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REVIEW ARTICLE

Evaporative Cooled Storage Structures: An Indian Scenario

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Abstract

Evaporative cooling is a well-known system to cool the environment. This is adiabatic process, in which ambient air is cooled as a result of transferring its sensible heat to the evaporated water carried with the air. In the evaporative cooled structure, the maximum advantage of the natural environment is taken for lowering down the temperature of outside ambient air to a considerable low level. Evaporative cooling storage system is easy to operate, efficient and affordable most especially for peasant farmers in developing countries who may find other methods of preservation quite expensive and unaffordable. In this review different evaporative cooling systems developed, their construction materials and efficiency in improving the shelf life of various agricultural commodities have been discussed.

Keywords: Evaporative cooling, evaporatively cooled, saturation efficiency, relative humidity, zero energy cool chamber, evaporatively cooled storage structure.

Introduction

The immense diversity in agro-climatic conditions across the different regions enables India to produce a large variety of fruits and vegetables that are generally grown under sub-tropical and temperate climatic conditions. 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). 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 (Chadha, 2001; Suryawanshi *et al.*, 2005; FAO, 2006; Arya *et al.*, 2009; Basediya *et al.*, 2013; Assocham, 2013) and the monetary losses are over Rs 2 lakh crore annually in country (Assocham, 2013)**.**

The lack of sufficient cool storage space at farm level and refrigerated storage at market level further enhances loss of fruits and vegetables (APO, 2006, FAO, 2006). Reducing the losses in postharvest fruit and vegetable operations is a worldwide goal (Clement *et al.*, 2009). Since ages, the human race has been practicing different methods to increase the shelf life of these commodities. 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). 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). 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). 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). Temperature can be controlled by using energy consuming methods such as air-cooling, hydro-cooling, vacuum-cooling, chilling, ice cooling, freezing, etc., and less or no energy method i.e. evaporative cooling system (Thomson *et. al.*, 1998). Former is achieved by mechanical refrigeration system while later uses evaporative cooling principle for lowering temperature.

Mechanical refrigeration

Refrigerated storage is a well-established technology widely used for storing horticultural crops all over the world (Chakraverty *et al.,* 2003; Chaudhary, 2004; Singh and Satapathy, 2006; Sunmonu *et al.,* 2014). 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). 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). 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). Because of these reasons its application has become limited. Evaporative cooling storage structure is an alternative of mechanical refrigeration system (Nitipong and Sukum, 2011).

Evaporative cooling storage structure

Evaporative cooling storage structure (ECSS) is a double wall structure having space between the walls which is filled with porous water absorbing materials called pads (Roy and Khurdiya, 1986; Singh and Satapathy, 2006; Jha and Aleksha Kudos, 2006). 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. Evaporative cooling is an adiabatic process occurring at constant enthalpy (Dash and Chandra, 2001; Kumar *et al.,* 2003; Bucklin *et al.,* 2004; Vala and Joshi, 2010; Banyat and Bunjerd, 2013). 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 friendly to environment (reduces CO_2). It does not make noise as there is no moving part. It does not use electricity i.e. saves energy. It does not require high initial investment as well as operational cost is negligible. It can be quickly and easily installed as this simple in design. Its maintenance is easy. It can be constructed with locally available materials in remote area and most important, it is eco-friendly as it does not need chlorofluorocarbons (Jha, 2008; Gomez *et al.,* 2010; Nitipong and Sukum, 2011; Banyat and Bunjerd, 2013).

Refrigeration system decreases both temperature and humidity while evaporative cooling decreases less temperature and increases humidity, which is more suitable for storage of agriculture produce, which does not require very low temperature (Wilson *et al.,* 1995; Nitipong and Sukum, 2011).

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). ECSS does not use energy or very less energy hence called zero energy cool chambers (ZECC) (Roy and Khurdiya, 1986). 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.

In India hot and dry weather prevails for a significant part of the year. Ambient hot and dry weather is suitable for efficiently working of the evaporative cooling concept storage structure (Jha and Chopra, 2006; Vala and Joshi, 2012). Perishable agriculture commodities can be safely stored in ECSS. Use of evaporative cooling concept in storage of agricultural produce may be one alternate as it can be used for short-term on-farm storage of perishables as well as for pre-cooling of fruits and vegetables before transit and storage in cold storage (Jha and Aleksha, 2006; Maini and Anand, 1992). Evaporative cooling is the simplest and cheapest method for extending shelf life of fruits and vegetables and can also be used as ripening chamber for banana (Bhatnagar *et al.,* 1990; Das and Chandra, 2001; Dharmasena and Kumari, 2005; Jha, 2008; Okunade and Ibrahim, 2011).

Many scientists carried out it efficacy for increasing shelf-life of fruits and vegetables namely; tomato, potato, mango, grapes, orange, santara, sapota, banana, plums, aonla, bitter gourd, capsicum, cauliflower, pineapple, peach, green pepper, cluster bean, brinjal, cucumber, chili, ladies finger, beat, peas, carrot, radish and leafy vegetables (Ganesan *et al.,* 2004; Habibunnisa *et al.,* 1988; Jha, 2008; Kumar and Nath, 1993; Mishra *et al.,* 2009; Nagaraju and Reddy, 1995; Roy and Khurdiya, 1986; Singh *et al.,* 1998; Singh and Satapathy, 2006; Samira *et al.,* 2013; Umbarkar *et al.,* 1991). They also constructed various sizes ECSS using different construction materials. The storage size of ECSS varies from few kilograms to few tones. Some researchers also evaluated ECSS using various pad materials, environment parameters, operational parameters, produce parameters for temperature drop and increasing relative humidity. The published information on all the above was reviewed and briefly presented here under four different heads; namely structural parameters, pad materials, operating parameters and performance in terms of shelf-life of farm produce.

Structural parameters of EC structure

Many researchers used different structural materials viz.; bricks, wood, mild steel, aluminum sheet as walls of the ECSS. Roof of the ECSS was also made of light weight, cheaper and easily available materials; asbestos sheet, gunny bag, jute bags, plywood, etc. (Chouksey, 1985; Roy and Khurdiya, 1986; Umbarkar *et al.,* 1991; Rama and Narasimham, 1991; Garg *et al.*, 1997; Kapdi *et al.*, 1997; Sandhu and Ghuman, 2002; Kumar *et al.,* 2003; Olosunde, 2006; Jha, 2008; Mishra *et al.*, 2009; Vala and Joshi, 2010; Samira *et al.,* 2011). These materials are cheaper and easily available. This makes construction cost of ECSS lower as compared to mechanical refrigeration (Table 1).

Pad materials of EC structure

Pad is important part of ECSS. Many researchers have studied the effect of cooling pads on cooling efficiency (Table 2). There is a lot of research studying the characteristics and performance of various types of evaporative cooling pads, namely sand, clay, brick bats, date palm fibres and leaves, clay, wood saving, sack, saw dust, wheat straw, jute, PVC sponge, morum, pumice stone, coconut coir, rice husk, charcoal, cotton fabric, green house shedding net (Roy and Khurdiya, 1986; Umbarkar *et al.,* 1991; Abdalla *et al.*, 1995; Mekonnen, 1996; Kapdi *et al.*, 1997; Al-Sulaiman, 2002; Liao and Chiu, 2002; Sandhu and Ghuman, 2002; Lalmani *et al.,* 2004; Gunhan *et al.*, 2007; Jha, 2008; Tilahan, 2010; Vala and Joshi, 2010; Chinenye, 2011; Kulkarni, 2011; Nitipong and Sukum, 2011; Samira *et al.*, 2011; Banyat and Bunjerd , 2013) and man-made commercial cooling pads; aspen pad and rigid pad (cel-dek) (Abdalla *et al.*, 1995; Al-Sulaiman, 2002; Vala and Joshi, 2010; Kulkarni, 2011). Although commercial pads gave good saturation efficiency, as they are specially made but they are expensive and not suitable to low income farmers and traders. Locally and easily available pads performed better with RH above 90% and maximum temperature drop of 25°C. However, performance is dependent on outside weather but saturation efficiency can further be increased by creating good porosity and air-water contact within pad.

Performance of the pad material depends on outside weather, both temperature and humidity but the material having good porosity and air-water contact within the pad performed better as compared to others.

Operating parameters of EC structure

Cooling efficiency, temperature drop and increase in humidity inside the cool chamber largely depends on operating parameters. Optimum designed parameters for a given size gives better performance in terms of saturation efficiency. Many scientists evaluated ECSS by using various operating parameters; pad thickness, pad density, pad face velocity, water flow rate, pad orientation, pad volume, porosity (Thakur and Dhingra, 1983; 1985; 1986; Umbarkar *et al.*, 1991; Yadav *et al.,* 2002; Jha and Aleskha-Kudos, 2006; Vala and Joshi, 2010). Optimum pad density, pad thickness, air flow rate and water flow rate are the important parameters and required to be designed for better cooling (Table 3).

Improvement in cooling efficiency can be increases with increase in pad density and pad thickness at certain level with proper water flow rate and pad-face velocity, than decreases for a particular material. Pad density, pad thickness, air flow rate and water flow rate are the important parameters required to be considered for efficient design.

Performance of EC for different agro produces

EC storage structures evaluated for their usefulness in increased shelf-life of commodity, reduction in physiological loss in weight, retention of nutritive value, curing effect, better ripening and other uses. The EC storage structure have been found suitable for extending shelf-life of potato, grape, orange, banana, carrots, ber, pointed gourd, aonla, leafy vegetables, sapota, kinnow, bitter guard, capsicum, cauliflower, pineapple, peach and some other fruits and vegetables (Roy and Pal, 1991; Das, 1999; Das and Chandra, 2001; Singh and Satapathy, 2006; Jha, 2008). The EC storage structure can be utilized for short-term storage of perishable commodities, when outside climate is hot and dry. Evaporative cooling system should be recommended for use by small scale farmers, retailers, wholesalers and exporters to nearby neighboring countries (Table 4).

Looking to the advantages and suitability of ECSS in country, this can be constructed in many parts for storage of fruits and vegetables at low cost as compared to costly mechanical refrigeration system. Being simple in design and operation, this system will be helpful in reducing the post-harvest losses at farm level.

Conclusions

Evaporative cooling system could be more efficient for storage of fruits and vegetables where the

Table 1: Structural Parameter of EC

Source	Structure details
Chouksey (1985)	Developed a solar-cum-wind aspirator type ventilated EC storage structure for potato, onion and other perishables. The details of the structure are; (I) Size : 10.0 x 5.0 x 3.5 m (ii) Shape : long and narrow (iii) Capacity : 20 tones (iv) Structural material: brick (v) Wall thickness : 32 cm (vi) Roofing material : asbestos sheet
Roy and Khurdiya (1986)	Developed EC zero energy cool chamber for storing fresh horticultural produce (Pudina, Dhania, Palak, Methi, Tinda, Chilli, Kerela, Bhindi, Radish, Beet, Carrot, Turnip, Peas, and Cauliflower). During peak summer average cool chamber temperature was maintained to about 23°C. (i) Size : 1.65 x 1.15 x 0.67 m (ii) Structural material: brick, khaskhas, bamboo, gunnybag
Umbarkar *et al.* (1991)	Constructed double brick walled EC storage structure under a shed for extending the shelf life of oranges. (i) Size : 0.75 x 0.75 x 0.75 m (ii) Capacity : 25 kg (iii) Structural material: brick, cement, mortar, gunny bag, bamboo
Rama and Narasimham (1991)	Constructed metallic EC storage chamber, which was covered with G. I. tray as lid and was placed in a G. I. tray. The surfaces of the EC chamber were covered with cotton cloth & kept in shade for storing potato. (i) Size : 1.00 x 0.25 x 0.50 m (ii) Capacity : 25 kg (iii) Structural material: aluminium sheet (28 gauge), cotton cloth, polystyrene sheet
Garg *et al.* (1997)	Developed three non-refrigerated storage structures namely, EC storage, passive draft EC storage and farm storage chamber. EC storage of tomato showed good results as compared to other storages. (i) Size : 1.80 x 1.36 x 1.65 m (ii) Structural material: Thick deodar wood, thermocole
Kapdi *et al.* (1997)	Developed a two walled small size evaporative cooled structure and same was evaluated with respect to the temperature drop obtained and saturation efficiency. (i) Size : 1.0 x 1.0 x 0.75 m (ii) Capacity : 100 kg (iii) Structural material: mild steel, plastic polymer sheet
Thakral *et al.* (2000)	Developed different models namely pot type, almirah model, basket type and zero energy cool chambers. Almirah model showed good results in terms of temperature drop obtained and saturation efficiency as compared to others. Structural details not mentioned.
Sandhu and Ghuman (2002)	Designed and constructed double wall EC storage structure by using low cost locally available materials for potato. (i) Size : 5.49 x 5.49 x 3.39 m (ii) Capacity : 8 tones (iii) Structural material: brick, sand
Kumar *et al.* (2003)	Constructed and evaluated three different capacity double walled evaporative cooled storage structures for potato. Outdoor domestic type store performed better than the other two. (i) Size : (a) 1.89 x 1.28 x 0.07 m (indoor, cap-50 kg) (b) 2.00x 2.00 x 0.75 m (outdoor, cap-100 kg) (c)5.5 x 5.5 x 3.5 m (large outdoor, cap-100 bag) (ii) Structural material : brick, jute bag
Babarinsa (2006)	Constructed a double-walled rectangular evaporative cooled storage structure for tomato. (i) Size : 108 x 108x 120 cm (ii) Capacity : 1.38 m^3 (iii) Structural material: Bricks, sand, cement, particle board

Jha (2008)	Constructed a double walled evaporative cooled storage structure for storage of potato, tomato, kinnow with RCC roof having 22 inclinations with horizontal. (i) Size : 3 x 3 x 3 m (ii) Capacity : 2tones (ii) Structural material: Bricks, cement, sand, iron rods
Mishra *et al.* (2009)	Constructed a double walled evaporative cooled storage structure for storage of potato. (i) Size : 6 x 6 m (ii) Capacity : 5 tones (ii) Structural material : Bricks, cement concrete
Rayaguru *et al.* (2010)	Constructed a double walled evaporative cooling structure for storage of potato, tomato, brinjal, mango, banana and leafy vegetables. (i) Size : 1.650 × 1.150 × 6.75 m. (ii) Structural material : Bricks, sand, cement concrete
Tilahan (2010)	Constructed forced ventilation evaporative cooling storage structure and worked out feasibility and economics of the structure for storage fruit and vegetables, reported that that the evaporative cooling system was capable of significantly ($P<0.001$) reducing the temperature and significantly ($P<0.001$) increasing the relative humidity as required for short time storage of selected fruits and vegetables such as carrot, mango, papaya, banana, mandarin, orange, lemon and tomato. (i) Size :2 x 2 x 1.3m (ii) Capacity : 0.5 ton (iii) Structural material: M.S. sheet, angles, wire mesh
Vala and Joshi (2010)	Designed and developed a forced draft metallic EC storage chamber covered with thick cotton cloth. (i) Size : 1525 x 1006 x 1220 mm (ii) Capacity : 100 kg (ii) Structural material: M.S. sheet, angles, wire mesh, thick cotton cloth
Chinenye N M (2011)	Constructed a jacketed type double walls evaporative cooling structure for storage of tomato. The top of the structure covered with an aluminium foil. (i) Size : 60 cm x 52 cm x 85cm (ii) Structural material : clay, bamboo stick, aluminium foil
Samira *et al.* (2011)	Developed a multi pad evaporative cooler having three units, viz., an air conditioning unit, a watering system and a storage chamber for storage of green pepper. (i) Size : 2 x 2 x 1.3 m (ii) Capacity : 0.5 tone (ii) Structural material : Sheet metal, iron angles, gunny bag

Table 2: Efficiency of EC Pad Materials

Source	Pad material	Performance
Roy and Khurdiya (1986)	(i) River bed sand	Inside temperature of cool chamber was 20°C less than the ambient temperature and relative humidity was 95% during peak summer months.
Umbarkar *et al.* (1991)	(i) Fine sand, (ii) Brick bat, (iii) Coarse sand	Maximum temperature drop of 18.5°C and maximum RH of 94.8% were observed for brick batt which were significantly superior over the fine sand and coarse sand material throughout the storage period. Coarse sand and fine sand showed more or less equal drop in temperature.
Abdalla *et al.* (1995)	(i) Date palm fibres, (ii) Date palm leaves, (iii) Cel-dek	Evaluated for 100 mm pad thickness and reported that best cooling was obtained by Cel-dek (temp. drop 12-23° C, SE 75.3-90.5%) followed by date fibre pad (temp drop 11-21°C, SE 69-83.3%) and date leave pad (temp drop 9-18°C, SE 54-69 %).
Mekonnen (1996)	(i) Clay particles, (ii) Wood shaving, (iii) Sack	Clay showed higher saturation efficiency and temperature reduction (8°C, RH 76%) than others. Wood shavings and sack showed susceptibility to decay.
Kapdi *et al.* (1997)	(i) Brick bat, (ii) Saw dust, (iii) Wheat straw	Brick bat gave better performance (temp drop 4.2- 8.8°C, RH 85-98 %, SE 48.5-97% over that with wheat straw (temp drop 2.1-5.9°C, RH 65.9-94.3%, SE 32-62.5%) and saw dust (temp. drop 1.5-7.2°C, RH 68.6-95.9%, SE 19-91 %).

Al-Sulaiman 2002)	(i) Jute (ii) Luffa (iii) Commercial pad (iv) Palm fibre	Jute performed better with cooling efficiency of 62.1% followed by luffa (55.1%), commercial (49.5%) and palm fibre (38.9%).
Liao and Chiu (2002)	(i) Coarse fabric PVC sponge (ii) Coarse fine PVC sponge	Reported saturation efficiency ranged from81.75% -84.48% with Coarse fabric PVC sponge whereas 76.68% - 91.64% with fine fabric PVC sponge
Sandhu and Ghuman (2002)	(i) Sand	Observed temperatures drop of 8–14.9ºC with RH 90-96.3 % inside the structure.
Lalmani *et al.* (2004)	(i) River bed sand, (ii) Morum, (iii) mixture of riverbed sand and morum	Reported temperature drop of 15.4º C, 14.4º C & 14.2º C in river bed sand, morum and mixture of riverbed sand and morum, respectively and maintained more than 80% RH in all three.
Olosunde (2006)	(i) Jute, (ii) Hessian, (iii) Cotton waste.	Reported that the jute material had the overall advantage over the other materials.
Gunhan *et al.* (2007)	(i) Pumice stones (ii) Volcanic tuff (iii) Greenhouse shedding net	It was found that volcanic tuff performed better and gave saturation efficiency of 63-81%.
Jha S N (2008)	(i) Partal wood shavings	The maximum drop in temperature in no-load condition was observed 20ºC as against outside temperature 45ºC. Whereas RH maintained about 75%.
Vala and Joshi (2010)	(i) Wood wool, (ii) Coconut coir, (iii) wood shavings	The highest temperature drop of 12.06°C was achieved with wood wool as compared to coconut coir and wood shavings. Coconut coir and wood shavings showed more or less equal drop in temperature.
Chinenye (2011)	(i) clay	Maximum temperature reduction of up to 10°C and relative humidity 92 % observed during storage period.
Kulkarni (2011)	(i) Aspen fibre (ii) Rigid cellulose (iii) Corrugated paper (iv) HDPE	The higher saturation efficiency in the range of 93.7–87.5% was observed with aspen fibre followed by 86.2-77.5%, 80.2 – 88.4% and 81.9 – 89.7% with rigid cellulose, corrugated paper and HDPE respectively.
Nitipong and Sukum (2011)	(i) Rice husk (ii) Recycled HDPE	The average saturation efficiency of 55.9% and 29.1% was observed with rice husk and recycled HDPE respectively.
Samira *et al.* (2011)	(i) Charcoal	Maximum temperature drop of 12°C and RH between 70–82.4% observed during storage period
Banyat and Bunjerd (2013)	(i) Curtain fabric (ii) raw cotton fabric	Curtain fabric gave higher average saturation efficiency of 54.8% as compared to raw cotton fabric of 33.2%.

Table 3: Effect of Operating Parameters on performance of EC Structure

Source	Operating parameters	Performance
Thakur and Dhingra (1983)	(i) Pad thickness, (ii) pad face air velocity, (iii) water flow rate, (iv) pad orientation	Saturation efficiency initially increased with increase in pad thickness, pad face air velocity and water flow rate then remained constant or decreased marginally. Saturation efficiency was observed higher in horizontal pad thickness as compared to vertical pad thickness. The effect of water flow rate remained less pronounced than the effect of pad thickness and pad face air velocity.
Thakur and Dhingra (1985)	(i) Pad face air velocity, (ii) Density, (iii) Pad thickness	Effect of pad-face velocity on the pressure drop was more pronounced than that of pad density and pad thickness.
Dhingra and Thakur (1986)	(i) Pad density (ii) pad thickness	When pad density of an evaporative cooling increased, the SE increased. For achieving SE 70-75%, a pad thickness of 5 cm and density in the range of 30-40 kgm^{-3} was desirable but when SE of more than 90% is required, a pad thickness of 5 cm and pad density

		of more than 45 kgm^{-3} may be used.
Umbarkar *et al.* (1991)	Pad thickness: 100, 150 and 200 mm	Thickness of cooling pad had no influence on relative humidity. The brick bat pad of 100 mm width gave best results.
Yadav *et al.* (2002)	(i) Pad thickness 50, 75 & 100 mm (ii) Air flow rate 0.3, 0.45, 0.6 & 0.75 m/sec (iii) Water flow rate 5,10 &15 l/min	If air and water flow rates were not limiting, pad thickness did not have any effect on cooling. Selection of water flow rate depends on air flow rate and pad thickness. As air flow rate increased, water flow rate increased. The pressure drop increased with increase in pad thickness.
Jha and Aleskha Kudos (2006)	(i) Pad thickness 3,7, 10 &15 mm (ii) Pad volume0.00075, 0 .175,0.00250 & 0.00375 m^3 (iii) Bulk density (iv) Porosity, %	Partal wood shavings with 7 mm pad thickness found best for maximum in cooling effect and porosity than safeda wood shavings and root (plants).
Vala and Joshi (2010)	(i) Pad thickness 50, 100 & 150 mm (ii) Pad density 15, 20, 25 kg/m^3 (iii) Water flow rate 3 lph (iv) Air flow rate 50kmph	The wood wool gave average maximum temperature drop, increase in RH and saturation efficiency with pad thickness of 150mm and pad density $25kg/m^3$. The highest saturation efficiency of 93.89% was achieved with wood wool material at density $25kg/m^3$ and thickness 150mm.

Table 4: Performance of EC for Different Agro Produce

Source	Agric. Produce	Performance
Maini *et al.* (1984)	Potato tubers	Potato tubers could be stored up to 5 weeks with PLW of 3.3 % in evaporative cool storage compared with 18.6 % PLW at room temperature and 9.3 % in the desert cooler for the same period.
Chouksey (1985)	Potato	Potato could be stored from first week of March to 16th June. Onion could be stored from July to November with proper ventilation.
Roy and Khurdiya (1986)	Leafy vegetables (Pudina, Dhania, Palak, Methi), Tinda, Chilli, Kerela, Bhindi, Radish, Beet, Carrot, Turnip, Peas, Cauliflower	Shelf life of leafy vegetables increased to 3 days with PLW of 13-18 % from less than 1 day with PLW of 30-58 % at ambient and for other vegetables the shelf life was increased to 6 days with 5-6.8 % PLW as compared to 1-3 days in the month of May-June.
Singh *et al.* (1987)	Grapes	PLW was higher at room temperature storage as compared to zero energy cool chamber under different treatments.
Thingu *et al.* (1991)	Tomato	Evaporative cooled storage showed 100% ripening index, double lycopene content and less shrinkage as compared to control sample.
Umbarkar *et al.* (1991)	Orange	Shelf life up to 32 days with less qualitative loss and PLW.
Reddy and Nagaraju (1993)	Sapota	Shelf life of sapota fruit cv. Kalipatti increased with reduced PLW and shriveling, higher firmness and less rotting leading to recovery of higher percent of marketable fruits.
Garg *et al.* (1997)	Tomato	Tomato could be stored up to 50 days in EC storage, 32 days in passive draft EC storage and 30 days in farm level storage as compared to 14 days in ambient storage.
Pal *et al.* (1997)	Kinnow mandarins	Shelf life increased up to 40 days in EC chamber as against 15 days at room temperature.
Kumar and Gupta (1999)	Potato	Potatoes could be safely stored up to 13th week of storage in EC storage as against 8th week in ambient storage without shrinkage and sprouting.
Wasker and Roy (2000)	Banana	Banana fruit cv. Basrai could be stored up to 20 days as against 14 days at room temperature.
Dash and Chandra	Economic feasibility	EC structures could be adopted in places where cold storage facilities

(2001)		are not available or the transportation cost to the cold storage is very high to offset the advantages of keeping produce in cold storage.
Bhardwaj and Sen (2003)	Mandarin (Nagpur santra)	Mandarin fruit with neem extract treatment could be stored up to 42 days for retaining post-harvest quality.
Dhemre and Wasker (2003)	Mango	Kesar mango fruits with wax treatment could be stored up to 25 days as against 20 days at room temperature.
Mordi and Olorundu (2003)	Tomato	Fresh tomatoes could be stored for 11 days as against 4 days at ambient temperature whereas tomatoes treated with film packaging could be stored for 18 days as against 13 days under ambient condition while completely sealed sample for 8 days as against 6 days under ambient condition.
Singh and Satapathy (2006)	Bitter guard, capsicum, tomato, cauliflower, pineapple, peach	The shelf life of bitter guard, capsicum & cauliflower was increased for 5 days whereas shelf life of tomato, pineapple, peach increased for about 6 to 9 days under evaporative storage as compared to ordinary room condition.
Jha (2008)	Potato, Kinnow, tomato	Safe storage period was found to be 50, 25 & 4 days for potato, kinnow and tomato respectively with 10% loss in weight
Mishra *et al.* (2009)	Potato, tomato	The shelf life of potato was observed 60 days as against 30 days in ambient storage while tomato was safely stored for 14 days as against 7 days at ambient condition.
Tilahan (2010)	Economical feasibility	The evaporative cooling system was capable of significantly (P<0.001) reducing the temperature and significantly (P<0.001) increasing the relative humidity as required for short time storage of selected fruits and vegetables such as carrot, mango, papaya, banana, mandarin, orange, lemon and tomato.
Chinenye (2011)	Tomato	The evaporative cooled storage was able to preserve freshly harvested tomato for 19days.
Mogaji and Fapetu (2011)	Tomato, carrot	The shelf life of tomato and carrot was extended by 14 days relative to ambient storage.
Samira *et al.* (2011)	Green pepper	The shelf-life of green pepper was effectively improved 20 days as compared to storage under ambient condition.

climate is hot and dry, can also be used under other climatic conditions. Being low cost of construction, negligible operational cost and having other advantages over mechanical refrigeration the evaporative cooled storage structures can be used in any place where cold storage facilities are not available. EC storage structure can have wide application if designed properly for different locations. Evaporative cooling system is easy to operate, efficient and affordable most especially for farmers in developing countries who may find other methods of preservation quite expensive and unaffordable.

References

Ai-Sulaiman F (2002). Evaluation of the performance of local fibres in evaporative cooling. *Energy Conservation and Management*, 43: 2267-2273.

Abdalla KN, Abdalla AM and Al-Hashim HA (1995). Utilization of date palm leaves and fibers as wetted pads in evaporative coolers. *Agricultural Mechanization in Asia, Africa and Latin America*, 26(2): 52-54.

Adamu UD, Igbeka JC and Audu I (2006). Performance efficiency of an active evaporative cooling system for the storage of fruits and vegetables in a semi arid environment. *Agricultural Mechanization in Asia, Africa and Latin America*, 37(4): 36-41.

Adebisi OW, Igbeka JC and Olurin TO (2009). Performance evaluation of absorbent materials in evaporative cooling system for the storage of fruits and vegetables. *International Journal of Food Engineering*, 5(3): 1-14.

Arya M, Arya A and Rajput SPS (2009). An environment friendly cooling option. *Journal of Environmental Research and Development*, 3(4): 1254-1261.

Babarinsa FA (2006). Performance evaluation of an evaporative cooling system for fruits and vegetables storage in the tropics. *Agricultural Mechanization in Asia, Africa and Latin America*, 37(4): 60-65.

Banyat N and Bunjerd P (2013). Performance study of cooling pads. *Advanced Material Research*, 664: 931-95.

Basediya AL, Samuel DKV and Beera V (2013). Evaporative cooling system for storage of fruits and vegetables-a review. *Journal of Food Science and Technology*, 50(3): 429-442.

Bhardwaj RL and Sen NL (2003). Zero energy cool-chamber storage of mandarin. *Journal of Food Science and Technology,* 40(6): 669-674.

Bhatnagar DK, Pandita ML and ShrivastavaVK (1990). Effect of packaging materials and storage conditions on fruit acceptability and weight loss of tomato. *National Workshop on Post-harvest Management of Fruits and Vegetables, 14-16 March, Nagpur, India.*

Bucklin RA, Leary JD, McConnell DB and Wilkerson EG (2004). Fan and pad greenhouse evaporative cooling system. *University of Florida, Gainesville, FL* 32611-0570.

Chadha KL (2001). Handbook of horticulture. *Indian Council of Agricultural Research, New Delhi*, pp. 1031.

Chakraverty A, Mujumdar AS, RaghvanGS and Ramaswamy HS (2003). Handbook of postharvest technology. Cereals, fruits, vegetables, tea and spices. *Marcel Dekker, Inc, New York.*

Chaudhary ML (2004). Recent developments in reducing postharvest losses in the Asia-Pacific region. *Paper presented at the seminar on "Reduction of Post Harvest Losses of Fruits and Vegetables" held during Oct. 5-11 at New Delhi.*

Chinenye NM (2011). Development of clay evaporative cooler for fruits and vegetables preservation. *Agricultural Engineering International,* 13(1), Manuscript no.1781.

Chouksey RG (1985). Design of passive ventilated and evaporatively cooled storage structure for potato and othersemiperishables. *Proceeding of Indian Society of Agricultural Engineering,* 3: I45-I51.

Clément V, James T and S W. (2009). *Postharvest Technologies for Horticultural Crops,* 2: 25-47 California, USA.

Dash SK and Chandra P (1999). Ananalysis of the thermal environment of an evaporatively cooled storage structure. *Journal of Agricultural Engineering,* 36(4): 59-73.

Dash SK and Chandra P (2001). Economic analysis of evaporativelycooled storage of horticultural produce. *Agricultural Engineering Today,* 25 (3-4): 1-9.

Dash SK, Chandra Pand Kar A (2006). Evaporatively cooled storage of horticultural produce. *Journal of Food Science and Technology,* 43(2): 105-120.

Dharmasena DAN and Kumari AHMRR (2005). Suitability of charcoal-cement passive evaporative cooler for banana ripening. *The Journal of Agricultural Sciences,* 1(1): 19-30.

Dhemre JK and Wasker DP (2003). Effect of post harvesttreatments on shelf-life and quality of mango in evaporative cool chambers and ambient conditions. *Journal of Food Science and Technology,* 40(3): 316-18.

Dhingra DP and Thakur BC (1986). Effect of pad density on thesaturation efficiency of an evaporative cooler. *Journal of Agricultural Engineering,* 23(3): 271-273.

FAO (1995). Fruit and Vegetables processing, FAO. *Agricultural Service Bulletin 119, Rome.*

FAO (2006). *Postharvest Management of Fruit and Vegetables in the Asia-Pacific.*

Ganesan M, Balasubramaniam K and Bhavani RV (2004). Studies on the application of different levels of water on zero energy cool chamber with reference to the shelf-life of brinjal. *Journal Indian Institution of Science,* 84: 107-111.

Garg S, Gupta AK and Kumar A (1997). Storage of tomatoes inevaporatively cooled chamber. *Journal of Research, Punjab Agricultural University,* 34(3): 320-327.

Gómez EV, Rey Martínez FC and Tejero González A (2010). The phenomenon of evaporative cooling from a humid surface as an alternative method for air-conditioning. *International Journal of Energy and Environment,* 1(1): 69-96.

Gunhan T, Demir V and Yagcioglu AK (2007). Evaluation of the suitability of some local materials as cooling pads. *Biosystems Engineering,* 96: 369-377.

Habibunnisa EA, Arora E and Narsimham P (1998). Extension of storage life of the fungicidal waxol dip treated apple and mangoes under evaporatively cooling conditions. *Journal of Food Science and Technology,* 25(2): 75-75.

http://www.assocham.org/ (Study report by The Associated chamber of commerce and industry, August-2013)

Jha SN (2008). Development of a pilot scale evaporative cooled storage structure for fruits and vegetables for hot and dry region. *Journal of Food Science and Technology,* 45(2): 148-151.

Jha SN and Aleksha Kudos SK (2006). Determination of physical properties of pads for maximizing cooling in evaporative cooled store. *Journal of Agricultural Engineering,* 43(4): 92-97.

Jha SN and Chopra S (2006). Selection of bricks and cooling pad for construction of evaporatively cooled storage structure. *Institute of Engineers, (I) (AG),* 87, 25-28.

Kadar AA (1992). Post harvest technology of horticultural crops, Cooperative extension. *Univ. of California Special Publication No.* 331: 35-43.

Kapdi SS, Joshi DC and Bhalodia VB (1997). Effectiveness of local material as cooling pad in evaporative cooled storage structure. *Paper presented at XXXIII Annual Convention of Indian Society of Agricultural Engineering, MPKV, Rahuri, Dec.* 18-20.

Kulkarni RK and Rajput SPS (2011). Comparative performance of evaporative cooling pads of alternative materials. *International Journal of Advanced Engineering Sciences and Technologies,* 10(2): 239-244.

Kumar A, Gupta AK, Ghuman BS and Grover L (2003).Effectiveness of evaporatively cooled stores of various capacities constructed under different ambient conditions. *Agricultural Engineering Today,* 27(2-3): 38-48.

Kumar S and Nath V (1993). Storage stability of aonla fruits-A comparative study of zero-energy cool chamber versus room temperature. *Journal of Food Science and Technology,* 30(3): 202-203.

Kumar Sand Gupta AK (1999). Studies on non-refrigerated storage of potatoes. *Journal of Research, Punjab Agricultural University,* 36(3-4): 242-51.

Lalmani PM, Balki PM, Kosale MN and Umbarkar SP (2004). Evaporatively cool storage for orange. *XXXIII Annual Convention of Indian Society of Agricultural Engineering,* 16-18: 301-02.

Liao CM and Chiu KH (2002). Wind tunnel modeling the system performance of alternative evaporative cooling pads in Taiwan Region. *Building Environment,* 37: 177-187.

Liberty JT, Okonkwo WI and Echiegu EA (2013). Evaporative cooling: apostharvest technology for fruits and vegetables preservation. *International Journal of Scientific and Engineering Research,* 4(8): 2257-2266.

Maini SB, Anand RK, Chandan SS and Visishth SC (1984). Evaporative cooling system for storage of potato. *Indian Journal of Agricultural Science,* 54(3): 193-195.

Maini SB, Anand JC (1992). Evaporative cooling system for postharvest management of horticultural crops. *Agricultural Marketing,* 35(3): 34-39.

Mekonnen A (1996). Effectiveness study of local materials as cooling media for shelters in hot climates. *Agricultural Mechanization in Asia, Africa and Latin America,* 27(2): 64-66.

Mishra BK, Jain NK, Kumar S, Doharey DS and Sharma KC (2009). Shelf life studies on potato and tomato under evaporative cooled storage structure in Southern Rajasthan. *Journal of Agricultural Engineering,* 46(3): 26-30.

Mogaji TS and Fapetu OP (2011). Deveplopment of an evaporative cooling system for the preservation of fresh vegetables. *African Journal of Food Science,* 5(4): 255-266.

Mordi JI and Olorunda AO (2003). Effect of evaporative cooler environment on the visual qualities and storage life of fresh tomatoes. *Journal of Food Science and Technology,* 40(3): 587-591.

Nagaraju CG and Reddy TV (1995). Deferral of banana fruit ripening by cool chamber storage. *Advance Horticulture Science,* 9: 162-166.

Nitipong S and Sukum K (2011). Recycled high-density polyethylene and rice husk as a wetted pad in evaporative cooling system. *American Journal of Applied Sciences,* 8(2): 186-191.

Okunade SO and Ibrahim MH (2011). Assessment of the evaporative cooling system for storage of Irish potato. *PAT,* 7 (1): 74-83 ISSN: 0794-5213.

Olosunde WA (2006). Performance evaluation of absorbent materials in the evaporative cooling system for the storage of fruits and vegetable. *M.Sc Thesis, Department of Agricultural Engineering, University of Ibadan, Ibadan.*

Pal RK, Roy SK and Shrivastava S (1997). Storage performance of kinnow mandarins in evaporative cool chamber and ambient condition. *Journal of Food Science and Technology,* 34(3): 200-203.

Rama V and Narsimham P (1991). Evaporative cooling of potatoes in small naturally ventilated chambers. *Journal of Food Science and Technology,* 28(3): 145-148.

Rayaguru K, Khan MdK and Sahoo NR (2010).Water use optimization in zero energy cool chambers forshort term storage of fruits and vegetables in coastal area. *Journal of Food Science and Technology,* 47(4): 437-441.

Reddy TV and Nagaraju CG (1993). Extension of postharvest life of sapota fruits by cool chamber storage. *Abstract of Golden Jubilee symposium on Horticultural Research- Changing Scenario, held at Bangalore.* May, 24-28: 360.

Region (2006). *Asian Productivity Organization,* ISBN: 92-833-7051-1.

Roy SK and Pal RK (1991). A low cost zero energy cool chamber for short-term storage of mango. *Acta Horticulture,* 291: 519-524.

Roy SK and Khurdiya DS (1986). Studies on evaporatively cooled zero energy cool chambers for storage of horticultural produce. *Indian Food Packers,* 40(6): 26-31.

Samira A, Woldetsadik K and Workneh TS (2011). Postharvest quality and shelf life of some hot pepper varieties. *Journal of Food Science and Technology,* 50 (5): 842-855.

Sandhu APS and Ghuman BS (2002). Design and construction of on-farm brick sand store for potatoes. *Journal of Research, Punjab Agricultural University,* 39(3): 417-25.

Singh JP, Singhrot RS, Sharma RK and Sandooja JK (1987). A note on comparison of zero energy cool chambers versus room temperature in combination with antifungal fumigants for storage of grapes. *Haryana Journal of Horticultural Science,* 16(1-2): 92-97.

Singh RKP and Satapathy KK (2006). Performance evaluation of zero energy cool chamber in hilly region. *Agricultural Engineering Today,* 30(5-6): 47-56.

Singh S, Singh R and Kumar J (1998). Shelf-life of plum as affected by some storage conditions. *Haryana Journal of Horticultural Science,* 16: 98-102.

Sunmonu M, Falua KJ and David AO (2014). Development of a low-cost refrigerator for fruits and vegetables storage. *International Journal of Basic and Applied Science,* 2(3): 85-93.

Suryawanshi SH, Unde PA and More HG (2005). Low cost storage of fruits and vegetables. *Proceeding XXXIX Annual Convention and Symposium of Indian Society of Agricultural Engineering,* 9-11: 260-261.

Thakral R, Sangwan V, and Sharma DN (2000). Performance evaluation of evaporative cooling systems for storage of perishable products in rural kitchens. *Agricultural Engineering Today, Indian Society of Agricultural Engineering,* 24 (4): 40-43.

Thakur BC and Dhingra DP (1983). Parameters influencing the saturation efficiency of an evaporative cooler. *Journal of Research, Punjab Agricultural University,* 20(3): 345-352.

Thakur BC and Dhingra DP (1985). Resistance to air flow in an evaporative cooler. *Journal of Research, Punjab Agricultural University,* 22(3): 521-526.

Thingu R, Chand N, Habibunnisa, Arvinda Prasad B and Ramana KVR (1991). Effect of evaporative cooling storage on ripening and quality of tomato. *Journal of Food Quality*, 14(2): 127-144.

Thomson JF, Mitchell FG, Runsey TR, Kasmire RF and Crisosto CH (1998). Commercial cooling of fruits, vegetables and flowers. *UC Davis, USA, DANR publication No.* 21567: 61-68.

Tilahan SW (2010). Feasibility and economic evaluation of low-cost evaporative cooling system in fruit and vegetables storage. *African Journal of Food, Agriculture Nutrition and Development,* 10(8): 2984-2997.

Umbarkar SP, Bonde RS and Kolase M N (1991). Evaporatively cooled storage structures for oranges (Citrus reticulatu). *Agricultural Engineering Today,* 1(1): 26-32.

Vala KV and Joshi DC (2010). Evaporatively cooled transportation system for perishable commodities. *Journal of Agricultural Engineering,* 47(1):27-33.

Wasker DP and Roy SK (2000). Zero energy cool chamber storage of fruits-A review. *Indian Food Packer,* Nov-Dec: 144-147.

Wilson LG, Boyette MD and Estes EA (1995). Postharvest handling and cooling of fresh fruits, vegetables and flowers for small farms. *Leaflets,* 800-804. North Carolina cooperative extension accessed on-line at:http//www.foodsafety.org/nc/nc 1055. (www.dualheating.com)

Xuan YMF, Xiao F, Niu XF, Haung X and Wang SW (2012). Research and application of evaporative cooling in China: A review (I). *Renewable and Sustainable Energy Reviews,* 16(5): 3535-3546.

Yadav VK, Singh A and Chandra P (2002). Experimental evaluation of the effect of fan and pad evaporative cooing system parameters on greenhouse cooling. *Journal of Agricultural Engineering,* 39(3): 49-53.