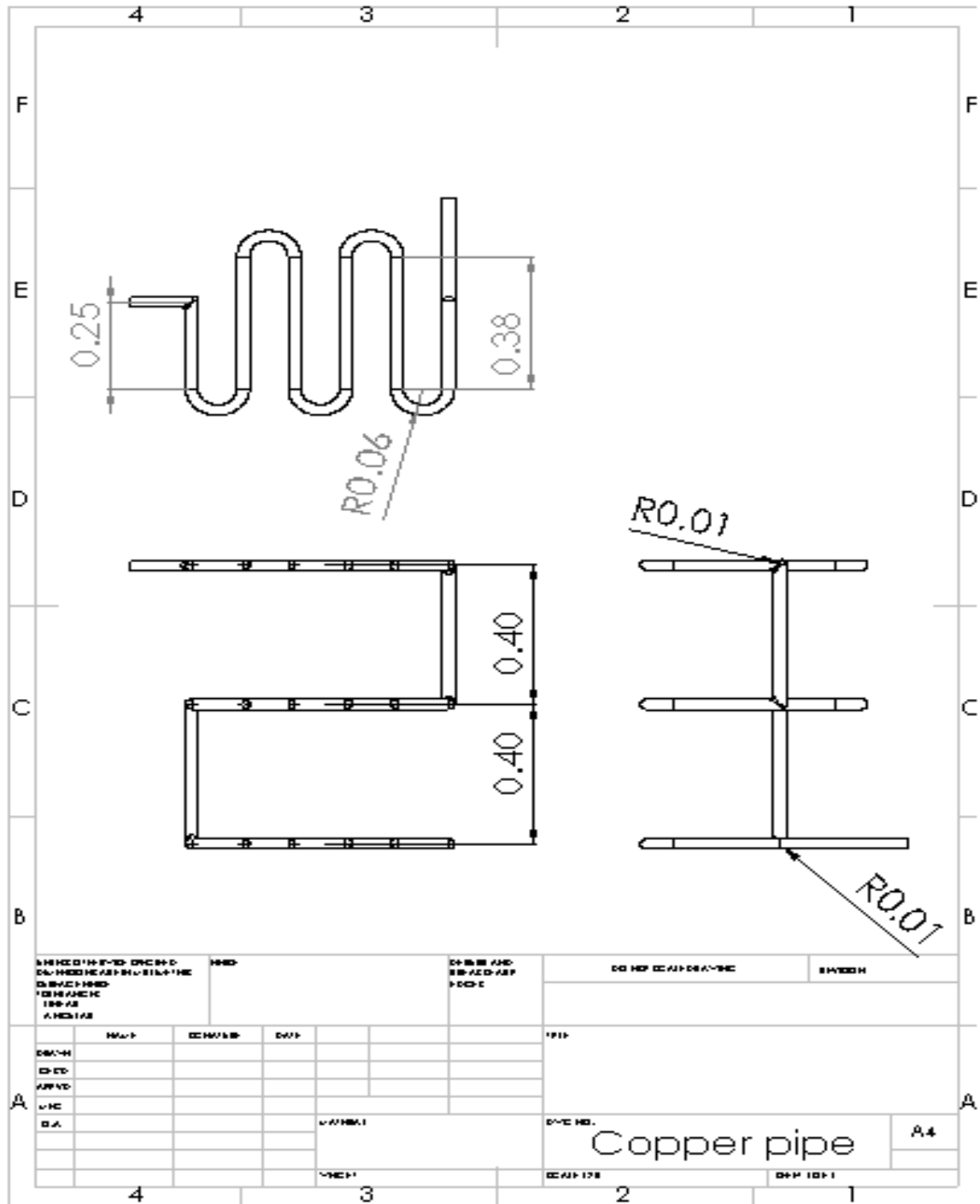


Figure B. 3: Manufacturing drawing for water circulating copper pipe

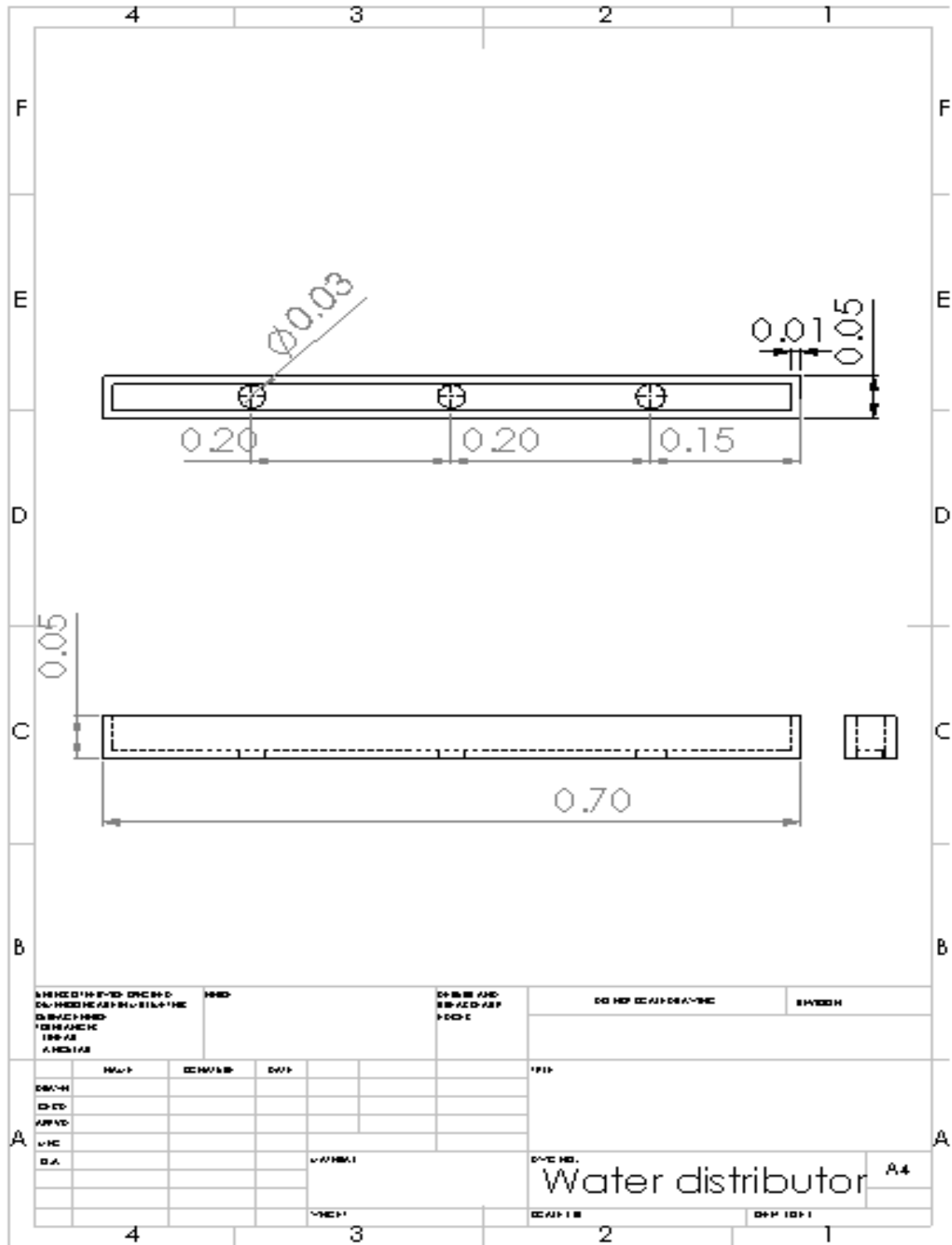


Figure B. 4: Water distributor manufacturing drawing

Appendix C

Weather data from Bahir Dar meteorology

Table C. 1: daily relative humidity data for four years

Reg:	Gojja m		Lat:	11°.4 '									
Stn:	B_Dar SYN		Lon	37°.3 '									
Ele:	RelativeHumidity												
<i>YEA</i> <i>R</i>	<i>Date</i>	<i>Jan</i>	<i>Feb</i>	<i>Mar</i>	<i>Apr</i>	<i>May</i>	<i>Ju</i> <i>n</i>	<i>Jul</i>	<i>Au</i> <i>g</i>	<i>Sep</i> <i>t</i>	<i>Oct</i>	<i>No</i> <i>v</i>	<i>De</i> <i>c</i>
2012	1	42	30	31	39	36	45	78	72	82	74	70	59
	2	31	36	30	39	31	50	79	75	74	64	62	54
	3	37	84	40	30	25	55	72	88	79	66	87	50
	4	37	34	49	34	26	53	76	83	77	67	70	51
	5	41	28	46	36	25	52	69	83	81	65	68	56
	6	45	26	48	27	33	57	72	74	80	62	72	55
	7	48	29	28	27	47	58	78	73	76	62	73	53
	8	42	24	31	28	52	57	76	79	75	61	79	49
	9	49	29	33	33	64	58	72	70	77	61	69	54
	10	46	24	34	34	50	53	66	75	80	60	65	44
	11	53	27	33	29	51	59	68	82	81	62	64	46
	12	52	24	35	32	59	50	78	79	73	66	60	39
	13	52	24	25	31	53	53	80	80	72	63	58	43
	14	59	28	26	32	49	56	75	75	74	88	62	44
	15	54	28	26	23	33	51	74	75	77	51	57	46
	16	59	23	32	21	42	54	82	xx	73	51	60	52
	17	51	25	30	23	54	58	78	80	74	50	52	63
	18	45	34	39	30	51	58	83	71	78	48	53	64
	19	37	31	40	25	50	59	81	78	75	58	55	63
	20	39	46	45	26	39	70	80	82	73	54	56	69
	21	50	43	48	30	44	66	78	81	73	59	57	68
	22	41	35	42	37	37	71	76	78	62	60	50	69
	23	46	30	42	32	48	76	72	76	69	69	58	61
	24	39	30	45	33	46	79	78	76	74	63	54	88
	25	32	30	46	24	50	76	82	74	69	63	58	53
	26	39	38	40	38	53	74	73	82	71	54	57	50
	27	36	39	36	25	64	68	76	72	70	57	60	61
	28	36	29	37	26	56	71	87	77	74	57	69	59
	29	38	31	37	31	52	80	74	78	70	65	63	51
	30	29	32	37	33	51	76	84	80	78	74	66	49
	31	29		37		41		72	90		68		53

2013	1	50	49	42	25	34	54	80	83	68	75	57	52
	2	51	41	34	23	37	57	69	91	77	71	54	44
	3	44	47	41	27	47	54	77	78	86	73	62	43
	4	44	48	43	34	53	57	73	93	78	71	54	38
	5	43	45	37	37	44	56	73	90	81	76	53	44
	6	53	44	33	34	34	61	80	87	81	84	53	41
	7	50	35	40	34	43	65	75	87	76	76	56	39
	8	54	39	39	30	45	68	68	80	75	80	62	38
	9	54	36	45	25	43	61	81	83	77	79	69	35
	10	59	33	45	28	39	65	74	80	84	82	69	40
	11	59	41	39	32	45	67	73	85	75	75	58	47
	12	60	38	46	29	52	53	75	78	79	70	50	52
	13	53	30	45	24	72	72	80	83	74	78	64	60
	14	48	40	47	29	66	68	81	91	75	78	61	63
	15	45	39	42	43	68	62	80	87	74	75	65	61
	16	40	32	36	42	62	61	81	83	77	76	67	57
	17	43	29	36	37	51	54	90	82	71	75	67	57
	18	46	29	31	46	44	51	83	81	73	75	65	63
	19	45	36	32	43	53	63	78	75	73	62	59	55
	20	34	38	34	43	59	71	77	77	68	63	57	53
	21	35	36	26	49	67	72	79	80	69	60	53	41
	22	33	30	38	52	60	71	72	82	71	62	58	37
	23	35	32	37	43	67	72	80	92	74	67	62	45
	24	34	32	38	35	60	73	76	82	72	60	58	47
	25	44	36	30	28	60	74	70	74	71	66	54	43
	26	43	33	32	34	65	77	82	80	68	63	53	44
	27	42	29	28	33	63	69	83	75	71	54	54	54
	28	40	37	28	29	56	73	76	76	67	60	50	43
	29	39		24	33	55	77	83	76	70	66	50	40
	30	50		35	28	54	73	72	83	74	60	53	39
	31	53		28		52		75	81		59		46

2015	1	35	33	28	50	35	75	72	74	78	52	72	60
	2	33	40	44	42	41	65	75	71	76	58	65	71
	3	30	34	28	32	57	62	69	76	80	60	56	73
	4	35	26	29	27	59	59	71	75	78	59	71	68
	5	49	32	30	40	59	54	66	80	76	61	74	73
	6	55	40	37	45	65	60	68	81	76	68	70	71
	7	56	38	44	45	64	60	70	72	76	75	66	74
	8	57	35	35	40	62	63	70	80	78	68	59	69
	9	70	34	23	29	68	63	74	74	86	67	70	69
	10	69	29	27	32	73	57	74	78	78	63	67	67

	11	69	36	35	33	64	57	74	68	66	76	60	65
	12	61	41	29	30	62	60	71	73	74	76	62	62
	13	61	45	30	35	64	61	74	70	75	64	69	60
	14	61	57	28	38	55	70	68	76	78	64	62	57
	15	54	59	31	36	52	70	74	72	72	57	58	59
	16	52	46	29	34	49	73	73	69	75	56	49	57
	17	48	43	40	35	55	72	71	75	80	58	65	66
	18	60	50	38	35	49	74	70	80	75	64	63	64
	19	56	40	51	38	53	74	78	72	72	77	54	62
	20	50	41	50	36	53	72	67	77	64	64	60	61
	21	52	46	50	31	51	75	73	74	69	64	52	61
	22	43	45	48	36	68	80	74	75	79	60	49	67
	23	52	42	48	35	61	79	71	75	76	64	52	61
	24	46	41	43	32	63	69	79	76	70	58	52	70
	25	47	35	38	30	52	69	80	74	70	64	58	63
	26	38	37	35	35	65	70	69	80	66	66	54	65
	27	35	30	38	29	74	82	80	81	69	67	59	66
	28	35	30	37	32	76	75	69	80	64	72	58	67
	29	28		39	29	66	67	75	71	66	68	60	64
	30	32		44	34	66	67	76	78	69	78	54	58
	31	37		51		61		77	76		67		55
2016	1	53	44	31	52	55	54	71	83	78	65	44	46
	2	55	52	38	39	71	58	71	77	82	72	45	55
	3	57	45	35	39	59	54	75	87	83	72	48	49
	4	52	48	35	35	56	56	77	78	77	66	48	36
	5	58	51	48	38	65	64	81	90	71	70	49	39
	6	54	37	39	36	73	64	83	85	76	67	51	33
	7	53	55	38	36	69	68	87	87	69	62	55	37
	8	52	49	36	26	62	69	85	82	73	62	62	37
	9	49	48	25	25	60	62	76	83	65	65	54	43
	10	43	50	25	36	76	66	75	86	76	64	55	46
	11	50	52	40	38	70	59	78	77	76	68	51	45
	12	52	44	39	38	64	63	75	80	79	76	35	45
	13	60	50	42	53	65	64	80	76	80	70	31	47
	14	51	41	50	46	62	68	82	79	73	69	43	51
	15	56	40	50	38	66	76	83	74	78	67	44	52
	16	60	42	44	30	62	75	78	75	77	64	43	62
	17	53	47	49	43	64	77	82	81	81	62	51	50
	18	44	45	53	42	62	75	76	75	81	65	51	53
	19	46	44	58	36	55	79	74	83	76	65	52	39
	20	53	43	50	36	60	77	74	17	71	66	54	46
	21	48	39	53	32	57	75	88	82	74	63	52	51
	22	57	45	47	35	60	74	84	74	75	74	53	50

	23	55	40	40	41	54	70	78	74	71	70	53	42
	24	50	50	43	30	54	76	92	73	76	73	50	41
	25	53	47	35	31	60	72	75	81	71	69	51	50
	26	53	41	39	38	67	75	84	77	73	61	47	53
	27	62	31	37	44	65	79	88	77	79	65	55	36
	28	58	40	39	42	68	76	90	75	78	63	51	32
	29	59	30	34	61	63	73	83	80	77	58	55	35
	30	55		38	57	69	74	83	74	69	60	44	38
	31	57		49		67		82	77		57		47

Table C. 2: Daily Maximum Temperature data

Reg :	Gojj am		Lat: 11°. 4′										
Stn:	B_ Dar SY N		Lon : 37°. 25′										
Ele:	Daily Maximum Temp.												
Year	Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2012	1	28.2	28.0	30.0	30.0	32.0	31.2	24.5	24.5	23.0	25.5	24.5	28.0
	2	28.0	28.0	30.0	29.0	32.7	30.0	24.5	25.0	25.0	26.0	26.3	27.0
	3	27.5	28.5	30.2	30.5	31.5	29.5	24.5	22.0	24.0	25.0	22.0	26.0
	4	27.2	29.0	29.5	31.0	30.5	30.0	24.0	25.0	25.2	27.0	25.0	26.5
	5	27.0	29.5	29.5	30.0	31.7	30.5	24.0	24.0	25.0	26.7	25.0	25.5
	6	27.0	30.7	29.5	28.6	31.5	28.0	24.5	25.5	24.0	27.0	25.0	26.0
	7	27.7	29.5	31.0	28.2	30.0	29.5	24.5	24.0	24.0	26.0	25.5	27.0
	8	27.0	29.2	30.0	28.5	29.5	29.5	25.0	23.0	24.5	27.0	24.0	27.5
	9	27.3	30.2	31.5	29.5	25.5	29.0	26.0	23.8	25.0	27.0	25.5	27.2
	10	28.5	29.5	31.0	30.2	30.5	30.0	26.0	23.5	24.0	26.5	27.5	28.0
	11	28.0	29.5	31.2	30.5	29.0	29.5	26.2	24.5	24.5	27.1	26.7	28.5
	12	26.5	30.0	31.0	30.5	30.0	29.5	26.5	23.5	25.0	27.0	27.0	29.0
	13	28.5	31.2	31.7	30.0	29.5	29.0	24.0	24.5	25.6	27.0	27.7	27.0
	14	26.5	30.5	31.5	28.5	30.0	30.5	24.5	25.0	26.0	26.0	27.0	27.5
	15	27.5	31.0	32.4	30.5	30.5	30.5	24.7	24.6	25.0	26.5	27.5	26.5
	16	26.5	29.6	32.2	31.0	31.5	30.0	24.6	24.0	25.5	26.1	28.0	27.5
	17	26.0	30.0	31.5	32.0	30.0	28.0	24.5	24.5	25.5	26.0	27.5	26.0
	18	26.0	29.5	31.0	31.5	31.0	29.0	23.5	25.0	24.5	28.0	27.7	27.0
	19	26.5	31.0	31.0	32.0	32.4	27.0	24.5	24.2	25.5	28.0	27.5	28.5
	20	27.0	29.5	31.5	31.5	32.2	26.8	24.0	24.0	25.2	28.0	28.0	29.0
	21	26.5	30.0	31.4	31.5	31.5	25.5	23.2	24.4	25.5	27.5	27.8	28.5
	22	27.2	30.0	30.0	29.4	33.0	26.0	24.5	23.0	26.0	26.5	28.0	28.0

	23	27.5	29.5	30.5	28.7	32.0	26.2	25.0	25.0	27.0	26.7	27.5	28.2
	24	26.5	29.7	30.0	30.0	30.0	24.5	24.5	26.0	25.5	28.0	28.0	27.0
	25	28.0	29.5	29.2	29.2	31.0	26.2	24.5	25.5	27.5	26.5	27.7	28.0
	26	28.0	28.4	30.5	29.5	30.0	25.0	24.0	23.5	26.5	26.6	28.5	28.5
	27	28.5	29.5	30.4	31.5	29.0	26.0	24.7	24.5	26.1	26.4	27.0	27.0
	28	27.7	30.2	30.2	30.5	30.5	26.0	22.8	25.5	26.0	27.0	26.0	26.0
	29	29.0	29.6	30.0	31.2	30.0	26.0	25.2	24.5	25.7	27.0	27.0	25.5
	30	29.0		30.0	31.0	30.0	24.0	23.2	25.0	23.5	25.0	27.5	25.7
	31	28.7		29.5		31.0		25.0	23.0		25.5		25.5
201	1	26.0	28.7	30.0	29.5	30.0	38.0	25.0	23.4	26.0	26.8	26.0	27.0
3	2	26.5	29.0	30.5	30.0	30.5	37.5	26.6	20.7	25.5	27.4	26.5	29.5
	3	27.0	30.0	32.0	29.8	29.4	38.0	27.0	23.0	25.6	26.0	26.6	28.5
	4	27.7	29.0	31.0	30.2	29.8	36.5	27.2	23.0	26.0	26.5	27.2	27.0
	5	28.0	29.5	32.0	31.0	30.0	38.0	27.0	21.0	26.2	26.0	27.5	26.7
	6	28.0	29.6	32.5	32.0	30.6	37.0	26.5	22.0	26.0	26.5	27.8	29.0
	7	26.5	30.0	32.6	32.0	30.5	37.0	27.4	23.0	26.5	25.5	27.0	28.0
	8	27.0	29.8	31.5	32.5	30.0	35.0	26.5	25.5	26.6	25.6	27.5	27.8
	9	26.0	30.0	32.0	33.0	30.5	37.5	27.0	25.2	25.5	25.8	28.0	27.0
	10	27.0	29.0	30.5	32.7	31.0	35.0	25.0	26.4	26.0	26.0	27.7	27.5
	11	26.5	29.5	30.0	32.5	31.2	35.0	25.6	23.2	26.5	26.5	27.2	27.0
	12	27.0	30.0	30.5	31.6	31.5	31.0	25.8	24.0	25.0	27.0	27.5	26.0
	13	27.7	29.0	30.0	32.5	30.5	35.5	26.0	24.5	27.2	27.0	28.0	26.5
	14	27.5	31.0	31.0	31.7	30.0	34.5	26.2	25.0	25.6	26.0	29.0	26.0
	15	27.8	30.0	30.5	31.5	30.6	38.5	25.0	24.6	26.0	26.6	27.0	26.2
	16	28.5	30.5	31.5	31.7	31.2	36.5	25.2	25.0	26.2	27.0	27.3	25.6
	17	28.0	31.2	31.5	32.0	31.5	36.0	25.4	25.5	27.0	27.2	27.2	26.0
	18	28.6	31.0	30.6	31.0	31.6	37.0	25.6	25.2	26.8	26.0	27.5	26.5
	19	28.0	30.0	30.5	30.6	32.0	36.0	25.5	26.0	27.0	27.8	27.2	26.7
	20	28.6	30.5	29.6	32.5	30.0	36.0	26.5	26.5	27.4	28.2	27.5	26.2
	21	29.0	31.0	31.2	32.0	30.5	34.5	27.0	26.4	26.6	26.2	28.5	27.0
	22	28.5	30.0	32.0	31.7	30.6	34.5	24.5	26.0	28.0	27.0	27.0	27.7
	23	29.0	31.5	32.5	32.0	31.0	30.6	25.0	27.0	28.4	27.5	27.2	26.5
	24	29.6	30.7	31.5	33.0	31.0	29.5	25.2	26.6	28.6	27.6	27.6	26.0
	25	28.8	31.0	31.5	33.0	30.0	34.5	25.5	27.0	28.0	28.0	28.0	27.0
	26	29.0	30.5	31.0	32.5	30.5	35.5	24.5	24.0	28.5	28.5	26.6	27.5
	27	29.0	31.0	32.5	31.0	29.5	34.5	23.7	25.0	28.8	28.5	27.0	26.3
	28	28.0	31.5	31.6	33.0	30.0	31.5	24.0	25.2	29.5	27.0	27.5	26.5
	29	28.5		31.0	32.0	30.2	36.5	24.0	26.0	27.8	27.2	28.0	26.7
	30	29.0		30.6	33.0	30.5	31.0	25.7	24.6	27.0	27.5	27.0	26.0
	31	28.5		29.8		31.0		26.5	25.0		26.6		27.5
201	1	26.5	30.8	31.5	32.0	30.5	29.0	29.0	24.5	25.8	27.0	28.0	26.0
4	2	27.8	30.5	31.5	31.2	27.0	30.0	29.0	25.2	25.5	27.0	28.0	27.0

	3	27.6	29.7	30.8	31.0	30.0	30.3	28.3	25.5	26.0	26.7	27.7	28.0
	4	28.3	31.3	31.0	29.3	30.5	31.5	27.4	22.5	25.0	25.5	28.5	27.0
	5	27.8	31.5	29.5	31.0	31.3	31.0	26.0	23.8	26.6	26.5	28.2	27.5
	6	27.5	30.3	29.5	31.0	31.0	29.3	26.4	23.5	23.6	25.0	29.4	26.5
	7	27.7	29.6	31.5	28.1	30.9	28.0	26.5	23.6	25.0	26.6	27.6	26.2
	8	27.6	28.7	31.7	31.5	28.0	27.7	27.0	23.6	25.5	26.5	27.6	27.0
	9	27.5	28.5	31.5	32.0	25.5	29.0	26.0	24.0	24.5	27.5	27.5	27.0
	10	28.0	28.6	31.6	30.5	28.2	27.0	25.5	24.5	23.5	26.2	28.5	27.8
	11	27.5	29.0	31.5	28.0	29.0	27.2	27.3	24.7	25.0	27.6	28.2	28.5
	12	28.0	29.5	28.2	29.7	29.0	28.0	26.5	26.0	25.5	27.2	27.6	28.5
	13	27.5	29.0	27.3	30.0	29.5	28.0	26.6	26.0	26.0	27.5	27.9	27.5
	14	28.4	26.7	28.0	31.2	28.0	28.2	27.5	25.5	24.8	26.8	27.5	27.5
	15	28.5	29.0	29.2	31.5	29.0	28.0	26.5	25.2	27.5	27.0	26.8	27.8
	16	29.0	29.2	30.5	32.0	29.5	28.0	27.0	27.0	27.0	28.5	27.5	27.5
	17	28.6	29.0	31.5	31.4	29.0	28.5	26.5	26.5	25.2	27.6	26.5	27.5
	18	28.6	28.6	30.4	32.0	29.0	29.5	26.5	26.0	26.5	27.5	28.0	27.0
	19	28.2	29.6	31.5	32.3	29.7	28.7	26.0	26.0	25.5	28.5	27.7	28.0
	20	29.0	29.0	31.7	32.6	29.6	28.0	25.2	25.5	27.0	26.5	28.5	27.6
	21	29.0	30.2	32.0	32.5	29.5	25.0	26.0	27.5	27.2	28.5	28.6	28.0
	22	30.0	30.0	31.0	32.0	27.2	25.5	26.0	26.5	27.6	27.2	27.6	29.0
	23	30.3	29.7	32.7	30.8	27.0	27.5	25.0	25.7	27.0	29.5	29.0	28.3
	24	29.5	30.8	32.5	30.5	28.0	27.6	25.6	27.0	27.3	28.2	28.6	27.5
	25	29.5	32.0	32.2	31.0	25.2	26.5	23.0	27.8	27.0	28.0	29.0	28.0
	26	29.0	31.9	31.7	31.5	28.0	26.0	24.5	25.5	27.8	27.8	26.0	27.2
	27	29.3	31.5	30.5	30.2	28.7	27.5	26.5	24.5	26.0	28.2	27.0	28.0
	28	29.2	31.8	31.2	29.5	29.0	27.9	24.9	27.5	25.8	28.0	28.5	28.5
	29	29.5		31.5	30.5	29.4	28.2	25.5	25.5	27.0	28.0	29.2	28.3
	30	31.0		30.9	31.5	29.5	28.0	25.2	26.5	27.5	27.8	27.5	30.0
	31	31.5		32.5		29.0		24.5	25.5		28.0		29.7
2015	1	27.0	30.5	31.2	31.5	32.0	30.0	27.5	28.5	26.2	27.6	27.0	26.5
	2	28.0	29.0	29.0	31.6	31.5	30.5	28.5	28.7	26.5	27.5	27.7	27.0
	3	28.0	29.0	31.6	32.0	32.5	29.0	27.0	26.0	26.5	28.0	27.5	26.5
	4	27.5	30.5	32.0	32.5	29.5	30.0	26.6	27.5	25.0	28.5	27.6	27.0
	5	27.7	31.0	31.0	31.0	29.0	29.0	27.0	27.0	25.0	28.0	26.0	27.5
	6	26.5	30.0	30.5	31.5	26.5	30.6	26.5	28.0	25.7	28.5	27.0	27.0
	7	28.0	30.5	31.0	32.0	27.0	31.2	27.0	26.0	27.0	28.5	27.5	27.5
	8	27.2	30.6	31.2	31.5	27.5	28.0	27.5	25.2	26.5	27.0	28.0	28.0
	9	26.5	30.5	31.0	31.0	28.4	29.5	27.2	27.2	26.0	27.5	27.6	28.5
	10	26.1	31.0	31.5	30.5	28.6	30.0	27.5	26.2	26.5	28.0	28.0	28.0
	11	25.0	30.0	32.0	31.0	28.5	29.5	28.0	26.0	27.0	27.0	27.5	27.0
	12	25.5	30.5	31.0	32.0	29.5	28.5	28.6	27.0	27.6	28.5	29.0	26.2
	13	26.0	31.0	31.5	30.5	30.0	29.0	23.0	27.5	28.0	28.0	28.5	25.0
	14	26.2	30.5	31.0	31.0	29.5	29.0	26.0	27.6	28.5	28.6	28.0	25.5

	15	26.0	31.0	31.7	30.0	31.6	28.0	26.5	28.0	28.0	27.5	29.0	26.0
	16	26.4	28.0	32.0	31.5	31.4	28.0	26.6	28.5	28.6	28.0	28.5	27.5
	17	25.6	30.0	31.5	31.5	31.5	28.5	27.0	26.0	28.0	28.7	29.0	28.0
	18	26.0	31.0	31.6	32.0	30.6	28.0	27.5	26.5	27.5	29.0	29.5	26.0
	19	24.6	30.5	32.1	31.0	31.6	28.4	27.5	25.6	28.5	28.5	29.0	28.5
	20	25.5	31.0	30.0	31.5	31.5	27.6	26.6	27.0	28.7	29.0	27.5	28.6
	21	26.5	31.5	30.1	31.0	32.0	28.0	27.0	26.6	29.0	29.0	28.0	29.0
	22	27.0	31.0	30.5	31.6	32.5	27.0	27.2	26.0	29.5	28.6	28.5	28.0
	23	28.0	31.5	29.8	32.0	28.5	25.0	27.5	27.7	28.0	29.0	27.6	28.5
	24	25.5	30.5	29.5	31.5	28.5	26.5	27.6	26.0	28.5	29.5	28.0	27.0
	25	28.0	31.0	30.0	32.0	29.0	27.0	25.2	26.5	27.0	27.2	28.5	27.5
	26	27.6	31.5	31.2	32.5	31.5	27.5	26.8	27.0	28.0	27.7	27.5	27.0
	27	28.8	31.0	31.5	30.0	31.6	27.6	26.4	25.0	27.0	28.0	28.0	27.5
	28	28.0	30.5	30.6	32.0	30.5	27.5	27.8	26.0	28.0	27.5	27.6	28.0
	29	29.0		31.0	32.0	27.6	27.0	28.5	27.0	27.0	28.0	28.5	27.0
	30	29.2		30.5	31.5	28.0	28.0	28.0	27.7	26.5	26.5	29.0	27.5
	31	29.5		31.0		29.2		27.5	26.0		29.5		28.0
201	1	27.6	27.7	31.5	32.0	28.7	29.0	27.5	25.7	25.0	28.5	27.5	28.0
6	2	28.0	27.5	32.5	32.2	28.5	29.5	27.6	25.0	25.2	28.5	28.0	27.8
	3	28.5	28.5	30.5	30.0	30.0	30.2	26.5	25.7	25.6	29.0	26.5	29.5
	4	29.0	28.6	31.5	29.5	31.0	30.5	27.5	26.0	27.5	28.5	27.0	29.6
	5	28.5	29.0	32.0	30.5	28.5	31.0	26.5	26.5	28.0	28.7	28.0	30.2
	6	27.0	29.5	31.6	30.5	28.7	29.5	27.7	25.0	28.0	27.0	28.0	27.0
	7	27.5	29.5	30.0	30.6	25.5	30.2	24.5	26.7	29.4	28.0	30.0	27.7
	8	28.0	27.5	31.0	31.5	28.5	28.5	25.0	23.0	27.0	29.0	26.5	29.0
	9	26.5	28.5	31.5	30.0	29.0	29.8	25.5	23.5	28.1	29.5	27.0	28.0
	10	27.0	29.0	31.8	30.5	29.7	29.0	26.0	24.0	26.5	27.5	27.6	29.0
	11	28.0	28.5	32.0	31.5	26.0	30.2	25.0	25.5	24.5	28.5	28.0	30.0
	12	28.5	29.5	33.0	32.0	27.7	31.0	26.2	25.5	25.6	26.5	28.5	27.2
	13	27.0	29.6	32.0	30.5	27.5	31.1	24.0	26.7	27.5	27.0	28.0	28.0
	14	26.1	29.0	31.0	31.0	29.5	29.0	24.5	25.6	26.7	27.5	28.5	27.5
	15	27.0	30.0	32.0	30.0	29.5	27.1	25.0	27.0	27.0	28.5	26.5	27.5
	16	27.5	29.5	32.5	32.0	30.5	28.0	26.2	27.5	27.0	27.2	28.5	28.0
	17	26.2	29.0	32.5	30.2	27.5	25.6	26.0	27.7	28.0	28.0	28.0	28.2
	18	26.5	29.5	31.5	30.2	29.5	25.6	27.5	26.0	27.5	28.0	27.5	26.5
	19	27.0	30.0	31.0	30.0	29.0	25.0	25.5	26.5	26.5	28.5	28.5	29.0
	20	27.5	30.5	30.6	30.2	30.0	25.0	26.0	25.5	26.5	27.0	29.0	28.5
	21	29.0	30.0	31.4	31.5	30.0	27.0	24.0	25.4	25.0	28.0	30.0	28.0
	22	27.5	31.0	31.0	32.2	31.0	27.0	25.2	26.0	27.0	26.0	29.0	28.2
	23	28.0	30.0	30.5	30.5	31.5	25.6	26.6	26.6	28.0	26.5	29.0	29.7

	24	27.5	31.0	31.5	31.0	31.6	26.4	27.5	26.5	27.1	26.0	29.0	27.6
	25	28.0	30.5	32.4	31.5	31.6	26.0	25.5	27.0	27.5	27.5	29.5	27.5
	26	28.5	29.5	32.0	32.5	27.5	26.5	26.0	25.0	27.5	28.0	26.2	29.0
	27	27.0	30.5	33.4	31.5	26.5	25.5	26.4	26.0	25.7	28.5	26.5	29.5
	28	29.0	31.0	33.2	32.0	28.5	26.5	23.5	26.7	26.5	28.0	27.0	29.7
	29	28.5	32.0	33.1	30.0	27.5	26.0	27.0	25.5	27.0	28.5	29.0	27.5
	30	29.0		33.0	30.0	26.6	27.0	24.2	25.0	27.0	27.5	29.5	28.5
	31	27.0		33.4		27.6		25.0	25.0		28.8		27.0

Table C. 3: Daily Minimum Temperature data

Re g:	Goj jam		Lat:	11°. 4'									
St n:	B_ Dar SY N		Lon :	37°. 25'									
El e:	Daily Minimum Temp.												
Ye ar	Dat e	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
20 12	1	6.0	9.5	9.0	15.0	xx	16.5	15.5	14.5	13.5	12.0	14.5	12.5
	2	6.7	7.5	10.2	13.5	xx	17.0	15.5	14.5	12.0	12.5	14.0	11.0
	3	8.5	10.5	8.5	9.0	xx	17.0	14.0	15.5	12.0	13.0	15.0	8.7
	4	6.5	9.0	8.0	10.5	xx	15.0	15.0	14.7	14.0	14.0	10.5	8.0
	5	7.0	9.0	15.0	15.0	16.0	16.6	13.5	15.0	14.5	14.0	15.0	9.5
	6	6.0	8.5	13.0	13.0	17.2	16.7	14.0	14.0	14.0	14.0	13.5	10.5
	7	5.1	10.2	xx	9.0	16.0	17.0	15.5	14.0	12.6	14.5	13.5	10.0
	8	7.5	11.5	10.5	8.5	15.5	13.6	14.0	13.2	14.0	14.5	14.5	8.0
	9	7.0	7.0	11.0	7.7	14.5	13.5	15.0	14.5	14.2	15.3	11.5	9.5
	10	8.5	9.0	xx	xx	15.0	16.5	14.0	15.0	14.5	15.0	13.5	7.7
	11	10.0	9.5	9.7	7.2	16.0	12.5	15.0	14.5	14.0	13.0	11.5	7.7
	12	9.5	8.0	xx	xx	16.4	14.0	14.5	13.7	14.5	14.2	12.0	8.0
	13	10.2	9.0	9.5	13.7	16.0	15.5	14.2	13.5	14.5	13.0	14.5	7.0
	14	11.0	8.0	10.5	10.0	16.0	16.0	14.5	13.2	14.0	14.0	13.0	6.7
	15	10.5	8.5	9.0	12.0	15.5	16.5	13.0	14.0	14.5	13.5	10.7	7.0
	16	10.2	6.5	xx	10.5	16.0	16.5	14.0	xx	13.0	8.7	15.0	8.0
	17	8.5	7.0	11.5	11.5	17.5	15.5	12.5	13.5	14.0	8.0	11.0	8.7
	18	9.0	7.0	12.0	14.0	15.5	15.0	15.0	13.0	12.2	9.2	12.0	12.0
	19	9.5	8.2	12.8	12.0	14.5	15.0	12.7	13.0	12.5	12.0	11.7	12.7
	20	9.0	10.0	12.2	12.5	13.5	16.0	14.0	14.5	13.5	11.5	11.0	11.2
	21	6.0	9.5	12.5	18.0	18.0	15.0	14.5	13.0	12.7	12.5	27.8	11.7
	22	6.5	10.5	14.0	17.0	16.7	16.0	13.5	12.2	13.8	11.3	10.2	11.2

	23	4.7	8.0	xx	15.0	15.5	13.5	15.5	13.5	15.0	13.5	9.0	12.5
	24	6.5	11.0	xx	11.5	13.0	14.8	14.5	14.0	14.5	14.7	8.7	12.2
	25	4.5	8.0	17.5	12.0	14.5	14.0	13.5	13.5	12.5	13.5	10.0	10.0
	26	6.7	9.0	18.2	12.0	14.5	15.0	15.5	12.4	12.5	12.0	10.5	7.5
	27	11.0	7.0	20.0	xx	15.5	14.5	14.0	14.0	12.7	10.0	12.5	6.5
	28	9.2	10.5	17.0	xx	14.6	15.0	15.5	13.0	12.5	10.5	12.7	xx
	29	9.0	12.0	13.2	xx	14.5	16.0	15.0	14.0	14.0	16.5	11.0	6.5
	30	9.0		14.0	xx	15.5	15.0	15.0	13.8	14.7	13.5	12.2	7.0
	31	9.6		12.5		14.6		15.5	14.5		12.5		6.7
20 13	1	6.7	8.6	9.0	6.2	13.0	2.0	15.5	15.0	13.5	14.6	11.0	10.0
	2	5.7	9.6	na	9.2	13.7	0.0	14.5	14.0	13.2	12.5	10.7	na
	3	5.6	8.5	9.0	10.2	16.0	6.0	14.4	14.0	14.6	15.0	13.0	5.0
	4	6.2	10.0	na	10.6	18.5	0.8	15.2	14.2	14.4	15.0	12.5	6.2
	5	6.2	8.6	15.5	13.5	19.5	4.5	14.0	14.5	12.5	15.6	11.0	6.0
	6	7.5	7.5	12.8	13.5	12.0	0.0	14.0	13.5	12.6	14.5	14.2	na
	7	6.7	9.5	14.0	14.2	13.5	3.6	13.6	15.0	14.0	14.6	14.2	10.4
	8	7.7	8.2	15.0	9.2	13.0	8.0	16.0	13.2	14.6	14.4	12.4	9.5
	9	13.2	6.6	na	10.0	17.6	0.0	15.6	14.1	12.5	13.0	13.5	6.6
	10	8.0	8.5	na	8.4	19.0	0.0	13.7	15.0	14.6	15.0	14.5	6.0
	11	7.0	6.8	na	10.5	20.5	0.6	14.2	14.6	14.0	12.6	14.0	5.0
	12	8.0	9.6	17.5	9.0	17.5	19.0	14.5	14.4	13.2	12.5	11.0	6.0
	13	12.0	8.6	18.5	10.0	15.0	5.7	15.2	15.2	13.0	14.6	11.6	6.0
	14	10.5	10.0	18.4	10.5	17.2	1.8	13.5	13.5	13.7	12.0	16.4	6.6
	15	6.5	10.5	19.0	13.2	16.0	0.0	14.7	15.2	13.5	14.5	15.6	6.5
	16	9.5	9.5	18.0	18.2	16.2	0.3	14.5	14.6	15.6	13.4	13.0	9.0
	17	7.7	10.5	15.0	15.7	17.0	10.2	13.7	14.5	na	15.0	14.5	10.2
	18	7.5	10.0	16.6	21.0	16.7	11.0	14.0	15.6	na	14.0	12.7	11.0
	19	8.2	8.0	15.6	17.5	18.5	6.0	14.2	14.7	na	13.7	10.5	10.0
	20	7.5	9.5	12.3	19.5	15.2	0.5	15.0	14.2	14.5	14.8	11.4	8.6
	21	7.0	9.6	11.0	17.5	15.5	TR	14.8	12.5	15.2	13.7	11.0	11.6
	22	7.6	8.2	13.4	16.7	16.5	18.0	13.5	15.0	13.5	14.0	11.4	8.0
	23	7.4	9.5	32.5	15.0	13.8	7.5	14.8	15.2	13.2	14.5	13.8	7.0
	24	6.0	12.0	10.0	12.7	16.5	9.0	14.0	14.5	14.2	14.5	11.5	7.2
	25	6.8	8.6	11.0	15.5	17.0	0.0	14.6	14.6	12.5	15.5	10.6	6.7
	26	7.4	11.0	31.0	13.5	15.5	TR	15.0	14.4	15.2	14.0	10.0	10.5
	27	7.0	13.8	9.2	12.8	16.2	0.7	14.0	14.0	14.0	13.2	9.5	7.5
	28	8.0	9.2	10.2	12.0	17.7	0.2	14.5	14.4	14.8	14.0	10.5	7.0
	29	8.5		9.2	13.2	16.7	TR	13.6	13.0	13.5	15.0	10.0	6.2
	30	12.5		8.5	13.7	16.5	6.0	14.5	14.0	15.8	14.0	12.2	6.2
	31	10.2		7.0		17.2		14.4	13.6		12.5		7.0
20 14	1	4.4	8.0	11.3	14.0	13.0	13.0	14.0	14.8	13.0	14.2	10.6	6.5
	2	5.0	7.5	10.5	13.0	14.5	12.6	14.5	14.5	14.0	14.0	12.4	6.5
	3	7.2	4.7	16.4	12.3	14.5	12.0	15.0	14.0	13.5	14.4	12.0	7.0

	4	4.0	5.4	14.8	na	15.0	13.8	11.5	13.5	14.0	14.7	11.8	7.6
	5	4.5	6.0	13.0	na	14.8	12.2	16.2	13.5	13.5	14.8	10.2	6.5
	6	5.0	6.0	13.2	na	14.0	14.0	13.5	13.0	15.2	14.0	10.8	5.5
	7	5.0	6.4	13.2	17.5	16.4	14.4	13.8	13.5	13.0	13.2	11.5	5.2
	8	6.8	4.0	13.5	na	16.2	14.0	13.5	13.5	13.6	14.0	11.5	5.6
	9	7.7	7.8	10.0	na	15.5	14.9	14.1	15.0	14.0	14.2	10.0	7.0
	10	6.8	3.0	12.5	16.0	14.5	14.0	14.0	12.8	15.0	24.5	9.8	7.0
	11	7.0	4.0	10.4	15.0	15.1	14.5	14.0	13.0	13.0	14.0	8.0	7.0
	12	5.0	4.5	12.0	14.5	14.8	14.8	15.5	12.7	13.5	14.6	8.5	6.7
	13	7.2	2.2	13.0	12.5	14.3	13.5	14.5	10.5	13.7	14.5	8.8	5.5
	14	6.6	2.0	12.8	12.8	13.5	15.0	14.5	12.7	11.5	15.0	8.5	4.7
	15	7.0	3.2	8.5	11.6	13.4	14.7	16.3	13.5	14.2	14.6	11.5	5.0
	16	6.5	4.5	8.0	12.5	13.0	13.0	15.0	14.0	12.5	12.5	12.0	5.4
	17	8.5	3.8	8.7	13.0	16.0	14.0	15.2	13.0	13.5	13.8	9.2	7.5
	18	8.3	3.6	15.3	13.6	15.2	13.0	15.5	14.7	12.2	13.5	10.0	7.5
	19	5.2	4.8	11.2	13.0	14.0	15.0	14.6	14.0	11.6	12.8	9.0	6.3
	20	7.0	5.8	11.0	13.7	14.3	14.8	14.9	15.2	12.5	14.0	12.7	5.4
	21	5.0	10.0	12.1	13.0	15.7	14.2	14.5	14.8	12.2	14.2	11.5	8.5
	22	5.5	10.6	14.0	12.5	15.3	14.0	14.3	12.4	13.0	12.0	10.5	5.5
	23	5.0	9.8	10.5	13.7	15.0	14.5	14.5	12.5	11.5	12.2	13.5	6.0
	24	4.7	10.2	11.2	14.0	15.0	15.6	15.0	13.1	13.0	11.4	10.0	6.5
	25	4.5	5.1	10.6	15.0	14.8	15.4	14.0	12.0	12.8	10.0	9.2	7.5
	26	5.0	8.5	10.9	14.8	14.5	13.5	15.0	14.0	12.0	12.0	7.2	8.0
	27	3.6	9.4	6.1	13.0	14.0	14.2	15.0	14.0	15.2	12.4	10.2	7.0
	28	8.2	9.6	8.0	14.7	14.4	14.5	14.5	12.0	13.0	11.5	7.5	6.8
	29	5.5		6.7	14.7	14.0	14.9	13.5	12.7	13.4	11.6	7.5	4.8
	30	6.2		7.6	14.8	14.2	15.0	14.5	13.7	11.8	11.5	9.8	5.2
	31	6.5		7.5		12.6		13.5	15.5		12.0		3.8
20 15	1	5.5	9.0	13.5	14.0	15.0	15.4	15.6	14.6	14.6	14.5	15.0	13.0
	2	5.6	4.2	11.7	14.0	18.5	16.4	15.5	15.5	13.8	14.2	16.4	13.8
	3	6.0	na	12.2	17.2	18.5	17.4	13.0	15.5	14.0	14.4	16.8	13.5
	4	5.4	5.2	8.5	14.0	18.0	14.5	13.4	15.6	13.8	13.0	15.8	12.6
	5	3.8	6.2	14.5	14.4	17.2	16.4	16.5	16.0	13.5	14.0	14.5	14.6
	6	7.5	6.5	14.6	17.6	14.0	14.5	14.8	14.5	14.0	15.0	15.8	13.0
	7	12.5	6.8	12.2	16.8	16.4	14.0	14.5	15.0	13.7	14.8	15.0	16.0
	8	8.5	7.5	14.2	16.5	15.2	14.0	15.6	14.0	16.5	14.5	15.0	14.0
	9	8.2	7.2	12.2	12.5	16.6	16.7	14.8	15.0	na	14.2	13.8	13.8
	10	8.0	8.6	NA	13.0	17.0	18.0	14.6	15.8	na	15.0	15.6	16.0
	11	7.5	8.4	10.5	12.2	15.5	16.0	14.2	14.5	16.0	15.2	15.0	12.2
	12	6.0	8.6	12.0	14.5	18.2	16.7	14.8	14.4	15.0	15.4	14.5	11.5
	13	12.0	10.6	13.4	15.0	15.2	16.8	15.6	14.5	16.0	14.5	16.0	9.0
	14	11.5	11.0	13.8	17.5	16.7	16.7	15.2	14.5	15.5	15.6	13.4	8.0
	15	9.6	12.0	13.0	14.0	17.8	14.5	14.2	15.2	14.6	15.0	14.5	6.5

	16	12.7	13.0	14.2	12.0	17.8	17.0	16.5	14.0	15.0	15.2	13.2	8.0
	17	8.6	14.5	16.5	12.8	16.0	17.2	16.5	15.2	14.5	15.5	15.4	10.6
	18	7.5	16.2	17.7	16.0	15.5	17.0	15.0	13.0	15.8	14.0	14.0	14.8
	19	8.2	17.6	17.5	13.4	16.5	14.8	14.0	15.0	14.5	14.6	13.0	15.2
	20	8.0	13.0	16.8	14.8	17.0	15.5	15.0	15.7	14.6	14.0	13.8	14.8
	21	8.2	10.6	16.6	15.2	14.5	15.0	13.8	15.8	14.8	15.5	13.5	11.6
	22	9.6	11.5	13.0	14.8	13.5	14.4	15.0	15.6	16.2	15.2	11.5	12.6
	23	8.8	13.0	16.4	14.5	13.6	15.0	15.2	13.0	12.5	16.0	10.8	11.0
	24	8.8	9.7	15.0	14.5	15.5	15.6	15.5	13.2	15.4	15.5	10.0	10.6
	25	8.1	12.7	11.0	15.2	18.7	14.5	14.6	15.0	16.0	13.6	9.0	10.5
	26	9.5	10.0	11.8	16.5	16.5	15.7	15.0	15.0	14.2	16.8	10.2	10.2
	27	11.6	17.5	17.0	17.2	16.0	16.2	14.0	14.6	14.2	16.0	15.2	11.5
	28	8.5	15.2	NA	14.5	16.2	16.6	14.5	15.0	14.8	15.6	11.5	14.2
	29	9.5		18.5	13.8	17.2	15.8	14.6	15.6	15.0	15.7	11.0	12.4
	30	9.6		15.6	15.2	15.5	15.8	15.6	13.0	15.2	15.0	13.0	15.2
	31	6.4		15.0		15.0		14.6	13.2		16.4		11.8
20	1	10.5	8.0	15.0	15.5	16.0	13.5	14.5	15.0	14.5	15.0	11.5	10.0
16	2	11.0	7.6	10.2	17.5	15.6	15.2	15.0	15.5	14.5	14.5	10.5	11.5
	3	9.8	9.8	10.2	12.0	16.0	17.5	15.0	15.5	14.0	13.5	8.9	10.0
	4	10.6	11.0	9.6	10.5	18.5	16.6	14.4	15.0	13.0	14.5	9.5	7.5
	5	13.0	10.8	11.6	11.5	16.6	15.6	15.5	15.0	13.0	13.5	10.0	4.5
	6	na	9.0	14.5	10.0	16.2	16.4	15.0	15.2	13.5	14.0	9.5	5.2
	7	9.6	8.5	12.6	10.0	16.2	15.6	13.7	13.4	13.7	15.0	10.0	5.5
	8	9.0	9.5	10.0	10.4	17.5	14.2	15.0	15.0	14.5	15.2	11.5	4.5
	9	8.0	10.2	9.5	11.6	18.2	15.0	14.6	14.0	14.5	15.8	8.5	5.6
	10	6.5	10.0	9.6	14.5	15.5	15.4	14.0	13.5	14.5	16.2	10.5	6.5
	11	5.8	9.5	12.0	13.0	15.2	14.5	14.6	14.6	14.0	14.0	8.0	7.0
	12	7.5	9.5	12.5	17.0	15.4	15.4	14.0	15.2	13.5	15.0	9.5	7.5
	13	7.5	11.5	10.4	15.6	15.5	17.6	13.4	14.0	13.2	15.5	7.8	8.1
	14	9.0	10.0	16.6	17.5	16.0	13.7	13.5	14.8	14.0	14.5	6.0	7.0
	15	8.4	10.0	12.8	12.2	14.2	13.5	12.6	15.8	13.5	14.0	5.2	7.0
	16	9.0	10.5	17.0	13.6	15.0	13.4	12.5	14.5	13.5	14.0	5.5	8.8
	17	10.8	10.0	14.0	13.2	16.4	15.0	13.2	15.0	15.2	14.0	7.5	8.5
	18	7.0	9.5	16.0	16.6	15.5	15.0	14.6	13.8	15.0	14.0	9.5	7.5
	19	7.0	9.0	17.0	13.0	15.2	14.2	13.5	13.5	13.2	14.5	10.5	9.0
	20	5.0	9.4	16.5	11.5	17.0	15.0	13.5	14.5	13.5	14.2	11.0	10.0
	21	8.0	9.6	15.0	13.0	16.5	12.4	13.8	15.5	13.5	14.5	10.5	7.5
	22	8.5	9.5	17.4	17.0	16.0	13.5	13.5	13.5	13.8	13.4	9.4	7.0
	23	9.5	10.8	12.5	19.4	17.2	14.4	14.0	13.5	13.0	13.5	8.0	9.5
	24	10.2	13.5	10.0	16.0	15.5	14.5	14.0	14.0	14.5	14.0	9.0	10.0

	25	10.6	14.6	11.0	13.6	16.0	15.0	13.6	13.6	16.2	13.6	7.6	9.5
	26	9.8	12.0	12.5	13.5	16.8	15.0	13.4	13.5	14.5	13.0	6.0	10.0
	27	8.0	9.8	13.6	15.2	15.5	16.0	12.5	13.6	15.0	14.0	6.5	7.8
	28	6.2	12.5	12.5	15.6	16.2	14.0	13.0	13.4	14.0	13.0	8.0	5.5
	29	4.5	14.2	13.8	16.2	15.8	15.0	14.5	14.0	15.0	14.0	8.0	7.0
	30	6.8		17.7	17.2	15.5	14.0	15.0	15.5	15.0	13.5	9.5	6.0
	31	7.2		16.5		13.5		14.8	14.0		13.0		4.5