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Zero energy cool chamber for food commodities: Need of eco-friendly storage facility for farmers: A review

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Abstract
Much of the post-harvest losses of fruits and vegetables in developing countries is due to the lack of proper storage facilities. While refrigerated cool stores are the best method of preserving fruits and vegetables they are expensive to buy and run. Consequently, in developing countries there is an interest in simple low-cost alternatives, many of which depend on evaporative cooling which is simple and does not require any external power supply. India is the second largest producer of fruits and vegetables in the world after Brazil and China respectively. Storage of fresh horticultural produce after harvest is one of the most pressing problems of a tropical country like India. India’s total fruits and vegetables production is lost during harvest, storage, grading, transport, packaging and distribution in a year which reduces the growers share. Due to their highly perishable nature, about 20-40% of total fruit and vegetable production go waste during various steps of the post-harvest chain, smooth transport and insufficient cool storage space / facility at farmer’s level and high cost of refrigerated storage so further enhances loss of fruits and vegetables. Temperature and humidity play major role in storage of fruits and vegetables Temperature can be controlled by using energy consuming methods such as air-cooling, hydro-cooling, vacuum-cooling, chilling, ice cooling, freezing, etc.

Keywords: Zero energy cool chambers, evaporative cooling, cost analysis, food preservation and storage condition

Introduction
India is the second largest producer of fruits and vegetables in the world after Brazil and China respectively. Storage of fresh horticultural produce after harvest is one of the most pressing problems of a tropical country like India. India’s total fruits and vegetables production is lost during harvest, storage, grading, transport, packaging and distribution in a year which reduces the growers share. Between 20 and 30% of total fruit production goes to waste owing to spoilage at various steps of the postharvest chain, reducing per capita availability of fruits to around 80 g per day which is almost half the requirement for a balanced diet. The fruit processing sector has grown at a rate of about 20% per annum (Rahul *et al.*, 2015) [38]. Hence, there is a need for maximum commercial utilization of fruits and vegetables. Hence, preserving these types of foods in their fresh form demands that the chemical, bio-chemical and physiological changes are restricted to a minimum by close control of space temperature and humidity (Chandra *et al.*, 1999) [11]. However, due to poor handling of the produce, post-harvest losses have been high, resulting in a significant gap between gross production and the net availability to the consumer (Singh and Satapathy, 2006) [49]. Due to their highly perishable nature, about 20-30% of total fruit production and 30- 35% of total vegetable production go waste during various steps of the post-harvest chain the lack of sufficient cool storage space at farm level and refrigerated storage at market level further enhances loss of fruits and vegetables (FAO, 2006) [18]. Reducing the losses in postharvest fruit and vegetable operations is a worldwide goal (Clement *et al.*, 2009) [13]. The zero energy cool chambers working on the principle of evaporative cooling was though developed earlier, the effort to popularize this low cost storage structure for on farm storage of perishables is snowballing only now. This could be easily constructed by the farmers themselves using locally available materials and could help in retaining the freshness of vegetables for a short period so that the farmers can store their produce for few days and can send the bulk of their commodity to the wholesale market avoiding distress local sale through middlemen. Temperature and humidity play major role in storage of fruits and vegetables. Temperature is the single most important factor affecting the deterioration rate of freshly harvested commodities; also proper relative humidity is required to be maintained during storage (Kadar, 1992) [25].

The storage life of fruits and vegetables can be extended greatly by removing the field heat and applying cooling as soon as possible after harvesting. The optimum storage temperature of most fruits and vegetables is above their freezing point (FAO, 1995) [17]. Proper storage is an important for marketing and distribution of horticultural commodities. Storage also balances the daily fluctuations of supply and demand (Chakraverty *et al.,* 2003) [10]. Losses can be minimized by using best post-harvest handling techniques during storage, transportation and distribution to market. There are various technologies available to create and maintain optimal temperature, relative humidity and atmospheric composition for harvested fruits and vegetables during storage (Chakraverty *et al.,* 2003) [10]. Temperature can be controlled by using energy consuming methods such as air-cooling, hydro-cooling, vacuum-cooling, chilling, ice cooling, freezing, etc. Refrigerated storage is a well-established technology widely used for storing horticultural crops all over the world (Chaudhary, 2004 and Sunmonu *et al.*, 2014) [12, 53]. However, mechanical refrigeration is energy intensive and expensive involves high initial investment, cannot be quickly and easily installed, requires uninterrupted supply of electricity, high operational cost, and cannot be constructed in remote area and not eco-friendly too. Because of these reasons this method is not widely used in many tropical and sub-tropical countries, where refrigeration is needed most (Kumar and Nath, 1993; Thakral *et al*., 2000; Kumar *et al.,* 2003 Adamu *et al*, 2006 Nitipong and Sukum, 2011) [1, 27, 28, 32, 54]. This method is not also affordable to small farmers, retailers and wholesalers (Samira *et al.,* 2013). Besides, it is not suitable for on farm storage in the rural areas (Basediya *et al.,* 2013). Moreover several tropical fruits and vegetables like banana, tomatoes, orange, leafy vegetables etc., cannot be stored in the refrigerator because they sustain chilling injury and colour change (Adebisi *et al.,* 2009 Liberty *et al., 2013*) [2, 29]. Use of chlorofluorocarbon (CFCs) and hydro chlorofluorocarbon (HCFCs) refrigerants in refrigeration system are partly responsible for ozone layer depletion and global warming (Xuan *et al.,* 2012) [56]. Because of these reasons its application has become limited. Evaporative cooling storage structure is an alternative of mechanical refrigeration system (Nitipong and Sukum, 2011) [32]. Evaporative cooling is the process by which the temperature of a substance is reduced due to the cooling effect from the evaporation of water. The conversion of sensible heat to latent heat causes a decrease in the ambient temperature as water evaporated provide useful cooling. This is the most economical way of reducing the temperature by humidifying the air. It has many advantages over refrigeration system, as it does not use refrigerant so it is environmental friendly (reduces CO2). It does not make noise as there is no moving part. It does not use electricity so its saves energy. It does not require high initial investment as well as operational cost in design and maintenance. It can be constructed with locally available materials in remote areas and most importantly, it is eco-friendly as it does not need chlorofluorocarbons. Evaporation of moisture from vegetables causes wilting and shriveling resulting in weight loss. The process of evaporative cooling is an adiabatic exchange of heat when ambient air is passed through a saturated surface to obtain low temperature and high humidity, which are desirable for extending the storage life of vegetables.

Principles of Evaporative Cooling

The design of the evaporative system was based on the principle of evaporation being always accompanied by a cooling effect to its surrounding. It is an enclosed system which comprises of four sides, such that one side was made of mesh wire and pad (jute material), while the remaining three sides were made of aluminum sheets in which the side opposite to the jute pad section is equipped with three suction fans well-spaced. Air is allowed to pass through the pad into the system with the help of suction fans. Water drips into the jute pad at a constant rate through a water distribution system. As the water drips into the pad the suction fan draws warm air from the system and passes it out. During this process the warm air which is the sensible heat passes through the wetted pad which is now changed to latent heat due to the evaporation that has occurred as a result of the water being evaporated which causes the cooling within the enclosure to achieve a temperature difference of about 10°C., as a result of this, the shelf life of the vegetable is expected to increase.

According to Rusten, (1985) [46] cooling through the evaporation of water is an ancient and effective way of cooling water. He further disclosed that this was the method been used by plant and animal to reduce their temperature. He gave the conditions at which evaporative cooling would take place which are stated below:

1. Temperatures are high
2. Humidity is Low
3. Water can be spared for its use
4. Air movement is available (from wind to electric fan)

Also he disclosed that the change of liquid stage to vapour requires the addition of energy or heat. The energy that is added to water to change it to vapour comes from the environment, thus making the environment cooler. Therefore, the use of the psychometric chart is of great importance in order to discover whether evaporative cooling has taken place. Air conditions can be quickly characterized by using a special graph called a psychometric chart. Properties on the chart include dry bulb and wet-bulb temperatures, relative humidity, humidity ratio, specific volume, dew point temperature, and enthalpy Beiler, (2009). When considering water evaporating into air, the wetbulb temperature, as compared to the air's dry-bulb temperature is a measure of the potential for evaporative cooling. The greater the difference between the two temperatures, the greater the evaporative cooling effect. When the temperatures are the same, no net evaporation of water in air occurs, thus there is no cooling effect (Wikipedia.com).Therefore for optimum cooling efficiency using the evaporative cooling technique temperature and the relative humidity measurement is needed to be taken and the psychometric chart defines these variables at various stages.

Classification of Evaporative Cooling

There are general two type methods include direct and indirect evaporative cooling.

Direct Cooling

Direct cooling involves the movement of air past or through a moist material where evaporation, and therefore cooling, occurs. This cooled moist air is then allowed to move directly to where to where it is needed. In contrast to this process, indirect cooling uses some form of heat exchangers that use the cool moist air produced through evaporative cooling, to lower the temperature of drier air. This cool dry air is then used to cool the environment, and the cool moist air is expelled. A direct evaporative cooling is a line of constant wet bulb temperatures. In the course of direct cooling operation, wet bulb temperature and enthalpy remains unchanged, dry bulb temperature reduces while relative humidity and specific humidity increases (Babarinsa, 1986) [5]. Direct evaporative cooling is the most commonly used form of evaporative cooling used to cool water. This system usually uses either a porous clay container or a water tight canvas bag in which water is stored. These containers are then either hung or placed so that the wind will blow past them. The water in the container slowly leaks through the clay or canvas material and evaporates from the surface as warm dry air flow past. This process of evaporation slowly cools the water.

Limitations

The drop in temperature will generally be only a small faction of the total evaporative reduction that is possible. This is primarily due to the large volume of water that needs to be cooled by a relatively small evaporating surface area. Only a small number of items can be placed in large water containers.

Indirect Evaporative Cooling

The high level of humidity that is produced by direct evaporative cooling may be undesirable for some applications. Indirect evaporative cooling attempts to solve this problem by using the cool moist air produced through evaporation to cool drier air. The resulting cool air is then used to cool the desired environment. This transfer of coolness is accomplished with the help of a heat exchanger (Singh and Narayah, 1999) [48]. All methods of indirect evaporative cooling require power to run both water pump and fans. For this reason, indirect evaporative cooling will have limited applications. It is primarily used to cool dwellings and rooms. In such situations these cooling system are generally less expensive to buy or build and operate than conventional air conditioning systems. On the other hand, indirect evaporative cooling cannot be used in all environments, and the reduction in temperature that can be achieved with this system is not as great as the reduction that can be achieved with conventional mechanical cooling systems. (Babarinsa, 2000) [6]. The primary advantage of indirect evaporative cooling for increasing the comfort level of rooms are relatively low purchase or building cost and the relatively low operation expense, as compared with convectional air conditioning systems (Singh and Narayah,1999) [48].

Factors Affecting the Evaporative Cooling

Evaporative cooling results in reduction of temperature an increase in relative humidity (Olosunde, 2006) [33]. It is necessary to understand the factors that can limit the efficiency of the system from producing the intended results. There are four major factors that affect the rate of evaporation which was analyzed by (Rusten, 1985) [46]. He later added that though they are discussed separately but it is important to keep in mind that they all interact with each other to influence the overall rate of evaporation, and therefore the rate of cooling. The factors discussed by (Rusten, 1985) [46] include:

Air Temperatures

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

Air Movement (Velocity)

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

Surface Area

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

Relative Humidity of the Air

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

Design and Construction

Zero energy cool chambers is an on-farm rural oriented storage structure which operates on the principle of evaporative cooling and has been constructed using locally available raw materials such as bricks, sand, bamboo, rice straw, vetiver grass, jute cloth etc. The chamber has been constructed above the ground and comprises of a double-walled structure made up of bricks. The cavity of the double wall is filled with riverbed sand. The upper part of the chamber was covered with vetiver grass mat on a bamboo frame. Zero energy cool chamber (ZECC) is a double wall structure having space between the walls which is filled with porous water absorbing materials. These pads are kept constantly wet by applying water. When unsaturated air passes through wet pad, transfer of mass and heat takes place and the energy for the evaporation process comes from the air stream. ECSS due to their low investment, almost no energy requirement and with other advantages over refrigeration system become a quite popular and better alternative for storage of horticultural produce (Dash and Chandra, 1999; Rayaguru *et al.*, 2010; Nitipong and Sukum, 2011) [11, 32, 41]. ECSS does not use energy or very less energy hence called zero energy cool chambers (ZECC) (Roy and Khurdiya, 1986) [34]. Only limitation with this system is it requires dry and hot climate (high temperature and less humidity), open space for movement of air and small quantity of water. Zero Energy Cool Chamber has been designed by IARI Pusa, New Delhi (Roy, 1988) [27] on the principle of evaporative cooling *i.e.* cooling effect created due to evaporation of water. The cool chamber maintains relatively lower temperature as compared to ambient temperature and unlike outside fluctuation in mercury, the temperature variations inside the cool chamber happen to be very low. Similarly, the relative humidity inside the cooling chamber is also relatively higher than that of outside.

Considering, the acute energy shortage in rural areas, there is better scope for adoption of small capacity, low cost, on-farm scientific storage structure like Zero Energy Cool Chamber (ZECC) developed at IARI, New Delhi by (Roy and Khurdiya, 1986) [34] based on the principle of evaporative cooling. The process of evaporative cooling is an adiabatic exchange of heat when ambient air passes through a saturated surface to obtain low temperature and high humidity, which is desirable to extend the storage life of fruits and vegetables (Das and Chandra, 2001) [14]. Storage of horticultural products inside the cool chamber has showed reduction in physiological loss in weight, optimum color, better firmness and extended shelf life by 1–2 weeks in other parts of the country. Cool chambers are effective in maintaining the fruit acceptability for a longer period and minimizing the weight loss during storage (Bhatnagar *et al.,* 1990) [8]. Relatively lower weight loss of fruits and vegetables under evaporative cooler than that of ambient has been reported by many researchers. (Sandooja *et al.,* 1987) [47] reported least deterioration in quality parameters of tomato such as TSS, acidity and ascorbic acid content when stored in zero energy cool chambers. (Wasker *et al.,* 1999) [55] reported slower rate of change of physicochemical constituents in fruits stored in cool chamber. Weight loss of fresh tomato has been reported to be primarily due to transportation and respiration, and limited shelf-life and losses in quality have been identified as the major problems faced in the marketing of fresh tomatoes (Bhowmic and Pan, 1992) [9]. Zero energy cool chambers along with packaging materials, ventilation and antifungal treatments can help in minimizing the losses of ascorbic acid in the stored lemon fruits to some extent compared to the storage under ambient conditions of storage (Prabha *et al.,* 2006) [36]. Different types of evaporative cooler have been reported in the literature, some of which are included in this review. A zero-energy cool chamber was developed using locally available materials in New Delhi, India (Roy and Pal, 1994) [45]. The chamber is designed for on-farm use, operates by evaporative cooling, and is constructed from double brick with sand-filled cavity walls. The shelf life of tropical fruits held in the chamber was increased by 2 to 14 days (15–27% increase) as compared to storage at room temperature, and the physiological loss in weight was lower. The chambers were shown to be suitable for short term storage of fruits and vegetables. (Ganesan *et al.,* 2004) [20] studied the application of different levels of water on Zero energy cool chamber with reference to the shelf-life of brinjal and concluded that the shelf-life at room temperature which was hardly 3 days enhanced to 9 days with the addition of 100 litres of water per day. (Jha and Kudas, 2006) [24] worked on physical properties of pads for maximizing cooling in evaporative cooled store and concluded that partal wood savings was found to be best among the safeda, partal and root pad for maximum cooling effect in evaporatively cooled storage system. A thickness of 7 mm of partal wood savings cooling was found to give maximum surface evaporation of 14.87 g of water per minute. (Singh and Satapathy, 2006) [49] evaluated the performance of IARI design Zero Energy Cool Chamber (ZECC) at ICAR Research Complex, Umiam, Meghalaya. The ZECC was evaluated for two consecutive years and shelf life of various fruits and vegetables like bitter gourd, capsicum, tomato, cauliflower, pineapple and peach was evaluated under cool chamber and ordinary room condition. It was observed that the mean maximum temperature inside the cool chamber was about 5 °C and 6 °C lower than the ambient during summer and winter season, respectively. Throughout the year, relative humidity (RH) inside the cool chamber was between 80 and 94%, whereas under the ambient it varies between 70 and 83%. The RH inside the cool chamber was nearly 13.34% and 12.34% higher during summer and winter months, respectively. It was observed that the shelf life of bitter gourd, capsicum, and cauliflower could be increased for 5 days whereas; the shelf life of tomato and peach and pineapple can be increased for about 6 and 9 days respectively.

Design Criteria of Evaluation

Design Criteria of the Cooling System: The storage system is rectangular in shape, and the design specifications for the system as well as the reservoir seat were done in accordance with (Adeniran *et al.,* 2011) as follows;

Design of Front and Rear Sides of the Storage System

The design of the rear side of the system was achieved using Equation.

$$Ar = H_r \times L_r$$

Where; Ar = Area of rear side, Lr = Length of rear side, Hr = Height of rear side

Design of Left and Right Hand Sides of the Storage System (Pad Area):

The design for the left side of the storage system was done using Equation.

$$A_l = H_l \times B_l$$

Where; A_l = Area of left side of the storage system,
H_l = Length of left side of the storage system,
B_l = Breadth of left side of the storage system.

Similarly, the right hand side of the system has the same design with the left side of the system, with three well-spaced circular openings for insertion of the suction fans. Each having an area as shown in equation.

$$A = \pi r^2$$

Where; A = Area, r = Radius

Design of Top of the Storage System The design for the top of the storage system was done using Equation.

$$A_t = L_t \times B_t$$

Where; A_t= Area of top of the storage system, L_t = Length of top of the storage system B_t= Breadth of top of the storage system,

Design of Reservoir Seat: The design for the reservoir seat was also done using Equation

$$A_s = Ls \times Bs$$

Where; A_s = Area of reservoir seat, L_s = Length of reservoir seat, B_s = Breadth of reservoir seat

Volume of the Storage System

The capacity of the storage system was determined using Equation

$V_c = L_c \times B_c \times H_c$

Where; V_c = Volume of the storage system, L_c = Length of the storage system, B_c = Breadth of the storage system, H_c= Height of the storage system

Volume of Reservoir

The volume of the reservoir was determined using Equation

$V_r = \pi r^2 H$

Where; V_r = volume of reservoir, π =3.14, r= radius of reservoir, H_r = height of reservoir

The aluminum frames that make up the storage cabin were extended upward by 0.1m to serve as reservoir stand while reservoir seat was constructed above. The water distribution network consists of pipes, an overhead tank and a bottom pipe network to collect the excess water that drips from the jute. The pipe network also consists of a control valve which will be used to regulate the flow rate.

Design and Selection of Suction Fan

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

Fan Capacity

8cfm/sqft × floor area in squared foot

Floor area:

$A_f = L_f \times B_f$

Fan Capacity = 8cfm/ sqft

Factor of safety is 10% of fan capacity given as:

$F_s = \frac{10}{100} \times \text{Fan Capacity}$

Required fan capacity =fan capacity +factor of safety

Where: A_f= Area of floor, L_f = Length of floor in ft, B_f = Breadth of floor in ft, F_s= factor of safety

Selection of Cooling Pad

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 (Thakur and Dhingra, 1983; Wiersma, 1983). In this work, Jute type of cooling pad of 0.06 m thickness was selected for an efficient performance of the evaporative cooling system as it has good water holding capacity, high moisture content, and percentage dry basis, high bulk density reported (Manuwa, 1991; Igbeka and Olurin, 2009) [2].

Heat Transfer Analysis of the System

The heat gain by the aluminum material used for the cabinet construction was estimated using Fourier's law of heat conduction

$Q_{hg} = \frac{-KA\Delta T}{x}$

Where; Q_{hg} = Quantity of heat gained by the material (W), A = Area of the material (m), k = Thermal conductivity of the material (W/m K), ΔT = Temperature difference of thermal (°C), x = Thickness of the material (m)

Selection of Solar Power Supply System

The installed suction fans on the evaporative cooling system have the following specifications: 12V (voltage ratings), 0.15A (Current), 1.8W (power ratings) and these specifications were considered in selection of the solar power source that will ensure the continuous functioning of the fans. The solar panel selected has the following specification: Voltage = 18v, Current = 0.36A

Design of Battery Charger

The battery charger was designed so that it can step down the voltage rating from the solar panel from 18V to 15V in order to charge the battery adequately. The battery charger was designed in accordance with (Tharaja, 1995) as shown in Equation.

RT= R1+R2+R3+R4

I= V/R

V= IR

Determination of Battery Capacity and Selection of Battery

The battery capacity was determined with reference to the suction fans specifications and this is in accordance with (Linden, 2002) as given in equation.

$C = H_n \times A$

Where; C = battery capacity, H_n = Hours from sunset to sunrise, A = Fan current

Based on the above findings, the appropriate battery that was selected has the following specifications:

Voltage = 12V, Capacity = 6AH.

Testing of Evaporative Cooling

No Load Test of the Evaporative Cooling System

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

Saturation Efficiency (SE)

The effectiveness of the jute pad was based on the cooling efficiency. The saturation efficiency (SE) of the cooler for the jute bag used was calculated using Equation, (Harris, 1987)

$$S_E = \frac{T1(db) - T2(db)}{T1(db) - T1(wb)}$$

Where,

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

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

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

Flow Rate

The flow rate of water from the reservoir was determined through the use of a stop watch to monitor the time it takes to collect a certain volume of water by the water collector at the bottom of the cooling system.

Load Test of the Evaporative Cooling System

The load test of the evaporative cooling system was subjected to the following:

Temperature and Relative Humidity Measurement

The temperature and relative humidity were determined. Both the temperature of the evaporative cooling system and that of ambient were determined. The temperature readings were taken using the dry and wet bulb thermometer. The relative humidity was then obtained using the psychometric chart which has reading for both the dry and wet bulb temperature. The readings were taken from 8am to 8pm at intervals of four hours for five consecutive days.

Percent Loss in Weight (PLW)

Percent loss in weight (PLW) was determined by weighing the vegetables during storage with the equation used by.

$$PLW = \frac{W1-W2}{W1} \times 100$$

Where,
W1=Weight of sample before storage, Kg
W2=Weight of sample after storage, Kg

Color Changes and Firmness

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

Storabilety of food commodities

The present study on the storability of vegetables under ZECC had proved its usefulness in extending the storability of tropical vegetables, with reduction in temperature up to 9ºC and increase in relative humidity by 18 per cent could be achieved inside the chamber compared to ambience. The ZECC proved useful in storage of vegetables with minimum PLW and decay and the freshness was retained for 3 days in lab lab, 4 days in bhendi, five days brinjal, bitter gourd and radish. The added advantage of the cool chamber is that it does not require any mechanical or electrical energy and is easily installable with cheap and locally available raw materials. Since significant evaporative colling temperature depression from the ambient air temperature always occurs during the times of the day when cooling is most desired, the cooling condition achieved are suitable only for the short term preservation of vegetables and fruits soon after harvest.

Effect on Physiological Weight Loss

Zakari *et al.*, (2016) [57] studies on design and construction of an evaporative cooling system for the storage of fresh tomato. There are worked a solar powered evaporative cooling system was designed and construction to increase the shelf life of stored vegetables. The daily weight loss during the experiment. These results revealed that the weight loss of tomatoes in the evaporative cooling system ranged from 1.7 to 5.7g per day while that of ambient system ranges from 9.3 to 18.6g per day while and the percentage of weight loss of tomatoes in evaporative cooling system and ambient ranged from 0.05 to 0.18% and 0.30 to 0.60% per day respectively.

The physiological weight loss in the range of 10-15 percent and rotten percentage to be in the range of 20-30 are allowable for maintaining the freshness and marketability of horticultural produces (Olosunde 2006 and Jha 2008) [33]. The temperatures in the range of 22-30 ºC, 27-39 ºC, 16- 21 ºC and 30-42 ºC were maintained respectively in ZECC, RC, REF and AC during conducting experiment. Similarly, humidities in the range of 70- 83 %, 50-72 %, 44-53 % and 38-68 % were maintained respectively in ZECC, RC, REF and AC. The reduction in PLW could be attributed to the reduced rate of respiration and moisture loss from vegetables, which was achieved by the reduction in temperature and increased relative humidity inside the chamber compared to room conditions. A temperature difference of 3 ºC to 9 ºC and an increase in RH by 10 to 18 per cent inside the ZECC was recorded at various periods. The PLW observed for brinjal stored in ZECC was only 10.13 per cent even at the end of seven days of storage, while it was 17.75 per cent in control. Considering the PLW (8.09 per cent) and rotten or unmarketable fruits (5.32 percent) together it could be concluded that brinjal could be stored for 5 days in ZECC as reported earlier by Ganesan *et al*., (2004) [20] and Rayaguru *et al*., (2010) [40]. In case of bitter gourd, the PLW was only about 9.57 per cent even after a storage period of 5 days and considering the weight loss together with loss of produce due to rotting (8.57 per cent) it could be well stored for a period of five days under ZECC.

Dash *et al.,* (2016) Studies on Short-term Storage of Paddy Straw Mushroom (Volvariella volvacea) in Zero Energy Cool Chamber during Summer Period of Coastal Area. Most of the farmers are not able to afford the cost of purchasing high-tech storage equipment for their harvested crops. Evaporative cooling has been found to be an effective and economical means of reducing temperatures and increasing humidity in an enclosure where the humidity is comparatively low (Jain 2007; Jha 2008; Jadhav *et al.*, 2010) [21, 22, 23]. Minimizing deteriorative reactions in horticultural produces enhances their shelf lives, implying that the produce will be available for longer periods; this would reduce fluctuation in market supply and prices. Evaporative cooler works on the principle of cooling resulting from evaporation of water from the surface of the structure. The cooling achieved by this device also results in high relative humidity of the air in the cooling chamber from which the evaporation takes place relative to ambient air (ASHRAE 2003) [4]. The atmosphere in the chamber thus becomes more conducive for storage of produces. Therefore, it is required to develop and popularize a low cost, less energy consuming and environment friendly cool chamber which would not only be affordable for resource poor farmers but also safe storage for a short period, resulting into a prospect of getting remunerative price of the produce. The evaporative cooling systems have prospect for use for short term storage of horticultural produces after harvesting (Libertya *et al.,* 2013) [30]. It reduces the storage temperature and also increases the relative humidity within the optimum level of the storage thereby helps in keeping them fresh.

Table 1: Physiological loss in weight (per cent) of vegetables in storage (Sundaram, 2016)

Crop	Day 1		Day 2		Day 3		Day 4		Day 5		Day 6		Day 7	
	Inside ZECC	Ambience	Inside ZECC	Ambience	Inside ZECC	Ambience	Inside ZECC	Ambience	Inside ZECC	Ambience	Inside ZECC	Ambience	Inside ZECC	Ambience
Bhindi	1.11	1.11	2.37	3.88	4.39	7.14	6.24	17.34	7.54	19.97	10.23	27.10	15.28	35.12
Brinjal	2.39	3.00	3.13	5.90	4.51	8.46	6.27	10.85	8.09	12.97	9.42	15.12	10.13	17.75
Bitter guard	2.41	4.14	3.35	6.19	3.94	10.11	6.46	15.41	9.57	16.42	12.77	27.12	14.12	32.05
Lab lab	4.64	6.04	6.85	11.94	9.21	18.42	15.24	24.88	25.99	42.79	-	-	-	-
Radish	1.29	3.10	3.38	5.38	4.42	7.49	5.30	9.59	7.00	13.09	9.03	18.54	11.82	21.41

Fruits and vegetables are highly perishable commodities that cannot be kept for a long period due to their perishable nature and, therefore, presents storage difficulties. This study is to assess the storage of fresh fruits and vegetables to reduce some of the postharvest losses and raise the value at the glut period. The intensity of weight loss during storage depends on maturity stage. Weight lose of fresh tomatoes is primarily due to transpiration and respiration. Cold stored fruits have low weight loss due to temperature effects on vapor pressure difference and increased water retention. Rab *et al.*, reported that the weight loss of tomato fruit is significantly affected by harvest stages. This finding is in accordance with the work done by Moneruzzaman *et al.*, who reported that storage of tomato at low temperature and high relative humidity decrease the early deterioration percentage

Table 2: Visual appearance on discard day of vegetables stored in room (Kumar *et al.* 2015)

S. No.	Vegetables (gms.)	Visual Appearance on discard day of vegetables stored in room		Shelf life(days)	
		Cool Chamber	Room	Cool Chamber	Room
1.	Tomato (1000)	5% Shrinkage, Skin appearance is good, Fine edible, Taste fine	30% Shrinkage, Skin appearance became dull, Inedible	12	7
2.	Radish (1000)	5% Shrinkage, Skin appearance, Fine, Edible	80% Shrinkage, Skin appearancedull, Taste changed, Not edible	7	3
3.	Coriander (250)	10% Shrinkage, Skin appearance fine, Edible	80% Shrinkage, color changed and leaves are dried, Inedible	5	2
4.	Peas (500)	Fine, Taste is good, Edible	50% Shrinkage, color changed and dries but edible	9	4
5.	Cabbage (1000)	10% Shrinkage, Skin appearance is fine, Edible	70% Shrinkage, color changed and dried, Appearance dull, not edible	9	5

Effect on Colour Change

Zakari *et al.*, (2016) [57] studies on design and construction of an evaporative cooling system for the storage of fresh tomato. There are studies on solar power evaporative cooling system and there storage. By the sixth day, tomatoes colour changed from yellowish red to deep red colour while some turned reddish black. Piloo and Vida (2014**)** [34] were worked on efficacy of evaporative cool chamber in Pasighat condition, Arunachal Pradesh, India. There are subject to store freshly harvested vegetables viz. brinjal, frenchbean, green chillies, coriander and tomatoes. They evaluated sensory quality (colour, texture) and acceptability depending on the condition of the vegetables, for brinjal, on the 4th day of storage, the colour was found deep purplein colour; Frenchbeans high with green; Chillies reported black stalks; Coriander light green in colour with wilting on 3rd days of storage; tomatoes high with red on 4th day of storage.

Effect on Firmness

The change in the firmness was much noticed in the tomatoes because of their spherical shape. The tomatoes stored in the evaporative cooler still retained its firmness but those stored in the ambient have started losing their firmness after the third day and after the sixth day most of the tomatoes have started rotting Zakari *et al.*, (2016) [57].

Conclusion

Due to adverse condition are high moisture content fruit and vegetables after being harvested tread to high deterioration and low storability. Moreover,s they are living commodities can carry transpiration, respiration and repining even after harvest. It is estimate that about 30-35% of total harvest, storage, grading, transport, packaging and distribution. The evaporative cooled storage structure has proved to be useful for short term, on-farm storage of fruits and vegetables in hot and dry regions. Evaporative cooling is an efficient and economical means for reducing temperature and increasing the relative humidity of an enclosure, and has been extensively tried for enhancing the shelf life of horticultural produce which is essential for maintaining the freshness of the commodities. Evaporative cooling is an environmental friendly air conditioning system that operates using induced processes of heat and mass transfer where water and air are working fluids. Such a system provides an inexpensive, energy efficient, environmentally benign (not requiring ozone-damaging gas as in active systems) and potentially attractive cooling system. The semiperisheble fruit and vegetables, milk and some products, cooked food, mushroom, meat, fish, flowers and that have a short shelf life can be stored inside the zero energy cool chamber.

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