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; Summon 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 (Adesibi 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 CO₂). 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; Jha 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; Lalmi 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 Dhirg, 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

<table>
<thead>
<tr>
<th>Source</th>
<th>Structure details</th>
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</table>
| 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. |
(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) 2.00 x 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 |
(i) Size : 108 x 108 x 120 cm  
(ii) Capacity : 1.38 m³  
(iii) Structural material: Bricks, sand, cement, particle board |
Jha (2008) Constructed a double walled evaporative cooled storage structure for storage of potato, tomato, kinnaw with RCC roof having 22 inclinations with horizontal.
(i) Size : 3 x 3 x 3 m
(ii) Capacity : 2 tones
(iii) 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 x 1.150 x 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 1.3 m
(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
(iii) 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 ton
(iii) Structural material : Sheet metal, iron angles, gunny bag

Table 2: Efficiency of EC Pad Materials

<table>
<thead>
<tr>
<th>Source</th>
<th>Pad material</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roy and Khurdiya  (1986)</td>
<td>(i) River bed sand</td>
<td>Inside temperature of cool chamber was 20°C less than the ambient temperature and relative humidity was 95% during peak summer months.</td>
</tr>
<tr>
<td>Umbarkar et al. (1991)</td>
<td>(i) Fine sand, (ii) Brick bat, (iii) Coarse sand</td>
<td>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.</td>
</tr>
<tr>
<td>Abdalla et al. (1995)</td>
<td>(i) Date palm fibres, (ii) Date palm leaves, (iii) Cel-dek</td>
<td>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 %).</td>
</tr>
<tr>
<td>Kapdi et al. (1997)</td>
<td>(i) Brick bat, (ii) Saw dust, (iii) Wheat straw</td>
<td>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 %).</td>
</tr>
</tbody>
</table>
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 from 81.75% - 84.48% with Coarse fabric PVC sponge whereas 76.68% - 91.64% with fine fabric PVC sponge.


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) Partial wood shavings The maximum drop in temperature in no-load condition was observed 20°C as against outside temperature 45°C. 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

<table>
<thead>
<tr>
<th>Source</th>
<th>Operating parameters</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thakur and Dhingra (1983)</td>
<td>(i) Pad thickness, (ii) pad face air velocity, (iii) water flow rate, (iv) pad orientation</td>
<td>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.</td>
</tr>
<tr>
<td>Thakur and Dhingra (1985)</td>
<td>(i) Pad face air velocity, (ii) Density, (iii) Pad thickness</td>
<td>Effect of pad-face velocity on the pressure drop was more pronounced than that of pad density and pad thickness.</td>
</tr>
<tr>
<td>Dhingra and Thakur (1986)</td>
<td>(i) Pad density, (ii) pad thickness</td>
<td>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</td>
</tr>
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of more than 45 kgm$^{-3}$ may be used.

Vala 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 volume: 0.00075, 0.00175, 0.00250 & 0.00375 m$^3$  
(iii) Bulk density  
(iv) Porosity, %  
Partial 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>
<thead>
<tr>
<th>Source</th>
<th>Agric. Produc</th>
<th>Performance</th>
</tr>
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<tbody>
<tr>
<td>Maini et al. (1984)</td>
<td>Potato tubers</td>
<td>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.</td>
</tr>
<tr>
<td>Chouksey (1985)</td>
<td>Potato</td>
<td>Potato could be stored from first week of March to 16th June. Onion could be stored from July to November with proper ventilation.</td>
</tr>
<tr>
<td>Roy and Khudiya (1986)</td>
<td>Leafy vegetables (Pudina, Dhania, Palak, Methi), Tinda, Chilli, Kerela, Bhindi, Radish, Beet, Carrot, Turnip, Peas, Cauliflower</td>
<td>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.</td>
</tr>
<tr>
<td>Singh et al. (1987)</td>
<td>Grapes</td>
<td>PLW was higher at room temperature storage as compared to zero energy cool chamber under different treatments.</td>
</tr>
<tr>
<td>Thingu et al. (1991)</td>
<td>Tomato</td>
<td>Evaporative cooled storage showed 100% ripening index, double lycopene content and less shrinkage as compared to control sample.</td>
</tr>
<tr>
<td>Umbarkar et al. (1991)</td>
<td>Orange</td>
<td>Shelf life up to 32 days with less qualitative loss and PLW.</td>
</tr>
<tr>
<td>Reddy and Nagaraju (1993)</td>
<td>Sapota</td>
<td>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.</td>
</tr>
<tr>
<td>Garg et al. (1997)</td>
<td>Tomato</td>
<td>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.</td>
</tr>
<tr>
<td>Pal et al. (1997)</td>
<td>Kinnow mandarins</td>
<td>Shelf life increased up to 40 days in EC chamber as against 15 days at room temperature.</td>
</tr>
<tr>
<td>Kumar and Gupta (1999)</td>
<td>Potato</td>
<td>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.</td>
</tr>
<tr>
<td>Wasker and Roy (2000)</td>
<td>Banana</td>
<td>Banana fruit cv. Basrai could be stored up to 20 days as against 14 days at room temperature.</td>
</tr>
<tr>
<td>Dash and Chandra</td>
<td>Economic feasibility</td>
<td>EC structures could be adopted in places where cold storage facilities</td>
</tr>
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</table>

Table 4: Performance of EC for Different Agro Produce
are not available or the transportation cost to the cold storage is very high to offset the advantages of keeping produce in cold storage.

Mandarin fruit with neem extract treatment could be stored up to 42 days for retaining post-harvest quality.

Kesar mango fruits with wax treatment could be stored up to 25 days as against 20 days at room temperature.

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.

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.

Safe storage period was found to be 50, 25 & 4 days for potato, kinnow and tomato respectively with 10% loss in weight.

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.

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.

The evaporative cooled storage was able to preserve freshly harvested tomato for 19 days.

The shelf life of tomato and carrot was extended by 14 days relative to ambient storage.

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**


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


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