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A COMPREHENSIVE REVIEW ON ZERO-COST EVAPORATIVE COLD STORAGE FOR FRESH FARM PRODUCE PRESERVATION

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Abstract: Fresh farm produce of horticulture is stored at a temperature lower than its surrounding due to its high susceptibility to spoilage. Therefore, maintaining the freshness of these produce requires minimizing its chemical, biochemical, and physiological changes through precise control of temperature and humidity levels in the storage space. There are many methods to achieve the temperature of the ambience lower than its surrounding, but the most effective and economic method is evaporative cooling. The principle of evaporative cooling revolves around the transformation of a liquid into a gas or vapor state. It occurs when molecules within a liquid gain enough energy to break free from the surface and enter the surrounding atmosphere. This process is influenced by several factors, including temperature, humidity, surface area, and airflow. This review paper has been undertaken the investigations that address the nature of various types of Evaporative Cooling techniques which can be used for Cold Storage purpose, different types of materials used for cooling pads and how to increase the efficiency of cold storages based on evaporative cooling purpose. These studies have led us to better understanding of the evaporative cooling techniques. As a result, many cold storages have been developed based on evaporative cooling purpose to preserve fruits and vegetables. Various modifications were done in the construction of walls, structure of fans, methods of air circulation, etc. A zero-cost cooling system has proven to be highly effective for temporarily storing fruits and vegetables, specially in hot and dry climatic conditions. Evaporative cooled cold storages are not only lowering the storage temperature but also enhances the relative humidity within the storage area, which is crucial for preserving the freshness of the produce.

Index Terms – Evaporative cold storage, Zero-energy cool chamber, Constructional features, cooling pads, cooling pads materials, heat load calculation, relative humidity

1. INTRODUCTION

Preserving perishable goods without conventional refrigeration presents a significant challenge, especially in areas with limited electricity access or high energy costs. Zero-cost evaporative cold storage offers a promising solution to this dilemma. By utilizing evaporative cooling principles, this innovative method efficiently extends the shelf life of fresh produce, dairy, and other perishables. In this overview, we delve into zero-cost evaporative cold storage, its advantages, and implementation steps. Maintaining optimal storage conditions is crucial for preventing post-harvest losses in fruits and vegetables. Controlled temperature and humidity reduce spoilage by minimizing physiological, biochemical, and microbiological activities. Rapid cooling during storage helps retain product quality, enabling farmers to supply seasonal produce year-round. Effective cold storage not only prevents rapid deterioration but also extends the market availability of produce, benefitting both producers and consumers. Zero-cost evaporative cold storage utilizes natural evaporation to create a cooling effect without external energy sources. Unlike traditional refrigeration, it minimizes infrastructure requirements and operates without electricity, making it ideal for rural areas with limited power access. Additionally, it is environmentally friendly, eliminating harmful refrigerants and reducing food waste by prolonging shelf life. Its affordability and simplicity make it accessible to small-scale farmers, contributing to sustainable food systems and enhancing livelihoods.

1.1 Types of Evaporative cooling.

1.1.1 Direct Evaporative Cooling

Direct evaporative cooling is a process that utilizes the principles of evaporation to cool the air without the need for refrigeration equipment. It is a simple and energy-efficient method commonly used in dry and arid climates to provide cooling and improve comfort in buildings or outdoor spaces. The process of direct evaporative cooling involves introducing outside air into a space and passing it through a medium, such as a wet pad or a water spray system. As the air comes into contact with the wet surface, water evaporates and absorbs heat from the air, resulting in a drop in temperature. The cooled air is then circulated into the desired area, providing a refreshing and comfortable environment. There are a few key components in a direct evaporative cooling system

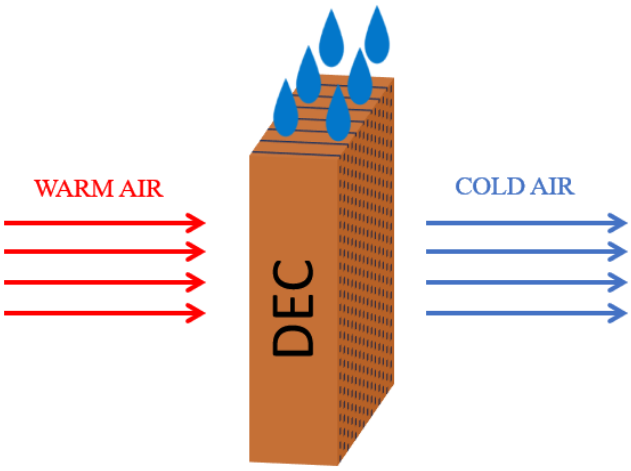

Fig 1.1: Direct Evaporative cooling

1.1.2 Indirect Evaporative Cooling

Indirect evaporative cooling is a cooling process that utilizes the principles of evaporation to cool air without adding moisture to the conditioned space. Unlike direct evaporative cooling, which introduces moisture into the air stream, indirect evaporative cooling keeps the air dry while achieving significant temperature reductions. The process of indirect evaporative cooling involves two separate air streams: the primary air stream, which is the air being cooled, and the secondary air stream, which is used to cool the primary air stream without directly mixing with it

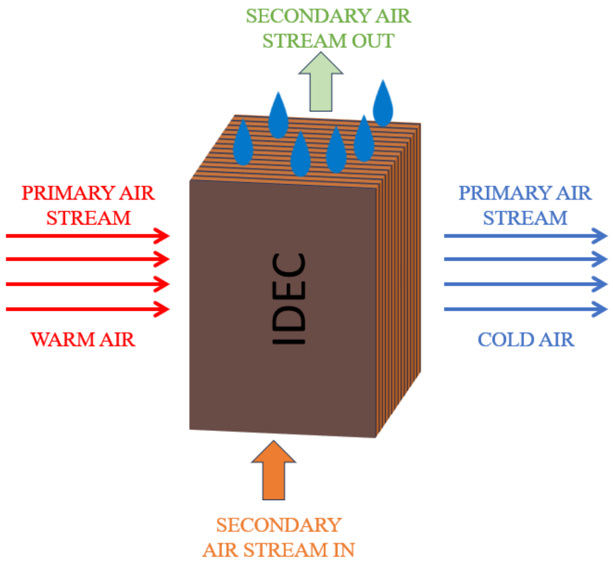

Fig 1.2: Indirect Evaporative Cooling

1.1.3 Two-Stage Evaporative Cooling

Two-stage evaporative cooling is an advanced cooling technique that combines the benefits of both direct and indirect evaporative cooling to achieve even greater cooling efficiency and improved humidity control. It is designed to provide effective cooling in areas with higher humidity levels where direct evaporative cooling alone may not be sufficient.

The two-stage evaporative cooling process involves two cooling stages:

First Stage (Direct Evaporative Cooling): In the first stage, the outside air is cooled using the direct evaporative cooling method. The hot outdoor air is drawn into the cooling unit, where it passes through wetted pads or a water spray system. As the air comes into contact with the wet surfaces, water evaporates, reducing the air temperature. This cooled air is then directed into the space that needs to be cooled.

Second Stage (Indirect Evaporative Cooling): In the second stage, the already cooled air from the first stage undergoes further cooling through indirect evaporative cooling. Instead of being discharged directly into the conditioned space, the cooled air passes through a heat exchanger or a cooling coil. The heat exchanger is wetted on one side, while the other side is in contact with the hot outdoor air. As the hot outdoor air passes over the wetted surface of the heat exchanger, evaporation occurs, extracting additional heat from the air. The heat is transferred to the cooled air from the first stage, resulting in further cooling of the air without adding moisture.

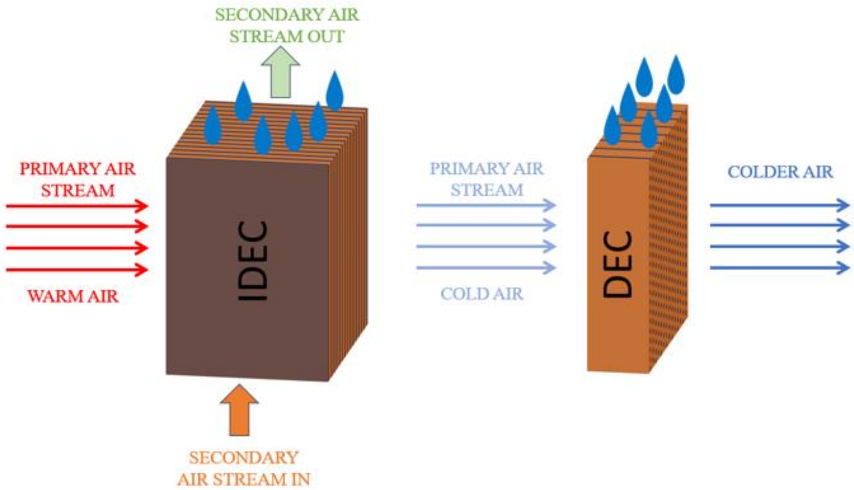

Fig 1.3: Two-stage evaporative cooling process

2. Literature Review

Zero-cost evaporative cold storage is an innovative and sustainable solution for preserving perishable goods without relying on conventional refrigeration methods. By harnessing the power of evaporative cooling, this approach offers a cost-effective and environmentally friendly alternative, particularly in regions with limited access to electricity or high energy costs. In this literature review, we will explore the existing body of research and literature surrounding zero-cost evaporative cold storage. By examining the key findings and insights from various studies, we aim to gain a comprehensive understanding of the technology's principles, applications, challenges, and potential for widespread adoption.

Based on recent publications, numerous studies have explored different Evaporative Cooling methods suitable for Cold Storage, investigated materials for cooling pads, and sought ways to enhance the efficiency of cold storage facilities utilizing evaporative cooling. These investigations have deepened our understanding of evaporative cooling techniques, leading to the development of numerous cold storage units specifically designed for preserving fruits and vegetables.

Zakari M. D, et al [1] have experimentally and numerically investigated that the average cooling efficiency of their evaporative cooling system was 83%. They also found out that the temperature in the system dropped drastically when compared to the ambient condition which ranges from 6 to 10°C and the relative humidity in the cooling chamber increased considerably to 85%. However, the testing of the evaporative cooling system shows that the tomatoes can be stored for an average of five (5) days with negligible changes in weight, color, firmness and rotting as compared to ambient conditions which started rotting after three (3) days. On the other hand, Ndukwu Macmanus Chinenye et al [2] have attempted to describe the development of an active evaporative cooling system for short-term storage of fruits and vegetable in a tropical climate where they have found that the temperature drop ranged from 40℃ to 13℃ while the relative humidity of the ambient air was increased to 96.8%. The cooler could drop the temperature close to wet bulb depression of ambient air and provided up to 98% cooling efficiency with a maximum cooling capacity of 2,529 Watts. K.V. Vala's research [3] highlighted the suitability of on-farm structures for intermediate vegetable storage, accommodating up to 2000 kg. These structures maintained a pleasant environment, maintaining temperatures 10-12°C lower than the outside ambient temperature. Taye S. Mogaji et al. [4] conducted experiments demonstrating a 14-day extension in the shelf life of vegetable produce within evaporative cooling systems compared to ambient storage conditions. This suggests the potential of such systems for short-term vegetable preservation post-harvest, particularly beneficial for developing economies. Robert Kraemer et al. [5] proposed a more efficient approach to storage by advocating for one large and one small room instead of two equal-sized rooms, enabling flexibility in cooling produce based on seasonal needs. Adams Abdul-Rahaman et al. [6] recommended the adoption of Charcoal Evaporative Coolers for small-scale and household-level cooling and extension of tomato shelf life in Wa Municipality. Additionally, K.V. Vala, F. Saiyed et al. [8] conducted a review discussing various evaporative cooling systems, their construction materials, and their efficiency in enhancing the shelf life of agricultural commodities. These findings collectively underscore the potential of evaporative cooling technologies in improving post-harvest preservation practices in agriculture. M. P. Islam et al [9] conducted a case study on a cost-effective solution called the 'Zero Energy Cool Chamber (ZECC)' for preserving fruits and vegetables through passive evaporative methods. Their research delved into farmers' perspectives on utilizing this zero-energy storage system. The study, carried out in the Mymensingh district of Bangladesh from 2011 to 2012, highlighted prevalent practices where farmers, faced with challenges such as inadequate transportation, energy shortages, and minimal storage investments, often sell their harvests to middlemen at low prices. This perpetuates poverty within rural farming communities. The findings underscored a demand for affordable storage solutions like the ZECC, which operates without electricity, to safeguard agricultural yields. Igbeka, J.C et al [10] conducted an assessment on the effectiveness of three natural absorbent fibers as cooling pads: jute, hessian, and cotton waste. Their study evaluated cooling efficiency, material performance, and the total heat load removed from the evaporative cooler. Findings revealed that jute exhibited the highest cooling efficiency at 86.2% under no-load conditions, surpassing cotton waste at 76.3% and hessian at 61.7%. Material performance tests indicated hessian had the highest resistance to mold formation, followed by cotton waste, while jute displayed poor performance in this aspect. Heat load analysis demonstrated that jute-cooled products exhibited the least heat of respiration, suggesting jute's overall advantage, despite its susceptibility to mold. Nonetheless, optimizing the surface area of cotton waste could make it a preferable alternative to jute due to its resistance to mold formation. Ndukwu Macmanus Chinenye [11] developed an evaporative cooler utilizing clay and locally sourced materials. The cooler's performance was assessed based on temperature reduction, evaporative effectiveness, and cooling capacity. Results demonstrated a remarkable decrease in daily maximum ambient temperature from 32-40°C to 24–29°C, representing a reduction of up to 10°C. Moreover, it elevated the relative humidity of incoming air from 40.3% to 92% within the storage chamber. Cooling efficiency ranged from 20% to 92%, achieving a maximum cooling capacity of 1207 W. The cooler exhibited heightened effectiveness during daytime hours (12 -16 h local time), aligning with peak farm produce harvesting and sales, preserving freshly harvested tomatoes for up to 19 days before visible deterioration. Edna Makule et al [12] conducted a review highlighting the vulnerability of fruits and vegetables to significant postharvest losses compared to other crops due to factors like perishability and inadequate handling and storage infrastructures. Sub-Saharan Africa faces postharvest losses ranging from 30% to 50%, emphasizing the urgent need for cold chain integration in value chains. However, developing countries lack essential infrastructure and management skills, especially in rural areas where up to 60% of losses occur. Controlled environment storage mitigates losses, enhancing food security, income, and environmental sustainability. The review advocates for improved precooling and cold storage methods, addressing energy requirements and distribution challenges to benefit small-scale farmers in rural settings. A.K. Singh et al [13] examined how high ambient temperatures hasten fruit and vegetable dehydration, leading to decreased water content, shortened shelf life, and eventual spoilage. Traditional preservation methods like air conditioning and refrigeration, while effective, are costly and energy-intensive. In response, they developed a low-cost, environmentally friendly, zero-energy passive cool chamber at ICAR-CAZRI, Jodhpur, employing evaporative cooling principles. Constructed with a double-walled design using baked bricks and filled with coarse sand, this improved chamber achieved quicker temperature reduction, preserving vegetables safely for 7 days in winter and 4-5 days in summer without spoilage. Notably, it reduced temperatures by 12-14°C in summer and 6-8°C in winter, with relative humidity ranging from 80-95%. This innovation offers easy maintenance and significant electricity savings, particularly beneficial for remote villages in the Indian Thar desert lacking proper storage facilities, effectively mitigating fruit and vegetable spoilage while conserving energy resources. K.O. Babaremu et al [14] conducted experiments demonstrating the high demand for tomatoes in their natural state due to their domestic importance. To mitigate post-harvest losses, effective storage is crucial for prolonging shelf life. Samples were stored in an active evaporative cooling system for seven days, with some subjected to a load test in the cooler's ambient environment. Results revealed that after the seventh day, tomatoes stored in the cooler experienced weight losses of 8.65% for red and 1.54% for green varieties, significantly lower than those stored in ambient conditions (47.20% for red, 5.14% for green). This indicates the cooler's substantial efficiency (86.01%) in extending the shelf life of both red and green tomatoes. Sangeeta Chopra et al [15] highlight the substantial impact of post-harvest losses, estimated at approximately 30%, on fruit and vegetable production in India, particularly affecting smallholder farmers. These losses are attributed to factors such as inadequate cold storage facilities, exacerbated by high temperatures and low relative humidity (RH), notably prevalent during summer months. Challenges in constructing cold storage facilities, including high capital requirements and unreliable power supply, hinder accessibility for India's vast smallholder farming community of 100 million. To address this issue, evaporatively cooled (EC) storage, exemplified by the Pusa EC room, offers a cost-effective solution. This innovative storage method, utilizing novel materials like fabric walls and insulative blocks, underwent rigorous evaluation over five years (2017–2021). Results indicated a potential doubling of storage life compared to ambient conditions during warm, dry periods, though the efficacy diminished during cooler, more humid seasons. A predictive model based on wet bulb depression facilitated estimation of EC storage benefits, particularly advantageous in warmer, drier climates. However, regional climate classifications were found insufficient due to local microclimate variations, underscoring the need for site-specific considerations in implementing EC rooms. O.B. Ayomide et al [16] provide an overview of the factors contributing to postharvest losses in tomatoes, along with the historical evolution of storage methods and their constraints. Their findings reveal that while traditional storage techniques have extended shelf life, they often result in notable reductions in both quantity and quality of the produce. Consequently, there is a demand for a postharvest storage solution that considers the optimal conditions necessary for preserving tomatoes effectively. Amrat lal Basediya et al [17] have conducted a review encompassing the fundamental concepts, principles, and methods of evaporative cooling, along with their applications in preserving fruits and vegetables. The review also discusses the economic aspects of these methods. It suggests that zero-energy cooling systems can be efficiently utilized for short-term storage of fruits and vegetables, even in hilly regions. Timothy Adekanye et al [18] conducted an assessment of an evaporative cooling apparatus designed for fruit and vegetable storage, aimed at enhancing their shelf life. Comprising an inner aluminum wall (0.6 mm thick), an external galvanized steel wall (1 mm thick), one suction fan, a water pump, and three trays, the device features polyurethane lagging (25 mm) and a water distribution system with two 20-liter tanks, PVC piping (25 mm diameter), a 0.5 hp pump, and a floated switch. Water circulates from the tanks to an overhead reservoir, trickling through a jute bag cooling pad. The suction fan generates airflow over the wetted area, reducing ambient temperature from 29.5°C to 22.8°C and increasing relative humidity to 95.7%. Evaluation involved storing sweet oranges, green tomatoes, and red tomatoes for 7 days, assessing firmness, color changes, and weight loss. Results showed significant reductions in weight loss, with red tomatoes experiencing 8.65% loss in the cooler compared to 47.20% in ambient conditions, and sweet oranges recording 4.27% loss in the device versus 9.25% in ambient storage. E.E. Anyanwu et al [19] have devised, constructed, and assessed the efficacy of a porous evaporative cooler tailored for preserving fruits and vegetables. With a storage capacity of 0.014 m³, the cooler features a cuboid-shaped porous clay container nested within another clay container, filled with coconut fiber in-between. A water reservoir, connected to the top of the cooler via a flexible pipe, continuously saturates the coconut fiber to maintain moisture. Transient performance tests demonstrated temperature reductions ranging from 0.1 to 12 °C compared to ambient air temperatures spanning 22–38 °C. The cooler exhibited superior performance when compared to open-air preservation methods, particularly during diurnal operations following harvest. C. P. Gupta et al [20] developed have devised an economical safety tractor cab featuring external side shades and a wet pad evaporative cooling system. This innovation aims to enhance the working efficiency and extend the effective working duration of farmers during summer, particularly those unable to afford expensive air-conditioned cabs. The cab's cooling mechanism involves passing air through a wet evaporative surface, comprising a layer of shredded wood sandwiched between coconut fiber layers. A low-capacity water pump continuously wets the evaporative surface, with the cooled air drawn into the cab via a centrally located fan on the roof. The pump and fan are powered by a 12-V DC battery. Additionally, white painted plywood side shades protect the cab's glass portion from direct sunlight. Under Bangkok's harsh climatic conditions, the cab achieved comfortable internal temperatures of 30 to 31°C with relative humidity between 70 to 72%, providing a favorable thermal sensation zone. Edward A. Awafo et al [21] have developed and implemented an evaporative cooler aimed at prolonging the shelf life of stored vegetables, specifically tested with freshly harvested roma tomatoes. Operating on evaporative cooling principles, the system enhances relative humidity while reducing temperature within the preservation chamber. Constructed with 25.4 mm thick wood, one side of the cooler utilizes moistened jute sack material, irrigated by water from a reservoir via perforated pipes, flowing by gravity. Relative humidity and temperature of the tomatoes were monitored using tinytag humidity and temperature data loggers, while weight loss was measured with a dial gauge scale. Results indicate a substantial difference in tomato storage between the evaporative cooling system and ambient conditions, with an average cooling efficiency of 81%. The system maintained an average temperature of 23°C, contrasting with the ambient average of 33°C, while relative humidity increased to 99% compared to the ambient average of 59%. Analysis suggests tomatoes can be preserved for over 6 days with minimal changes in weight, color, and firmness, compared to deterioration observed after day 3 under ambient conditions. Tilahun Seyoum Workneh et al [22] devised a forced ventilation evaporative cooler utilizing locally sourced materials, evaluating its efficacy in reducing storage air temperature, increasing relative humidity (RH), minimizing physiological weight loss, and enhancing the marketability of banana, papaya, orange, mandarin, and lemon. Results showed a significant ($P < 0.05$) reduction in air temperature by approximately 10°C, coupled with a RH increase exceeding 27% during storage. Fruit moisture loss was notably mitigated by the cooler compared to ambient storage conditions. Weight loss percentages for banana, papaya, orange, mandarin, and lemon over 32 days were substantially higher under ambient conditions, ranging from 4.1% to 66.5% compared to storage in the evaporative cooler. This method remarkably extended the shelf life of all fruits, surpassing 20, 14, 29, 23, and 24 days, respectively, in contrast to less than 8 days under ambient conditions. Roy, S.K.et al [23] developed a zero-energy cool chamber using locally available materials in New Delhi, India. 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 percent increase) as compared to storage at room temperature, and the physiological loss in weight was lower. Kittas C. et al [24] elucidated a significant issue with greenhouse evaporative cooling systems utilizing cooling pads and extraction fans: the development of thermal gradients along the airflow direction. These gradients can detrimentally impact plant growth, prompting growers to incorporate shading alongside cooling pads. A simple climate model is proposed to predict temperature gradients within a greenhouse, considering ventilation rate, roof shading, and crop transpiration. Calibration of the model involved measurements in a commercial greenhouse with fans, pads, and partial shading. Results showed effective temperature regulation but notable temperature gradients, particularly over the considerable length of the greenhouse (60 m), reaching up to 8°C from pads to fans. The model, validated with independent data, was employed to analyze ventilation rates, shading effects, and external environmental factors on system performance, demonstrating its utility in enhancing cooling pad system design and management. S. A. Venu et al [25] developed a cost-effective cooling system to determine the most suitable insulation material with optimal water retention capacity for low-cost evaporative cooling. Various physical and rheological properties of industrial coir pith, fine charcoal, and different side covering materials were assessed. Coir pith and charcoal exhibited bulk densities of 58-60 kg/m³ and 82-90 kg/m³ respectively, with corresponding porosities of 38-41% and 59-63%. Water holding capacities of different materials, including onion bagging cloth, gunny cloth layers, felt cloth, coir pith, and charcoal, ranged from 28.1% to 72.3%. Charcoal demonstrated the highest water retention capacity, making it suitable for increasing relative humidity within confined spaces, thereby reducing produce respiration and transpiration rates to maintain freshness.

Table 1. Constructional features of an evaporative cold storage

Author	Constructional Details
Zakari M. D, et al [1].	Developed a evaporative cold storage system; Front and Rear Sides of the Storage System Ar =Hr x Lr Ar = 0.8 × 0.4=0.32 m2 Left- and Right-Hand Sides of the Storage System (Pad Area) Al =Hl x Bl Al = 0.8 × 0.5= 0.4 m2 Volume of the Storage System Vc = Lc×Bc×Hc Vc = 0.4 × 0.5 ×0.8= 0.16 m3
Ndukwu Macmanus Chinenye et al [2].	Attempted to describe the development of an active evaporative cooling system for short-term storage of fruits and vegetable; Size: 0.24 m^3 Shape: Hexagonal shaped storage housing structure mounted on a steel frame with stainless wire partitions. Cooling pad Holder size: 0.009 m3 cuboids' shaped Material: double walled galvanized steel net. No. of Fan: Three suction fan of 20 cm swept diameter
K.V.Vala [3].	Highlighted the suitability of on-farm structures for intermediate vegetable storage: Size: (4500x3250x3750 mm) and (300 mm above ground level) platform in the farm. Storing Capacity: 2 tons of produce Shape: Hut shaped evaporative cooled storage structure Door of 750x1950 mm. Wind Speed: 1250m^3 /h.
Taye S. Mogaji et al [4].	Developed an evaporative cooling system; Size: 0.075 m3 Shape: Pyramidal shaped, Material: galvanized mild steel, stainless steel and internally insulated with 0.025m polystyrene foam, Fan Capacity: a suction fan of 4.3 m/s velocity air flow and 0.5 W (1250 rpm), cooling pad Size: (Jute) of 0.06 m thickness water pump discharge capacity: 3.5 lit/min as well as a power rating of 0.5 W. Water reservoir of capacity: 62.5 m^3.

Adams Abdul-Rahaman et al [6].	recommended the adoption of Charcoal Evaporative Coolers for small-scale and household-level cooling Size: 50mm x 25mm in section leaving a 25mm cavity which was filled with pieces of charcoal. Water spraying quantity: 20 liters of water Material Used: Mesh, Nails, Charcoal, Pieces of wood example (Wawa board)
Igbeka, J.C et al [10].	An active evaporative cooler was constructed and tested with three different absorbent materials (jute, hessian and cotton waste). storage cabin Size: 475 x 475 x 980mm, pad end of dimensions: 475mm x 980mm, Material Used: plywood and internally insulated with 25.4mm polystyrene materials, Fan Wattage: suction fan of 20 watts power rating.
Ndukwu Macmanus Chinenye [11].	The evaporative cooler is made up of double jacket walls storage structure with partitions for storage of fruits and vegetables. Size: The inside wall is 60 cm long × 52 cm wide × 85 cm deep & the outside wall is 75 cm long × 67 cm wide × 100 cm deep with a 15 cm gap separating it from the inside wall. Shape: Cuboid Material: Mud (Clay), reinforced with bamboo sticks and casted on a mud floor 30 cm thick. cooling pad Size: 42 cm long × 8 cm thick and 85 cm deep Material: wood shaven stacked in between perforated (pin hole) bamboo sticks 42 cm long and 0.4 cm thick to prevent sagging. The top of the structure is covered with an aluminum foil (75 cm long × 67 cm × 85 wide) because of its high heat reflectivity. The foil contains pin holes (2.5 mm in diameter) for the exhaust air.
A.K. Singh et al [13]	It consisted of a double walled chamber made of baked bricks with coarse sand filled annular space. Size: The dimensions of both chambers are 1200 mm × 1200 mm (outer chamber) and 800 mm × 800 mm (inner chamber). The height of the chambers were 730 mm (outer chamber) and 420 mm (inner chamber). Hole Size (Outer Chamber): 40 holes (dia 1.5 cm, depth 40 cm) were bored and the distances between these holes were 12 cm. Hole Size (inner chamber): 28 holes were bored (dia 1.5 cm, depth 20 cm) with a distance of 11.5 cm between the holes. Insulation: To cut-off solar radiation, a slanting shed (3250 mm × 3000 mm) was fabricated.
K.O. Babaremu et al [14]	The evaporative cooler that was used for this experiment was designed and fabricated Materials: galvanized steel, aluminium, polyurethane water tanks capacity: 20litres suction fan Capacity:38mm swept dept Pump wattage: 0.5hp
Sangeeta Chopra et al [15]	An EC storage, termed the Pusa EC room, was built using novel construction materials including fabric walls and insulative blocks and evaluated year-round over a period of 5 years Size: 3 m × 3 m × 3 m Storage capacity: 2000 kg Materials: cement, sand, bricks
Amrat lal Basediya et al [18].	Fabricated a metallic EC chamber measuring Size: 45×45×45 cm (approx. 0.1 m3) with a 2 mm GI sheet with the top side open. Basket size: 30×30×30 cm.
Timothy Adekanye et al [19].	The cooler was made of metal sheets. Size: Outer wall 0.5 m long × 0.45 m wide × 0.9 m deep :inner 0.45 m long × 0.425 m wide ×0.85 m deep. Water tank Capacity: 2 x 20 litres capacity Pump: 0.5 hp electric pump Tray Size:40 cm length × 35 cm breadth. Material: Galvanized steel, aluminum, PVC pipes
C. P. Gupta et al [21].	The cab is cooled by passing air through a wet evaporative surface, Size: 40-mm-thick layer of shredded wood packaged between two 15-mm-thick layers of coconut fiber. Battery: The motor of the pump and fan are energized by a 12-V DC battery of the tractor.
Edward A. Awafo et al [22].	The evaporative cooler was constructed. Size: 1.02 m × 0.61 m × 0.61 m. Material: jute sack, PVC pipes
Kittas C. et al [25].	The greenhouse, Size: 50 m wide and 60 m long, is made of eight adjacent 6·25 m wide arches covered with double inflated plastic polyethylene – ethylene vinyl acetate (PE-EVA) films. Ambient air is forced through a 61 m^2 area of 10 cm thick cooling pads set on the 50 m wide south wall. These corrugated cellulose pads offer a 200 m^2 m^{-3} specific exchange surface for evaporation. After crossing the pads, air travels a 60 m distance before being extracted by nine fans situated on the opposite north wall.

Table 2. Data Reduction of an evaporative cold storage

AUTHOR	FORMULAE
Zakari M. D, et al [1].	1.Heat Transfer Analysis of the System Qhg = -KAxdeltaxT / x 2.Saturation Efficiency (SE) SE = T1 (db)- T2(db) / T1 (db) -T 1(db) Percentage Weight loss = Original Weight- NewWeight / Original Weight x 100
Ndukwu Macmanus Chinenye et al [2].	cooling efficiency η= Tdb-Ts / Tdb-Tw x 100 cooling capacity of direct evaporative cooler Coolcap=1.08∗Q∗(Ts-η[Tdb-Tw])
Taye S. Mogaji et al [4].	1.Determination of temperature gradient across the insulating materials U=1 / ∑R ∑R = Ri + R1 + R2 + R3 + R0 QH L = t0 -t3 / ∑ R 2.Heat transfer analysis Qhg = kA deltaxT / x 3.Heat balance Q= Power Generated / A 4.Velocity of air (v) =
Igbeka, J.C et al [10].	1.Temperature and Relative Humidity Measurement; Se= T1(db) - T2(db) / T1(db) – T1(wb) 2.Heat Load of the Evaporative Cooler; Q= KA dT / dt 3. Infiltration of Air; Ql= (Qc + Qf + Qr) x 15/100 = (Qc + Qf + Qr) x 0.15
A.K. Singh et al [13].	1.Qualitative evaluation Physiological loss in weight; (%) =W1-W2 / W1 x 100 2.Energy balance ρVC= (dTch/dt)= HQ+UAc (Ta -Tch)-(hp+ hcp). A (Tch –Tw)
Sangeeta Chopra et al [15].	Fold change in storage life = cramb / crEC Relative change in storage life = (cramb − crEC) / crEC * Relationship between reduction in respired CO2 (%) and wet bulb depression Percent reduction in respired CO_2 = 100 × (1− EXP (− K × (Tdry.amb − Twet. amb))
Amrat lal Basediya et al [18].	1.Temperature and Relative Humidity Measurement; Se= T1(db) - T2(db) / T1(db) – T1(wb) 2.Heat Load of the Evaporative Cooler; Q= KA dT / dt 3. Infiltration of Air; Ql= (Qc + Qf + Qr) x 15/100 = (Qc + Qf + Qr) x 0.15
S. A. Venu et al [25].	Bulk density (kg/m^3) =Weight of sample in container (kg) /Volume of wooden box (m^3) True volume of sample (m^3) =Weight of displaced toluene / Weight density of toulene (m^3) True density (kg/m^3) = Weight (kg) / Volume (m^3) Moisture content = __Wm /Wm + Wd x 100 Porosity (%) =True density – Bulk density / True density x 100 Water holding capacity (%) = Initial weight – final weight / initial weight

Conclusion

The evaporative cooling system proves to be highly effective for preserving fruits and vegetables in hot, dry climates, but its utility extends to various other climatic conditions as well. With its low construction costs, minimal operational expenses, and numerous advantages over mechanical refrigeration, evaporative cooled storage structures offer a viable solution in areas lacking traditional cold storage facilities. Through proper design, these Evaporative cold storage structures can be adapted to suit diverse locations, showcasing their versatility and broad applicability. This system's ease of operation, efficiency, and affordability make it particularly beneficial for farmers in developing countries, providing a cost-effective alternative to other, more expensive preservation methods.

References.

1. Zakari M. D, Y. S. Abubakar, Y. B. Muhammad, N. J. Shanono, N. M. Nasidi, M. S. Abubakar, A. I. Muhammad, I. Lawan and R. K. Ahmad, Design and construction of an evaporative cooling system for the storage of fresh tomatoes,ARPN Journal of Engineering and Applied Sciences,VOL. 11, NO. 4, FEBRUARY 2016.
2. Ndukwu Macmanus Chinenye1,2*, S. I. Manuwa2, O. J. Olukunle2, I. B. Oluwalana3, Development of an active evaporative cooling system for short-term storage of fruits and vegetable in a tropical climate, Agric Eng Int: CIGR Journal, December, 2013.
3. K.V.Vala, On-Farm Evaporative Cooled Storage Structure, International Journal of Innovative Research in Science, Engineering and Technology, Vol. 5, Issue 8, August 2016
4. Taye S. Mogaji1, 2* and Olorunisola P. Fapetu1, Development of an evaporative cooling system for the preservation of fresh vegetables, African Journal of Food Science Vol. 5(4), pp. 255 – 266, April 2011

5. Robert Kraemer, Andrew Plouff, John Venn,BE 487: Biosystems Design Project.
6. Adams Abdul-Rahaman, Nasiru Alhassan and Haadi Halidu, Charcoal evaporative cooling technology for storage of dwarf ger marglobe tomato fruits, International Journal of Technical Research and Applications, Volume 2, Issue 6 (Nov-Dec 2014), PP. 149-151.
7. CargoHandbook.com
8. K.V. Vala1, F. Saiyed and D.C. Joshi published a review article on Evaporative Cooled Storage Structures: An Indian Scenario in Trends in Post Harvest Technology | July-September, 2014 | Vol 2 | Issue 3 | Pages 22-32
9. M. P. Islam, T. Morimoto, K. Hatou, L. Hassan, M. A. Awal, S. T. Hossain, Case study about field trial responses of the zero-energy storage system, Agric Eng Int: CIGR Journal Vol. 15, No.4, Online available at: http://www.cigrjournal.org
10. Igbeka, J.C, and Olurin T. O. (2009). Performance Evaluation of Absorbent Materials in Evaporative Cooling System for the Storage of Fruits and Vegetables. Int. J. Food Eng., 5(3): 2
11. Ndukwu, M. C. 2011. Development of clay evaporative cooler for fruits and vegetables preservation. CIGR Journal, 13 (1)
12. Edna Makule, Noel Dimoso and Savvas A. Tassou, Precooling and Cold Storage Methods for Fruits and Vegetables in Sub-Saharan Africa—A Review, Horticulturae 2022, 8, 776. Available online: https://doi.org/10.3390/horticulturae8090776
13. Ak Singh, Dr. Surendra Poonia and Priyabrata Santra, Design, Development and Performance Evaluation of Low Cost Zero Energy Improved Passive Cool Chamber for Enhancing Shelf-life of Vegetables, Agricultural Engineering Today, 24.08.2017, available online: at: https://www.researchgate.net/publication/322055442
14. K.O. Babaremu, T.A. Adekanye, I.P. Okokpujie, J. Fayomi, O.E. Atiba, The Significance of Active Evaporative Cooling System in the Shelf-Life Enhancement of Vegetables (Red and Green Tomatoes) for Minimizing Post-Harvest Losses, 2nd International Conference on Sustainable Materials Processing and Manufacturing (SMPM 2019)
15. Sangeeta Chopra , Norbert Müller , Devinder Dhingra , Indra Mani , Tushar Kaushik , Ankit Kumar , Randolph Beaudry, A mathematical description of evaporative cooling potential for perishables storage in India, Postharvest Biology and Technology 183 (2022) 111727 .
16. O.B. Ayomide, O.O. Ajayi, A.A. , Advances in the development of a tomato postharvest storage system: towards eradicating postharvest losses, Journal of Physics: Conference Series, Volume 1378, Issue 2 022064.
17. Amrat lal Basediya & D. V. K. Samuel & Vimala Beera, Evaporative cooling system for storage of fruits and vegetables - A Review Journal of Food Science Technol. 2013 Jun; 50(3): 429–442. Published online 2011 Feb 5.
18. Timothy Adekanye, Kunle Babaremu, Abiodun Okunola, Evaluation of an active evaporative cooling device for storage of fruits and vegetables. Agricultural Engineering International: CIGR Journal, 21(1): 203–208.
19. Anyanwu, Emmanuel. (2004). Design and measured performance of a porous evaporative cooler for preservation of fruits and vegetables. Energy Conversion and Management – ENERG CONV MANAGE. 45. 2187-2195. 10.1016/j.enconman.2003.10.020.
20. Thermal Comfort Inside a Tractor Cab by Evaporative Cooling System Published by the American Society of Agricultural and Biological Engineers, St. Joseph, Michigan www.asabe.org Article in Transactions of the ASAE, published January 1995.
21. Edward A. Awafoa, Samuel Nketsiaha , Mumin Alhassana , Ebenezer Appiah–Kubia design, construction, and performance evaluation of an evaporative cooling system for tomatoes storage. ISSN 2083-1587; e-ISSN 2449-5999 2020, Vol. 24, No.4, pp.1-12 Agricultural Engineering www.wir.ptir.org .
22. Seyoum Workneh, Tilahun & Woldetsadik, Kebede. (2004). Forced ventilation evaporative cooling: A case study on banana, papaya, orange, mandarin, and lemon. Tropical Agriculture. 81. 179-185. .
23. Roy, S. K., and Pal, R. K. (1994). A low-cost cool chamber: an innovative technology for Developing countries [tropical fruits storage].[Poster paper]. ACIAR Proceedings-Australian Centre for International Agricultural Research (Australia)
24. Kittas, C & Bartzanas, Thomas & Jaffrin, A. (2003). Temperature Gradients in a Partially Shaded Large Greenhouse equipped with Evaporative Cooling Pads. Biosystems Engineering. 85. 87-94. 10.1016/S1537-5110(03)00018-7.
25. S A, Venu & Kumaran, G.S. & Bali, V.B.. (2014). Determination of some physical properties of insulation materials and for selected vegetables to design a low-cost evaporative cooling system. Plant Archives. 14. 507-510.