



Innovative composite wall designs for evaporatively cooled structures for storage of perishables

SANGEETA CHOPRA¹ and RANDOLPH BEAUDRY²

ICAR-Indian Agricultural Research Institute, New Delhi 110 012

Received: 3 December 2016; Accepted: 30 July 2018

ABSTRACT

The thermal performance of prototype evaporatively cooled (EC) structures using novel wall materials like pervious concrete (PC) and mesh supported fabric (MSF) were compared to a traditional brick-sand-brick (BSB) design. Structures were constructed at the Indian Agricultural Research Institute, Delhi and instrumented with thermocouples on the floor, on inner and outer surfaces of the walls and roof and in a 100 kg mass of simulated produce. The composite walls, roof, and floor were of unique designs and were made of specialized materials unused till now in EC structures. The thermal transmittance of the wall materials varied widely. Compared to BSB, average product temperatures over 5 days in June were approximately 2.5°C lower in PC and 3.5 °C lower in MSF structures. The low thermal mass of the composite walls of MSF structure (almost 1/60th that of BSB walls), made the MSF structure cooler at night as it could follow the ‘cooler’ night air. Cost estimates for labour and materials suggested that PC and MSF structures would be 40 to 60% cheaper to construct than BSB structures.

Key words: Brick sand brick, Evaporatively cooled structures, Pervious concrete, Mesh supported fabric

India is the second largest producer of fruits and vegetables in the world. Losses of vegetables and fruits during packaging and transport are estimated to be about 30% (Chadha 2001) and when coupled with poor offtake, it can spell major economic disaster for the farmers.

Farmers are sometimes faced with surplus production. In this situation, the surplus results in a drop in the demand and a concomitant reduction in price. Produce also suffers postharvest losses in quantity and value due to a lack of appropriate storage options. Smallholder farmers have little capacity to improve their situation if they cannot preserve the value of their harvested products. As a result, farmers have been seeking other options for employment and rapidly relocating to urban centers as they try to improve their prospects. Farmers are increasingly leaving farming as an occupation, because there is not sufficient money in the activity to sustain their activities or their families. This also places the stability of the Indian food supply at risk.

Evaporatively cooled (EC) storage structures have

been evaluated in India and a number of other countries for storage of a variety of fresh fruits and vegetables (Chouksey 1985, Roy and Khurdiya 1986, Umbarkar *et al.* 1998, Chopra *et al.* 2001). These have been suggested to be a better option in comparison to refrigerated storage structures, owing to less initial capital investment and minimal operational cost, making them accessible to lower income farmer/entrepreneurs (Vala *et al.* 2014) and not subject to intermittent electrical power.

The EC storage structure is based on the principle that evaporation causes cooling. In most configurations, a room is built with a wetted medium sandwiched between outer and inner walls like the traditional brick-sand-brick (BSB) design. The exterior wall is porous and permits water vapour to be lost from the wetted medium. As the water evaporates, heat is drawn from the structure, cooling it and any produce that resides within.

Technological innovations in EC rooms are needed to make them more effective with lower costs and, in the end, more impactful on farmer profits. This paper deals with the evaluation of innovative prototype evaporatively cooled storage systems with different wall materials and designs and the comparison of these innovative designs with the traditional BSB structure design. Our long-term goal is to design an EC storage structure that is efficient in terms of heat loss from the commodity, is inexpensive and easy to construct, and is capable of being converted into a refrigerated storage.

¹Principal Scientist (email: dhingra.sangeeta@gmail.com), Division of Agricultural Engineering, IARI, New Delhi. ²Professor and Graduate Program Director (email: beaudry@msu.edu), Michigan State University, Department of Horticulture, Plant and Soil Science Bldg., 1066 Bogue Street, Room A22, East Lansing MI 48824-6252.

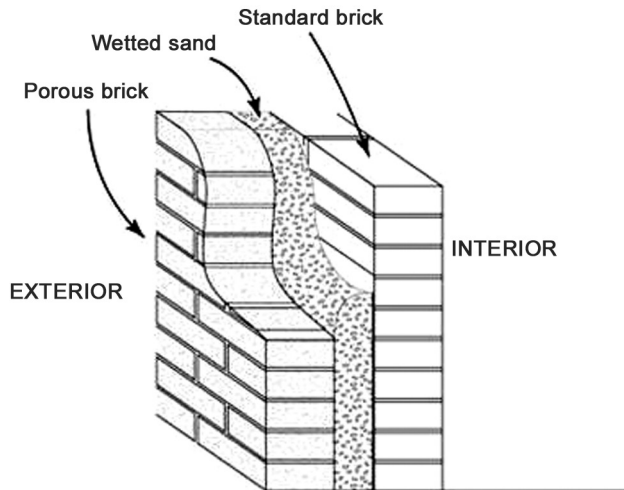


Fig 1 Wall detail of a traditional brick-sand-brick EC room such as that built at the CIPHET research station (Chopra *et al.* 2004).

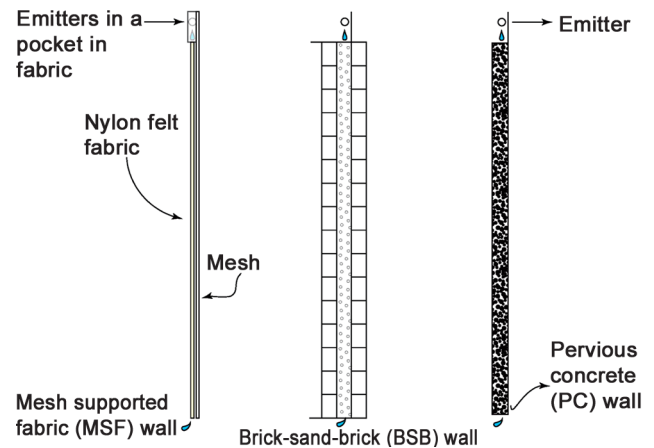


Fig 2 Novel wall designs of pervious concrete (PC) and mesh supported fabric (MSF) as compared with brick sand brick wall (BSB) design.

MATERIALS AND METHODS

Prototype evaporatively cooled (EC) structures of novel innovative structural designs and materials (Chopra and Beaudry 2016) along with the traditional brick-sand-brick (BSB) design (Fig. 1) as described by Roy and Pal (1994) and Chopra *et al.* (2004) were constructed at the Division of Agricultural Engineering, Indian Agricultural Research Institute (IARI), New Delhi (28°37'52.5"N 77°09'05.2"E).

These designs were novel because of the design of the composite walls and the selection of previously unused materials in EC structures. The new designs included the use of pervious concrete (PC) and *mesh supported fabric* (MSF) named after the composite wall design (Fig 2). PC is a specially made concrete that possesses a high degree of porosity and capillarity such that wetting a vertical slab of the material permits both vertical and horizontal water movement in the composite. Mesh supported fabric (MSF) uses an iron mesh to support a fabric that, like pervious

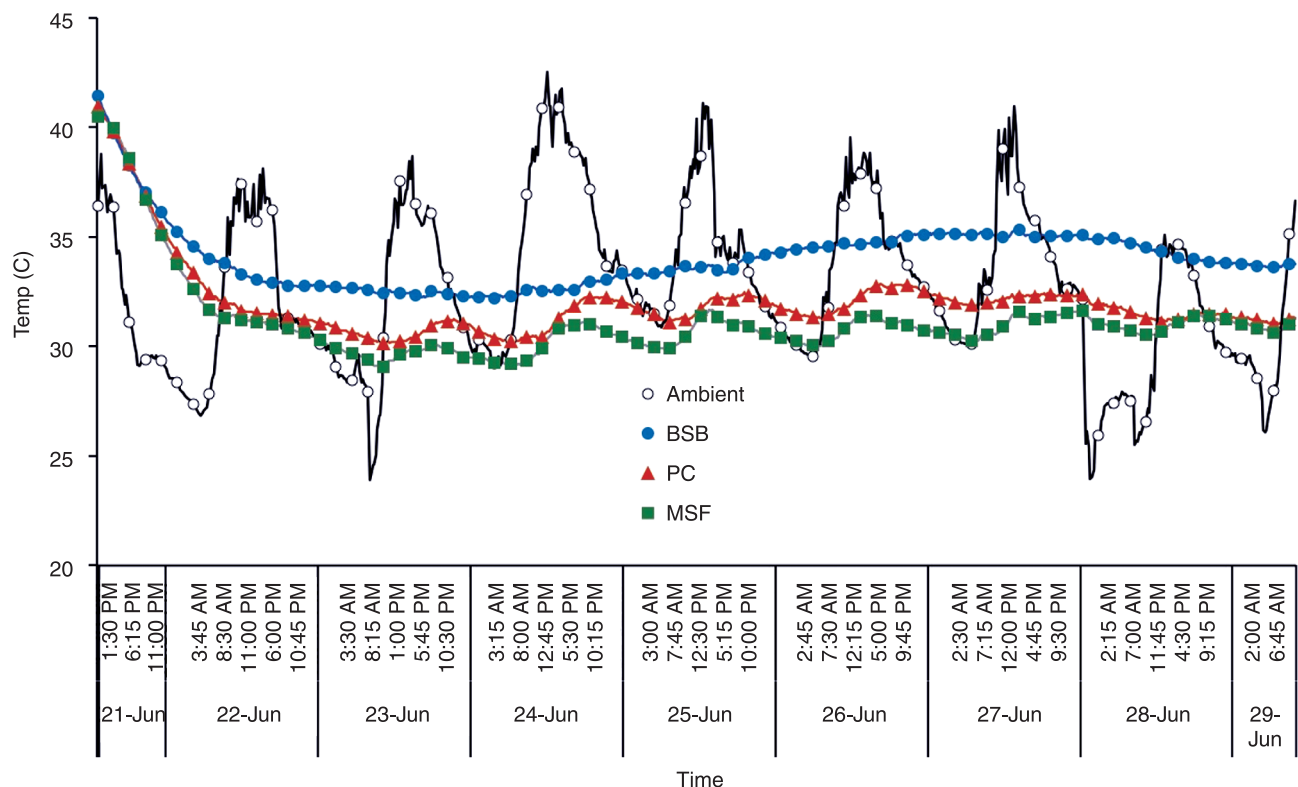


Fig 3 Average 'product' temperatures for 100 kg of water in 1- and 2-l water bottles heated to 40°C, then placed inside pre-cooled EC structures from 21 June to 29 June, 2016 at IARI, Delhi, India. Rain events on 23 and 28 June brought about rapid cooling of the ambient air, but the elevated humidity hindered cooling by evaporation.

Table 1 Thermal mass and transmittance of the composite walls of the EC structures

Type of the structure	Thermal mass (W-h °C ⁻¹)	Estimated thermal transmittance, U value (Wm ⁻² °C ⁻¹)
BSB - Brick-Sand-Brick	5804	2.01
PC - Pervious concrete	749.7	4.12
MSF - Mesh supported fabric	41.58	6.60

concrete, has a high degree of capillarity and water sorptive capacity to enable water to thoroughly wet the fabric when oriented vertically.

The thermal mass of the BSB wall was very high compared to the MSF wall and the thermal mass of the PC wall was intermediate (Table 1). This was an intentional feature of the prototype development. The PC structure had 2-inch-thick porous concrete wall and the roof and floor were made of autoclaved aerated concrete (AAC) blocks. AAC blocks have very low thermal conductivity (0.12 Wm⁻¹K⁻¹), which is 1/8th of that of conventional brick. The MSF structure had walls made of mesh and fabric, the roof and floor were made of same AAC blocks. The structures were all roughly 1 m in length and width and 0.9 m in height and had an estimated 100 kg capacity. Each was filled with 100 kg of water in 1- and 2-L polyethylene terephthalate (PET) bottles was placed in each structure to represent the thermal mass of fruits and vegetables to be stored. A lightbulb (40 W) was placed inside each structure to simulate the heat of respiration of 100 kg of produce.

The structures were extensively instrumented using copper/constantan thermocouples. Temperature was tracked for the ambient air, the interior air, the interior and exterior wall surfaces, the interior and exterior roof surfaces, the interior floor surface, and the product (average of two measurements). The thermocouples were connected to a data logger via relay multiplexers and the temperature was recorded every 15 min continuously over two weeks in June of 2016. A 12-V battery, charged daily using a 60-W solar panel, was used to power the instrumentation.

RESULTS AND DISCUSSION

Product temperature was lower in the MSF than in PC and BSB structures (Fig 3). The product temperature inside MSF also followed the cooler night air more closely than in the BSB and PC structures. This is likely because of the lower thermal mass of MSF walls compared to the BSB and PC walls (Table 1). Dash (1999) reported similar advantages of structures having walls made up of wood wool sandwiched between wire mesh. Product temperatures in BSB remained higher than that in PC and MSF structures and was unable to take advantage of the cool night air because of the high thermal mass and low thermal transmittance of the composite wall made of bricks and sand. The average product temperatures over 5 days in June was 34.4±0.63°C in BSB, 31.8±0.4°C in PC and

30.9±0.46°C in MSF structures (Fig 3).

The maximum and minimum ambient air temperatures over these days averaged 39.05±2.32 °C and 27.71±2.61 °C, respectively (Fig 4). The minimum (night time) temperatures of the MSF structure were lowest among all the structures and very similar to the minimum ambient temperatures, whereas the minimum temperatures in the other structures were higher than ambient during the night (Fig 4). The maximum temperatures of the inner air are not different between the structures probably due the relatively high humidity in the ambient conditions, which ranged from approximately 70% during the day to near saturation at night (Fig 4).

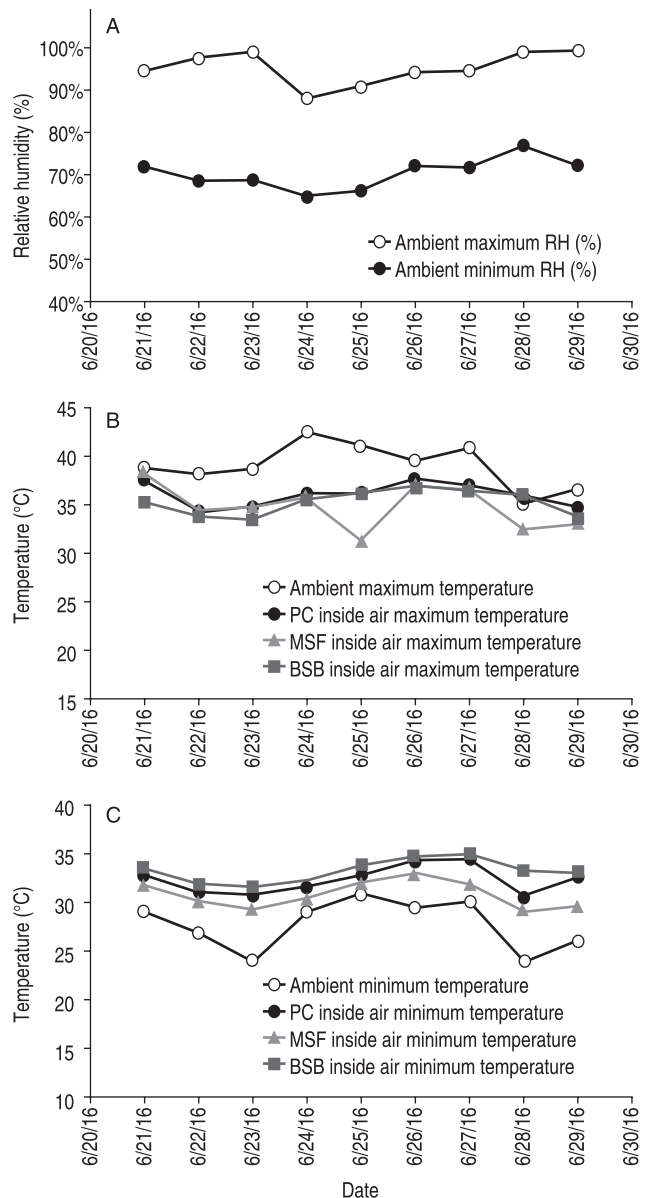


Fig 4 Minimum and maximum relative humidity of the environment (A), maximum air temperature of the environment and inside the EC structures (B), and minimum air temperature of the environment and inside the EC structures (C) from 21 June to 29 June, 2016 at IARI, Delhi, India.

The high humidity at the IARI site made the evaporative cooling less effective than desired. We expect better performance of the evaporatively cooled structures in low humidity and high temperature conditions, but the advantage of night air cooling of the MSF structure is evident even in the conditions encountered in the current study.

The innovative MSF structure performed better (in terms of lower product temperatures) than the traditional BSB design because of its lower (almost 1/60) thermal mass and higher thermal transmittance, which allowed it to more efficiently shed heat and more closely follow 'cooler' night air temperatures.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the funding given by Global Centre for Food Systems Innovation (GCFSI), MSU, USA and the material support provided by Department of Horticulture, MSU, USA and Division of Agricultural Engineering, Indian Agricultural Research Institute, New Delhi, India.

REFERENCES

- Chadha K L. 2001. *Handbook of Horticulture*, pp 1031. Indian Council of Agricultural Research, Directorate of Information and Publications of Agriculture, New Delhi, India.
- Chopra S, Baboo B, Kudos Aleksha S K and Oberoi H S. 2001. Development of passive evaporative cooled room for on-farm storage of fruits and vegetables. (In) *Proceedings of International Conference on Emerging Technologies in Airconditioning and Refrigeration*. Agarwal R S (Ed). Allied Publishers Ltd., 26-28 September 2001, New Delhi, India, pp 265-73.
- Chopra S, Kudos Aleksha S K, Oberoi H S, Baboo B, Ahmad K U M and Kaur J. 2004. Performance evaluation of evaporative cooled room for storage of kinnow. *Journal of Food Science and Technology* **41**(5): 573-7.
- Chopra S and Beaudry R. 2018. Redesigning evaporatively cooled rooms to incorporate solar powered refrigeration in India. *Acta Horticulturae* **1194**: 609-15.
- Chouksey R G. 1985. Design of passive ventilated and evaporatively cooled storage structures for potato and other semi perishables. *Proc. Silver Jubilee Convention of ISAE*, pp. 45-51. 29-31 October 1985. Bhopal, India, pp 45-51.
- Dash S K. 1999. Studies on evaporatively cooled storage structures for horticultural produce. Ph D thesis, Division of Agricultural Engineering, Indian Agricultural Research Institute, New Delhi.
- Roy S K and Khurdiya D S. 1986. Studies on evaporatively cooled zero energy input cool chamber for storage of horticultural produce. *Indian Food Packer* **40**: 26-31.
- Roy S K and Pal R K. 1994. A low-cost cool chamber: an innovative technology for developing countries (tropical fruits storage). *International Conference on Agricultural Machinery and Equipment; Handling, Transport, Storage and Protection of Plant Products*, 19 July 1993. Chiang Mai, Thailand.
- Umbarkar S P, Borkar P A, Phirke P S, Kubde A B and Kale P B. 1998. Evaporatively cooled storage structure. *Technical Bulletin No. 35*, Dr. PDKV, Akola.
- Vala K V, Saiyed F and Joshi D C. 2014. Evaporative cooled storage structures: An Indian scenario. *Trends in Post-Harvest Technology* **2**: 22-32.