

Vapour Compression Cooling System Powered By Solar PV Array for Potato Storage

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ABSTRACT

Refrigerated storage, which is believed to be best method for storing the fruits and vegetables in fresh form, is not available in rural or remote locations where grid electricity is almost not available. So, without having a conventional energy source at these areas, the present study was taken up to design and fabricate a solar PV powered vapour compression refrigeration system to attain favourable conditions for potato storage, and to evaluate its shelf life under different operating conditions. The system is designed and fabricated in the division of Agril. Engineering at IARI, New Delhi. It consisted of PV panel, lead-acid battery, inverter and the vapour compression refrigeration system consists of a drier-cum-filter besides the main components: compressor, condenser, expansion device, evaporator, exhaust and evaporator fans. The 2.50 m³ cold storage structure was constructed and insulated with proper materials. An evaporatively cooled storage structure (1.0 m³) was used for curing process. The cured potato cultivar (Kufri Chandermukhi) were stored for 5 months. The stored tubers were divided into two lots, one used as control (free sprouting) and the second was manually desprouted. Measuring of moisture loss, dry matter, sprouting, rotting, sugars content, starch and chipping quality reflected the shelf life of potato. The average daily solar photovoltaic (SPV) energy output and energy consumption by the load were 5.65 and 4.115 kWh, respectively, under full load. The obtained results indicated that, the average daily actual COP for loaded and air circulated cold storage structure was 3.25. The average temperature and relative humidity maintained inside the loaded and air circulated storage structure were 283.13 K and 86 %, respectively. Solar panel can serve as an alternative source of energy for powering cooling system.

Keywords: Solar photovoltaic, cold storage, potato, curing.

1. INTRODUCTION

Energy is a vital input for sustainable development and economic growth of any country. Electrical energy is considered a most convenient form of energy sources in rural and urban areas. Rural inhabitants represent 70% of the total population in developing countries, or almost 50% of the world's population (Usmani, 1985).

Photovoltaic systems some times called solar cells have found widespread application because they are simple, compact, and have high power-to weight ratio. The SPV system has no moving parts and probably yields the highest overall conversion of the solar energy into electricity. In the field, PV require only modest amount of skilled labor to install and maintain, making them well suited to village power systems. In order to supply the required power, the arrays should be capable of producing sufficient current and voltage to run the applications, and it can be

connected in series and in parallel to obtain the desired voltage and current, respectively.

The installation of PV system has been growing by 20-25% per annum over the past 20 years, which is mainly due to the technological advances, increasing production volume of PV components and ecological taxes on traditional energies. The PV and wind power installation growth-rate curves are similar in the European Union. Therefore, the PV system has a great bright future in the forthcoming years (Masters, 2004). For example, Beshada et al. (2006) constructed and optimized a new PV to drive stone mill with a millstone-diameter of 150 mm and a maximum capacity of 3 kg per hour.

There are several cases, where small or medium size PV powered refrigerators are required (El Tom et al., 1991; Thomachan and Srinivasan, 1996 and WHO, 1988).

Those have to be optimized in size; both the PV generator and its components, as well as the refrigerator volume, in order to meet efficiently the start up power and the cooling load, in general. The cooling load to be met by the PV-generator depends essentially on:

(a) the ambient temperature, (b) the refrigerator's room temperature, determined by the special conditions the refrigerator has to operate, i.e. food preservation 10–20 °C, preservation of vaccines 0–8 °C [WHO, 1988], etc. (c) the size of the cooling space. (d) the matching conditions between the PV generator and the power consuming compressor.

Cooling, like heating, is an expensive process. Reduction in cooling loads through careful building design and insulation is desirable and will be less expensive than provision of additional cooling (Tiwari, 2002). Reduction in post harvest losses of horticultural products, which is presently in the range of 25-30%, may have considerable impact on increasing the availability of fruits and vegetables to consumers.

India is the second largest producer of fruits and vegetables in the world. The varied agro-climatic conditions (ranging from temperate to tropical) provide an enormous scope for the cultivation of a wide range of horticultural produce. In the year 2004, India and Egypt produced of about 127.560×10^6 and 24.105×10^6 million tonnes of fruits and vegetables and shared in world production with 9.22 and 1.74, respectively (FAO, 2006). Fruits and vegetables constitute 18% of the gross agricultural output. Less than 2% of this production is used by the processing industries and the remaining produce is either consumed just after harvest or stored for future use in fresh form (Anon, 1997).

The potato is the most important food crop in the world after wheat, rice and maize. Over one billion people consume potatoes worldwide and potatoes are part of the diet of half a billion people in the developing countries. Potatoes ranks 4th in the world and third in India with respect to food production.

The potato is a living botanic organ and therefore, special demands have to be met for a good storage in order to restrict losses as much as possible. Storage temperature and humidity of the atmosphere play an important role in keeping the losses low and maintaining the quality of stored potatoes. Even when storage of potatoes is done under ideal conditions, losses will occur and also its chemical composition will change somewhat. These losses and changes in composition relate to the product being a living one and are determined by various factors such as maturity of the tubers at harvesting and storage temperature.

To avoid quick loading and overloading of storage chambers, it is best to keep tubers in pre-cooling chambers for one or two weeks before they are transferred to cold storage chambers (Eltawil et al., 2006). One of the most important changes is the equilibrium between the contents of starch and sugars. This balance is affected by the conversion of starch into sugars, the formation of starch from sugars and the conversion of one form of sugar into another. The rate of conversion of starch into sugar increases with lowering of the temperature, whereas the formation of starch from sugar and respiration decreases.

Cold stored (at 275-277 K) potatoes become sweet due to accumulation of sugars and are not suitable for processing and table purposes. The ideal temperature for storing potatoes for processing (chips) and table purposes is 283-286 K. While seed potatoes are required to be stored at 275-277 K. In addition to considerable savings on energy, this type of arrangement would benefit the farmers by reduced storage costs and industries by assured supply of processable potatoes round the year. Most horticultural crops consist of 80 per cent or more water and water loss should be minimizing during storage. The relative humidity should be maintained at about 85- 90% (ASHRAE, 1998).

This accounts for the high sugar content at a low temperature of the tubers. The storage losses to which the product is subjected include (1) respiration, (2) transpiration or water loss, (3) sprouting after dormancy is over, (4) rotting, and (5) damage from pests. As potato tuber is a living material, respiration is essential; its excess not only involves loss of dry matter but also metabolic heat, which could harm tubers. Transpiration is a necessary evil as lenticels are common portals for the entry of air and the exit of moisture. Physiological losses (respiration and transpiration) are generally low in the period till dormancy is over but increase rapidly as sprouting is initiated and sprout growth progresses. Consequently, under natural conditions, the period of storage from initiation of sprouting till utilization involves heavy physiological losses, because of respiration, transpiration and weight loss in the formation of sprouts. Losses due to rotting or damage from pests, which account for the major wastage, could occur before and after the termination of dormancy (Rastovesky, 1987; Burton et al., 1992 and Chourasia and Goswami, 2001).

A study was taken up to design and fabricate a solar PV powered cooling system using vapour compression refrigeration to attain favourable conditions for potato storage, and to evaluate its shelf life under different operating conditions.

2. MATERIALS AND METHODS

2.1 Description of the System

The system is designed, fabricated and tested in the division of Agril. Engineering at IARI, New Delhi, which lies at latitude 28.63°N and 77.2°E. A PV panel consisting of 14 modules (1.02 m length x 0.41 m width, M/S Udhaya Semi-conductors, Ltd., Coimbatore) connected in series and parallel was used to obtain the desired voltage and current, respectively. A 24 V lead-acid storage battery was charged by solar PV array during daytime and used to supply power to the loads as needed. An inverter (1.0 kW) was used to convert the DC solar panel and battery electricity into single-phase AC electricity. All electrical wires used with the system are of size 50 mm² to keep the voltage loss of the PV panels and batteries less than 1% at designed distance

(4 m between the solar panel and store). Batteries and inverter were protected and carried by moving trolley fabricated for that purpose. Vapour compression refrigeration system consists of an oil separator, a receiver and a drier-cum-filter besides the main components: a compressor, a condenser an expansion device and an evaporator. Freon-12 was used to serve as refrigerant for low, medium and high temperatures. It condenses at moderate pressure under normal atmospheric conditions and boils at 243.66 K.

A 2.50 m³ double walls store structure (inside dimension of about 1.68 m length X 0.9 m width X 1.65 m height) was constructed. The store have a rectangular shape, East-West orientation and its walls were coated from outside with white paint to reflect solar radiation. For insulating the storage structure, fiberglass was attached to the walls, door, windows and ceiling (roof), because it is light in weight, low in cost, non-hygroscopic and high in strength. It could be used in temperature range of 253.16 to 553.16 K (Ahmed, 1999). Also, a vertical air space between walls is provided because still air has low thermal conductivity.

The walls were constructed having two red brick walls each of thickness 0.12 m with 0.04 m air space sandwiched between them. The inside walls were covered with 0.01 m cement plaster and insulated with 0.05 m fiberglass. To decrease heat transfer and side effect of condenser temperature on the evaporator, East wall was fabricated from 0.15 m fiberglass sandwiched between two hard plastic sheets with dimensions of 0.77 X 1.65 m. Figures 1, 2 and 3 shows the construction of walls, windows and door and ceiling.

The cold store was provided with exhaust fan to control relative humidity and reduce CO₂ concentration released by stored tubers. The ventilation process takes place in the early morning, where ambient temperature is at lower level and relative humidity is higher to reduce the moisture loss from stored potato. Also, the structure is provided with evaporator fan for circulation of air and to homogenize temperature and relative humidity inside cooling room. Where the recirculation fan is located after the evaporator coil, the heating effect imparted to the air by the fan will reduce the relative humidity of the air, which should have been at saturation point as it left the coiling coils. The fan was hanged under the ceiling and was left to work on full speed. Dark condition was maintained in the cold store (without diffused light) to avoid greening of potato tuber.

A 0.830 m³ removable storage bin is fabricated from 2-inch steel frame, with its side walls made of welded wire mesh. A reasonable air space between storage bin and main structure was provided to improve recirculation of air and to avoid moisture condensation on the storing tubers. Also, after loading potato in the storage bin it was covered from top by clean rice straw to protect it from any condensate.

Before designing the refrigeration system, the cooling (refrigeration) load of potato store is made up of six basic components as follows:

- i) Sensible heat gain through walls, floor, and roof.
- ii) Heat removed to cool from the initial temperature to some lower temperature (field heat).
- iii) Respiration of potatoes.
- iv) Heat produced by fans.
- v) Heat supplied by air renewal.
- vi) Heat produced by equipment-related load.

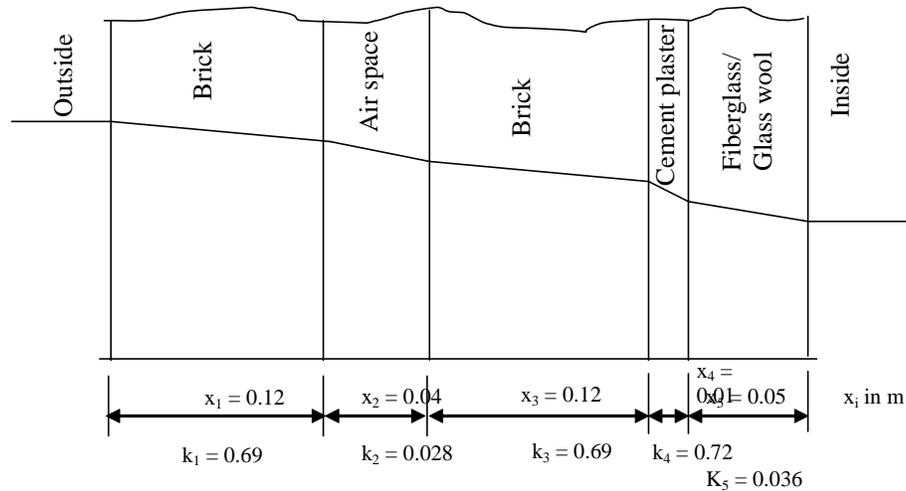


Figure 1. Construction of wall.

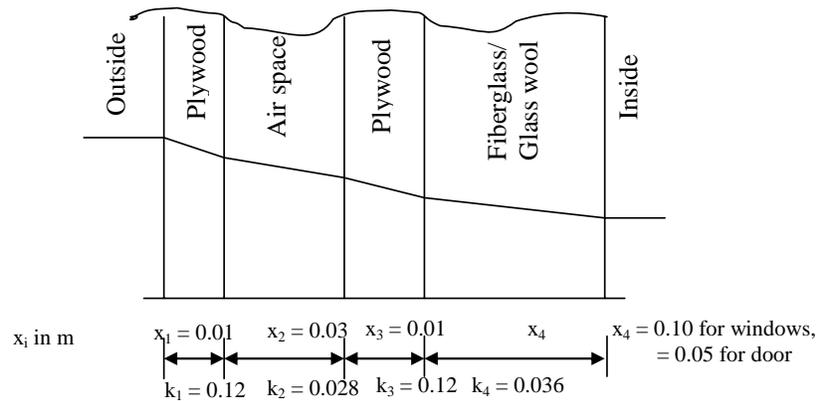


Figure 2. Construction of windows and door.

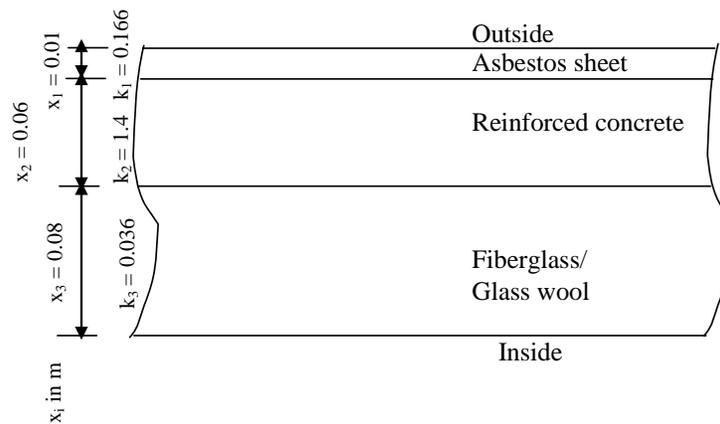


Figure 3. Construction of ceiling (roof).

2.2 Design of Experiment

Performance evaluation of solar panel was planned as first step for evaluation of a solar powered cooling system. The power output of the panel was measured under no-load, on load, with and without recirculation of air inside cold store. The following parameters were identified for performance evaluation of a solar powered cooling system.

- i) Solar intensity for clear sunny days;
- ii) Ambient temperature;
- iii) Ambient relative humidity; and
- iv) Wind velocity

The cooling performance was evaluated with and without load (with and without storing commodity) in the following terms:

- i) Temperature inside cold store;
- ii) Relative humidity inside cold store;
- iii) Energy consumption by cooling system in kWh;
- iv) With recirculation of air inside cold store;
- v) Evaluations of shelf life of potato tubers.

2.3 Test Methodology

To test the solar cooling system, the Solar panel and prefabricated complete sets were placed outdoors in the real sunlight (Figure 4). The DC open circuit voltage (V_{oc}) and Load voltage (V_L) were measured with the help of Fluke 73 series multimeter (connected in parallel). Short circuit current (I_{SC}) and Load current (I_L) were measured with the help of Ammeter (connected in series). The energy consumption in kWh was measured with the help of energy meter.

Global solar insolation, S_{Ins} , in W/m^2 was measured by thermoelectric pyranometer, which was set in the same plane as the solar panel for instantaneous insolation measurements.

The ambient (outside) temperature (T_o) and ambient relative humidity (r.h._o) were measured under shade to avoid the effect of direct solar radiation by using digital sensor. The wind velocity (WV) was measured by using Vane type anemometer.

Temperatures for cooling system were measured with the help of an iron-constantan thermocouples and digital temperature indicators. All the thermocouples were checked for their calibration at the freezing and boiling points of water. The temperatures for compressor suction (T_1) and delivery (T_2), condenser (T_3), evaporator (T_4), and cold store structure temperatures at the inside bottom (T_5), center (T_6), and top (T_7) were recorded hourly.

The average relative humidity inside evaporative cooled (EC) structure, r.h._{inEC}, and cold storage structures, r.h._{inCS}, were measured at an interval of one hour with the help of digital r.h. indicator, type Humitherm-842C.

2.4 Potatoes for Experiment

The required quantity (600 kg) of freshly harvested potato cultivar Kufri Chandermukhi, was procured and used as experimental material. The potatoes were cleaned and bruised, blemished and other defective potatoes were removed manually. No chemical was applied on the potatoes for the present study, because the main purpose is to utilize SPV to power cooling system and evaluate its performance on the shelf life of potato tubers. The tubers were cured for two weeks from March 15 to 31st, 2001 and were placed in the cold store for 5 months from April 1st to August 31st 2001.

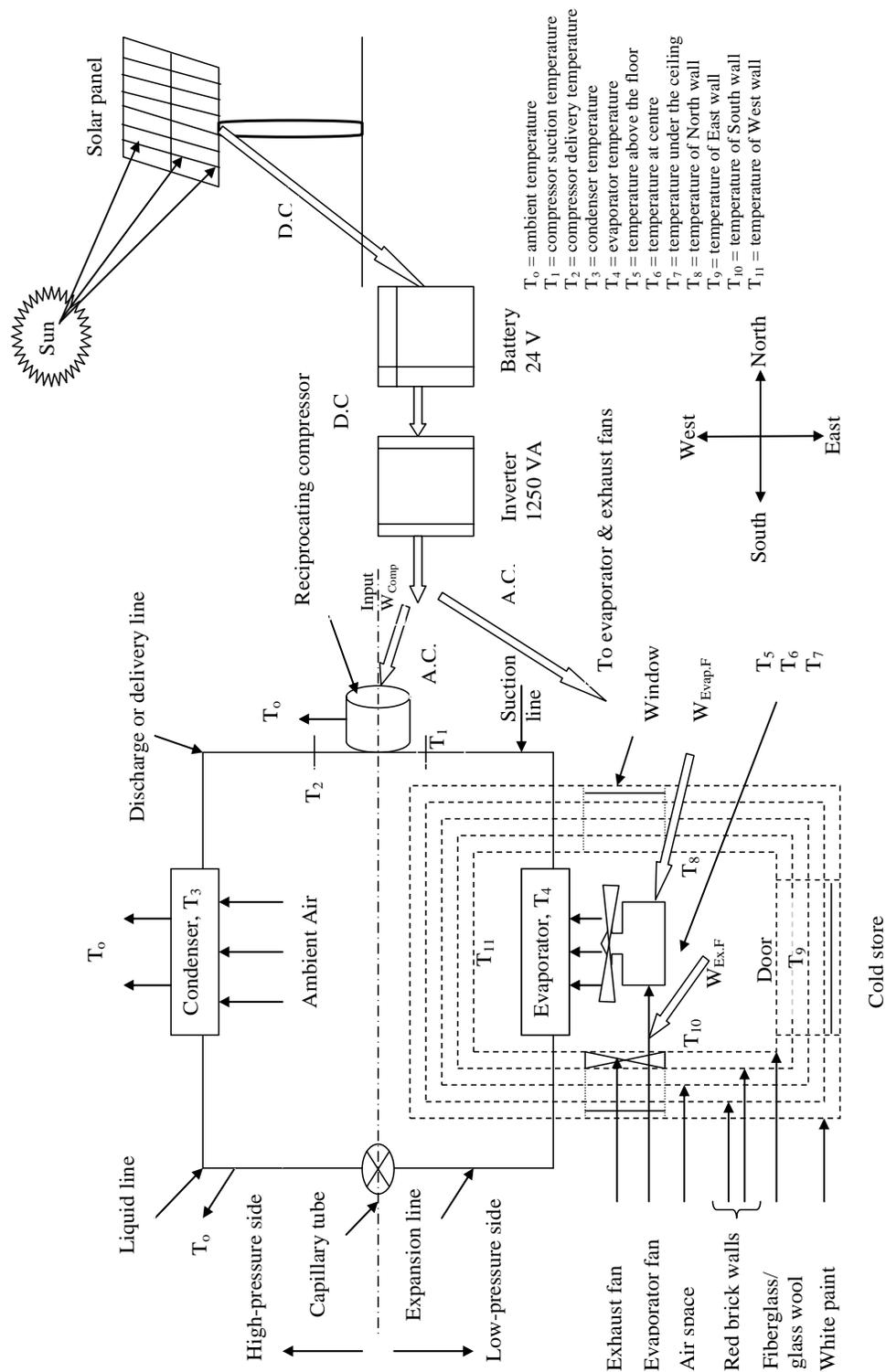


Figure 4. Schematic diagram for solar PV powered vapour compression cooling system for potato storage.

2.4.1 Curing Process

A 1 m³ evaporatively cooled rice straw storage structure with length-breadth ratio of 1.0 was used for curing process (Figure 5). The inner height of the structure was 0.5 m. The side wall thickness was kept at 0.20 m, which was made by rice straw pads covered with jute sack, and sandwiched between two layers of welded wire mesh. The pad layers were carefully laid to the frames of the structure without leaving any gaps. The floor of the structure was 12.5 cm above the ground. This was done to prevent moisture seepage through walls and accumulation of water on the floor of the structure.

The top cover of the structure was made of 10 cm thick layer of the same material as of walls, suitably sandwiched between two layers of welded wire mesh. To keep the surfaces of the structure wet for evaporative cooling, plastic drip laterals with drippers were used at equal intervals. A water tank of 250-liter capacity was used as water reservoir. The specified discharge rate of drippers was 4 liters per hour. The reasonable height of the tank was observed to be 1.2 m for maintaining the desired discharge rate (Dash, 1999). After curing, the tubers were grouped (sorted out and graded) manually into three sizes by weight viz. small (25- 60 g/ 25-58 mm diameter), medium (>60-120 g/ >58-75 mm diameter), and large (>120 g/ >75 mm diameter). The green and bruised potatoes were separated as culled ones.

The pre-graded tubers were manually loaded into the cold storage structure, and the time consumed was recorded in man-h.



Figure 5. Curing of potato tubers using evaporatively cooled (EC) chamber.

2.4.2 Shelf-life of Potatoes

Twenty randomly selected and marked tubers in each of the three sizes (Small, medium and large) were weighed before storage and at 15 days interval of storage period for measuring the loss in weight of tubers. The percentage of sprouting (number of sprouted tubers), and rotting potatoes, were recorded out of the tubers kept for physiological loss in weight. Dry matter

content was determined at 15 days interval in an air convection type oven using samples cut into 10 mm x 10 mm x 10 mm cubes, placed in a single layers and dried at 403.16 ± 1 K for 4 hrs (Ghadge et al. 1989). Reducing sugars were estimated as per the procedure given by Somogyi (1952), and starch determined by anthrone reagent method (Thimmaiah, 1999), at 30 days intervals of storage period.

Another set was taken up to study the effect of manual desprouting on storability and quality of potato tubers. The desproutings were made by hand 5 times each at 30 days interval. The number of tubers with well-developed sprouts were counted. Control was maintained without any desprouting. After each desprouting, the tubers were analysed for different physiochemical parameters viz. physiological loss in weight, dry matter, reducing sugars, starch, specific gravity, shrivelling, rotting, sprouting, black spot, and reconditioning after storage, according to the methods described in Eltawil (2003).

After 5 months storage the potatoes were kept for one week reconditioning at room conditions to avoid chilling injuries and reduce accumulated sugar. Potato samples were taken and analysed for different parameters such as reducing sugar and starch etc.

3. RESULTS AND DISCUSSION

3.1 Energy Consumption

The energy is necessary for compression of the refrigerant vapour by increasing its pressure and temperature. The mechanical energy necessary to drive the compressor is finally converted into heat. This heat must be removed by the condenser to condense the refrigerant vapour. The energy consumption of a refrigeration system is determined by the refrigeration capacity and the difference between the condensation and evaporation temperatures.

Energy consumption by the cooling system for empty and air circulated cold storage structure varied from 130 to 210 Wh during the days of experimentation. This variation attributed to the higher solar insolation, ambient temperature and lower air velocity, which caused a difference between condensation and evaporation temperatures and therefore the running time, was increased. The maximum energy consumption was recorded at noon hours, while minimum energy consumption by the load was recorded at very early morning hours. The average daily overall energy consumption of the cooling system was 3.970 kWh/d (energy used by exhaust fan was excluded).

The actual energy consumption by the cooling system (compressor) for *empty and non-air circulated cold storage structure* varied from 125 to 205 Wh. The average daily overall energy consumption of the cooling system was 3.850 kWh/d (energy used by circulation and exhaust fans were excluded). The same trend of energy consumption by cooling system was noticed to be as discussed above (maximum and minimum energy consumption were observed at noon and early morning, respectively).

Figure 6 shows the variation of SPV power output, P_{output} ; condenser and evaporator temperatures and energy consumption by the cooling system, E_{cons} , under full load (with stored commodity and with circulation of air inside cold store) as affected by weather conditions with

respect to zonal time of tested days is . The average daily SPV energy output and E_{cons} were 5.65 and 4.115 kWh/d, respectively, under full load, while, the corresponding average daily S_{Ins} , T_o , T_3 and T_4 were 7.263 kWh/m²/d, 305.78 K, 340.31 K and 272.79 K, respectively during tested sunny days in summer 2001.

The recorded data revealed that the difference between condenser and evaporator temperatures under full load is *more* than that of empty and air circulated cold store. The energy consumption under full load is higher, which may be due to certain amount of heat continuously produced by

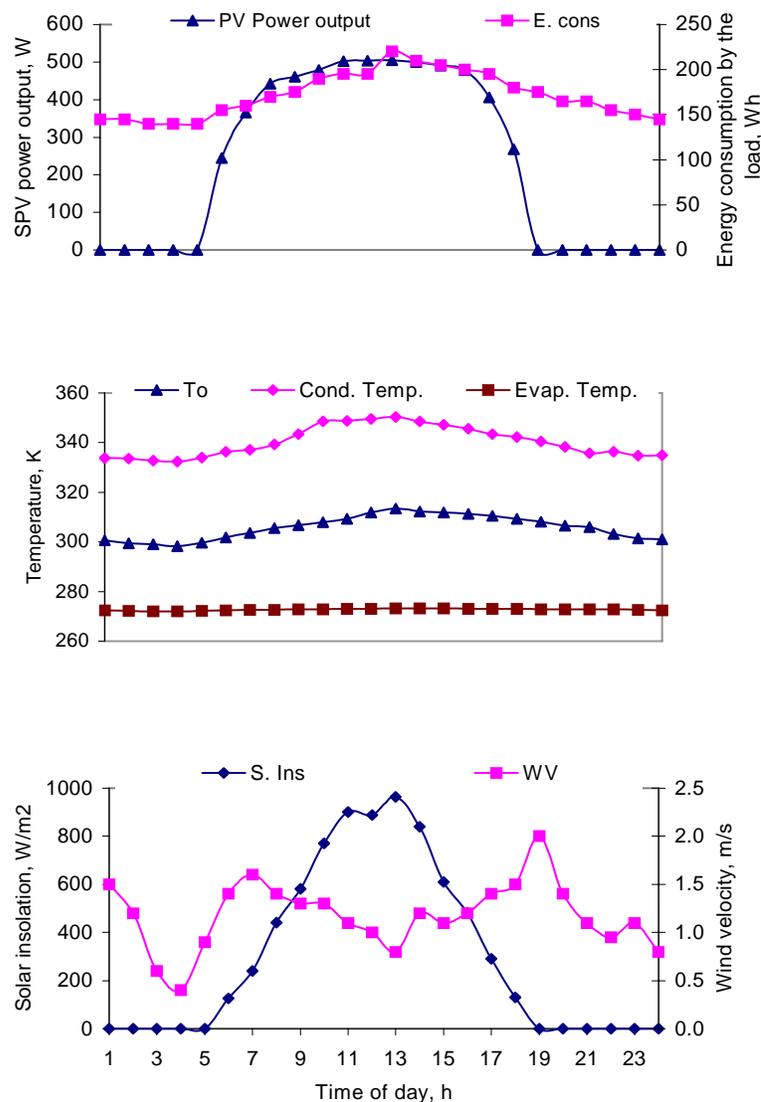


Figure 6. Effect of weather conditions on the SPV power output and energy consumption by vapour compression cooling system under full load during tested sunny days in summer 2001.

potatoes and evacuation of this heat consumes more energy. Energy consumption by cooling system under full load ranged of 140 to 220 Wh, while condenser and evaporator temperatures ranged of 332.3 to 350.3 and 272.1 to 273.2 K, respectively.

3.2 Coefficient of Performance of Refrigeration System

The maximum possible coefficient of performance, COP, is that of a Carnot cycle, and is given as follows (Arora, 2000):

$$\text{COP}_{\text{Carnot}} = T_{\text{evap.}} / (T_{\text{cond.}} - T_{\text{evap.}})$$

and

$$\text{COP}_{\text{real}} = 0.8 * \text{COP}_{\text{Carnot}}$$

The $\text{COP}_{\text{Carnot}}$ of the cooling system ranged of 3.55 to 4.73 with average daily of 4.17 for empty and air circulated cold storage structure during tested days. The actual COP for empty and non-air circulated cold storage structure varied from 2.9 to 3.82 with average daily of 3.44 during tested sunny day. Whereas, the actual COP for loaded and air circulated cold storage structure varied from 2.83 to 3.62 with average daily of 3.25 during tested sunny days.

Based on the actual data, the maximum COP_{real} was calculated at a very early morning and late evening hours, while the minimum values were calculated at noon hours. This is attributed to higher temperature difference between condenser and evaporator at noon hours. The results show that the COP of cooling system decreases, and power consumption increases as we go to lower refrigeration temperatures. The COP represents the overall efficiency of the system (evaporator temperature divided by the temperature difference between condenser and evaporator). The calculated value is realistic for Freon refrigeration systems of this size and type.

The recorded data revealed that the COP_{real} for loaded and air circulated cold storage structure is lower than that of empty and air circulated case. This is attributed to heat generated by potatoes during respiration process, in addition to larger temperature difference between condenser and evaporator.

3.3 Effect of Ambient Conditions on the Evaporative Cooled Structure

Attempts were made to observe the effect of ambient conditions on the thermal environment of the empty and loaded (with potato) 1.0 m³ rice straw pad structure as shown in Figures 7 and 8 for selected tested day and during curing period, respectively.

The average ambient and inside temperature of empty EC structure were 297.99 and 288.1 K, respectively, while the difference between ambient and inside temperature for the same structure ranged of 7.0-14.4 K with average difference of 9.89 K. The average ambient and inside r.h. of empty EC structure were 49.67 and 96.42%, respectively, while the difference between ambient and inside r.h. for the same structure ranged between 31- 61% with average difference of 46.75%. These results correspond to average wind velocity of 1.54 m/s and solar insolation of 410.41 W/m².

The average temperature and relative humidity achieved inside loaded curing chamber during curing period were 291.33 K and 93.38%, respectively, while average ambient temperature and relative humidity were 297.7 K and 49.36%, respectively. The temperature inside EC structure, T_{inEC} , was close to the ambient wet bulb temperature at early morning time. The observed results are in agreement with Alam and Devnani (1979); Ali *et al.*(1975); Booth (1974); Dash (1999); Kishore (1979); Meijers (1981); Sparenberg (1979); and Sukumaran and Verma, (1993).

Experimental studies revealed that the inside relative humidity of the evaporatively cooled, r.h._{inEC}, rice straw pad structure would remain above 90% for empty and loaded conditions because the air entering the structure was almost saturated. The maximum effect of

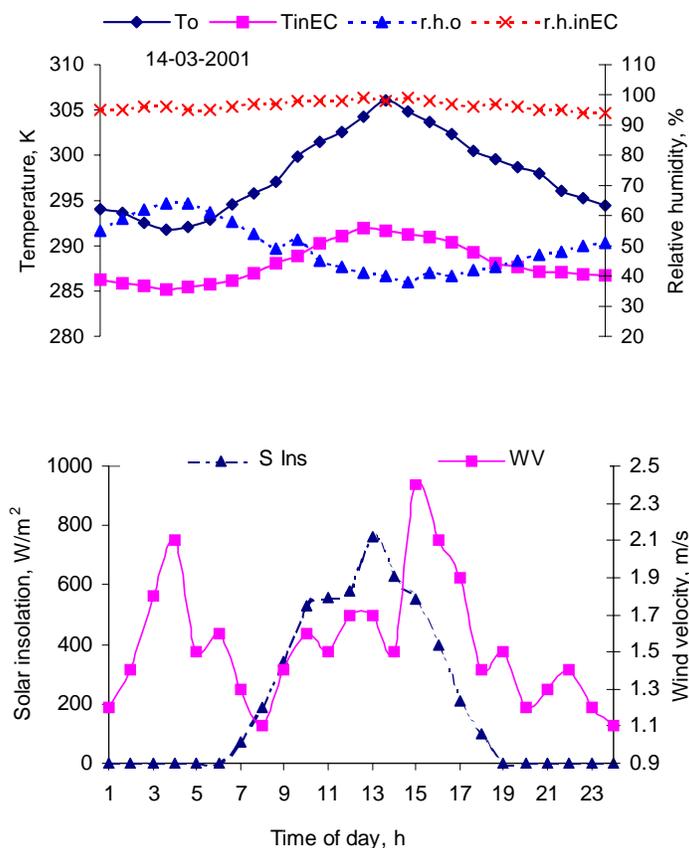


Figure 7. Effect of ambient conditions on the thermal environment in a 1m³ empty EC structure with rice straw pad walls on a tested day (14-03-2001).

evaporative cooling is obtained when the ambient r.h. remains at its lowest level in tested days (summer). The daily temperature fluctuation was reduced in the loaded structure due to the heat storage with the produce. As solar radiation is one of the major sources of heat gain, keeping the structure completely under shade without restricting airflow in the vicinity of the structure would help in further reducing the accumulated heat.

The pad structure, being lightweight, can be conventionally shifted from one place to another, and after the curing period, the structure can be dismantled and the space can be used for other requirements. It can also be used for transportation of potatoes to distant places. On curing of potatoes for two weeks there was proper subrization and development of wound periderm layer.

3.4 Effect of Weather Conditions on the Inside Environment of Cold Storage Structure

The average temperature and relative humidity measured inside empty, insulated and air circulated cold store without storing potatoes were 280.94 K and 81.21%, respectively; while,

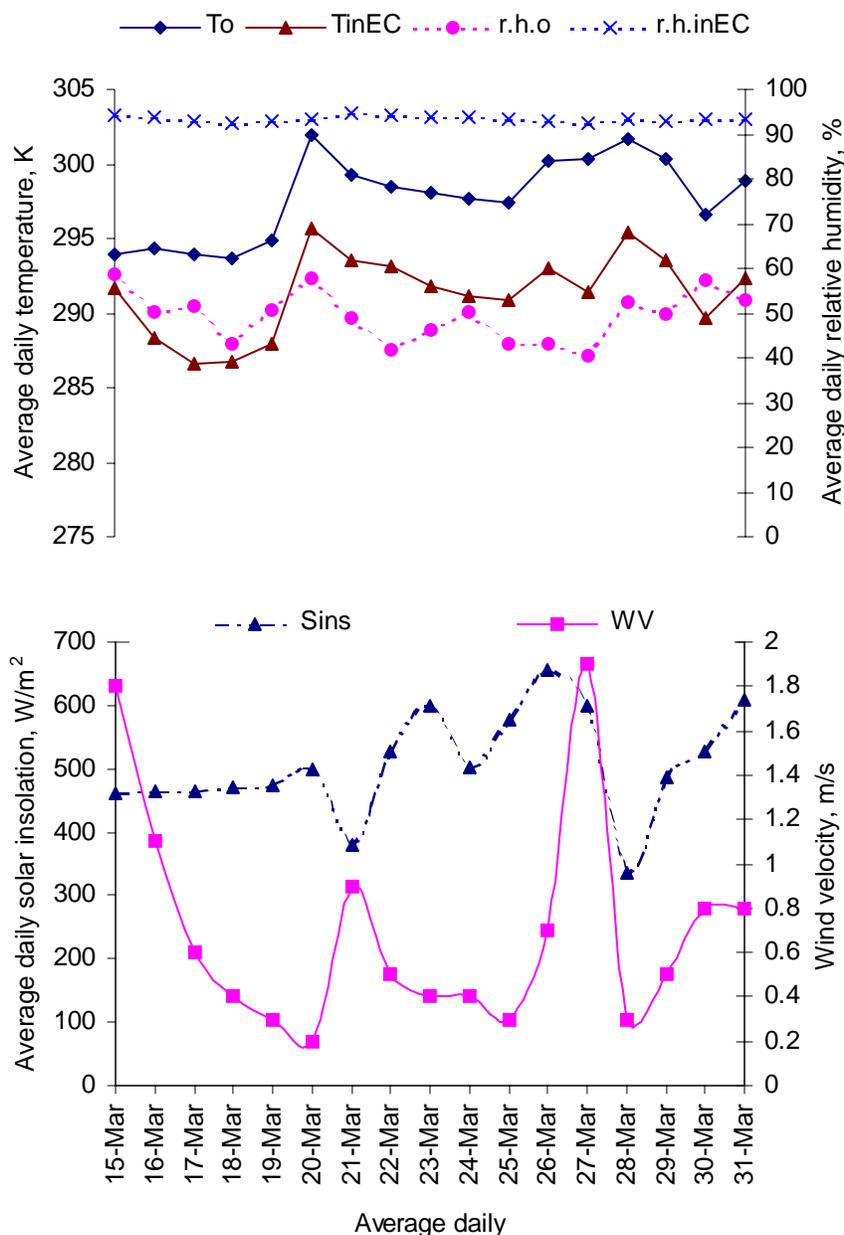


Figure 8. Effect of daily ambient conditions on thermal environment of 1.0 m^3 loaded EC structure during curing period (March 15-31, 2001).

average ambient temperature and relative humidity were 303.28 K and 52.08%, respectively. It was noticed that the temperature gradation was higher under the ceiling compared with the centre and floor (bottom). The reason may be attributed to the fact that cooled air with higher density and tends to be at the bottom and the warmer air being low in density and then move upward towards the ceiling. Also, it was found that the variation of wall temperatures started from lower to the higher one i.e. East, North, East and then south walls. The reason for that may be due to

evaporator position, which tends to cool the surrounding air and then the nearest walls (Fig. 4). The leeward wall (South) temperature is higher than windward side (North wall), which may be due to the lower rate of heat movement because wind velocity at south wall is very low in addition to effect of solar radiation on the exposed part of south wall, which tends to heat it up.

During tested day, the r.h. inside empty and air circulated cold storage structure ranged between 78 to 83%, while, r.h._o ranged of 24 to 73%. It is clear that the wide variations of ambient relative humidity and temperature might be the possible cause of severe losses in potato quality, and hence, cold storage is necessary to prolong shelf life of potato and maintain its quality by reducing storage losses. The narrow variation in observed temperatures and relative humidities inside cold storage structure might have been due to the adequate insulation and mixing of air in different regions inside the storage structure.

The average temperature and relative humidity measured inside empty, insulated and non-air circulated cold storage structure were 285.39 K and 73.94%, respectively. While average ambient temperature and relative humidity were 304.24 K and 52.04%, respectively.

It was noticed that the temperature gradation was higher under the ceiling compared to the centre and roof location and the reason may be attributed to density differences of the air inside the cold storage structure, and the natural air convection, where the cold, heavier air flows downward to the bottom and displaces the lighter, warm air upward towards the ceiling. With stored potatoes, the cold air gets heated in the heap, becomes lighter and in turn is displaced from the heap by the ambient air, which causes the heap to be ventilated. This form of ventilation is known as natural draught ventilation or ventilation by free convection. The motive power for this air movement is the pressure, or pressure head caused by the difference in weight between the colder ambient air and warmer air in the heap. This pressure head is proportional to the difference between the temperature of the air in the heap and the ambient air (Rastovski, 1987).

3.5 Effect of Weather Conditions on the Inside Environment of Loaded and Air Circulated Cold Storage Structure During Storage Period

Effect of weather conditions on the inside thermal environment of loaded and air circulated cold store during storage period in summer 2001 is shown in Figure 9. Heat exchange takes place between the store and ambient conditions due to temperature difference between them. The average 15 days interval was considered to study the effect of developed thermal environment inside cold storage structure on the potato quality. The average maximum inside temperature, T_{incs} , of 284.33 K and r.h._{incs} of 87.43% were recorded for the period of May 1-15. The averages degrees of temperature and relative humidity maintained inside the loaded and air circulated storage structure during storage period were 283.13 K and 86 %, respectively.

The inside temperature and r.h. during storage of potatoes was relatively high compared to the conditions without potatoes. Since the partial vapour pressure in cold air is always lower than the vapour pressure in warm potatoes, a positive vapour pressure difference always exists between potatoes and air during cooling and causes the water to evaporate from the potatoes. The tubers thus lose moisture during cooling- i.e., simultaneous heat and moisture transfer takes place between the potatoes and the air, where, the moisture loss is accompanied by latent heat transfer during cooling (Rastovski, 1987).

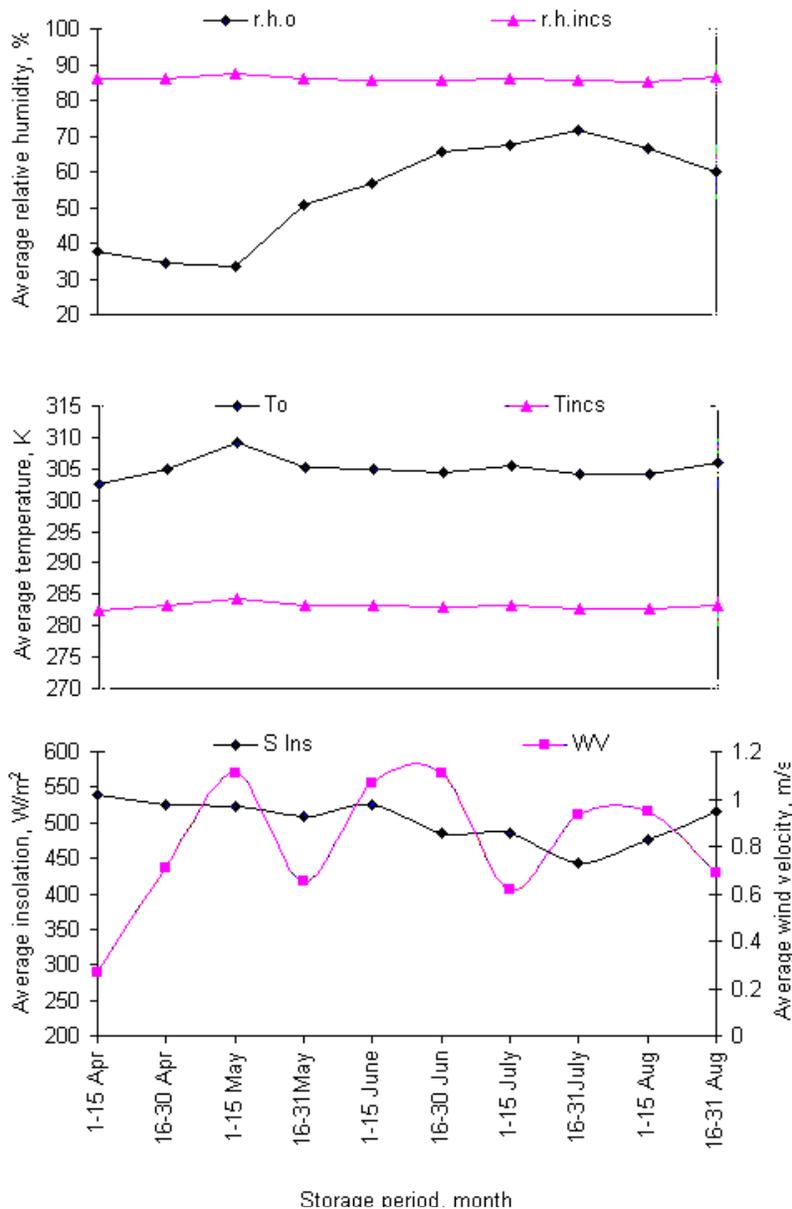


Figure 9. Effect of weather conditions on the thermal environment of loaded and air circulated cold storage structure during storage period in summer 2001.

The maximum variation of temperature gradients within a bed of potatoes during the day was approximately 1 K for the three tested locations (bottom, center and top) inside the cool storage. The temperature at the centre remains higher compared to the bottom and top of the storage bin. This attributed to more resistance and lack of cold air distribution at the centre, therefore, storage depth are restricted to usually 2-3 m in unventilated or convected ventilation stores. Analysis of the data indicated that, there were no significant temperature gradients within the bed of potatoes. It is recommended to use forced ventilation for economic storage depth of 4.0-5.5 m.

3.6 Ventilation with Outside Air

The ventilation process started with ambient air temperature of 300.8 K and relative humidity of 90%, while the inside temperature and relative humidity were 282.3 K and 87.6%, respectively. The observation was recorded during ventilation period at three minutes interval. The inside temperature and humidity increased rapidly and reached 284.9 K and 100.8%, respectively, after 27 min, then the ventilation process stopped, i.e. exhaust fan turned off and the inlet and outlet closed, to isolate the store from outside conditions.

After stopping the ventilation process it was found that the relative humidity continued to increase and reached 101.8% at 33 min and the condensation process takes place after that the relative humidity started to decrease. Hence, it is recommended to control the ventilation process by observing relative humidity inside the store and stop this process before reaching 100% to avoid condensation. These control operations can be performed by the storekeeper himself. It was noticed that the higher ventilation rate caused a rapidly increase in relative humidity inside the store within a short time. Forced circulation through the potatoes is required to reduce temperature at the center of storage bed, specially for the higher storage temperature of processing potatoes and seed stock in the warmer parts of the late-crop area. Rapid air circulation may lower the relative humidity of the air immediately surrounding the potatoes; it is conducive to drying and loss of mass, which may be desirable if there are disease problems but undesirable with sound potatoes because of increased shrinkage ([ASHRAE., 1998](#)).

3.7 Physiological Properties of Potatoes in Relation to Cold Storage

It was observed that the cumulative physiological loss in weight (PLW) in control as well as manually desprouted tubers increased by increasing storage period as shown in Figure 10. It was higher in manually desprouted tubers upto 8 weeks comparing with control, and thereafter the control tubers showed higher PLW. Results revealed that small tubers had higher weight losses as compared to medium and large tubers, which could be due to the fact that the large surface area of the small tubers exposed to the greater airflow leading to quick evaporation. Also weight losses increased with increasing period of storage. The results are in agreement with [Das et al. \(2000\)](#). After five months storage, the total weight losses were 7.89, 7.75 and 7.62% for control tubers while it were 6.51, 6.42 and 6.36% for manually desprouted tubers, with respect to small, medium and large tubers, respectively.

It was observed that the tubers PLW remained below 10% and free from shrivelling until 20 weeks from storage. Therefore, under the developed conditions the potatoes could be stored for about 5 months without affect its marketability. The findings from the results that so far as PLW is concerned cured potatoes would store in good conditions in cold store. The observed results are in agreement with [Booth and Shaw \(1981\)](#) and [Hegde \(1992\)](#).

The sprouted tubers first noticed after 4 weeks and increased with advancing of storage. The maximum sprouted percentage of 69.8, 84.30 and 89.20% for small, medium and large size tubers, respectively, were recorded at the end of storage period. Also, it was observed that the length of sprouts were 60, 57 and 48 mm for small, medium and large size tubers, respectively.

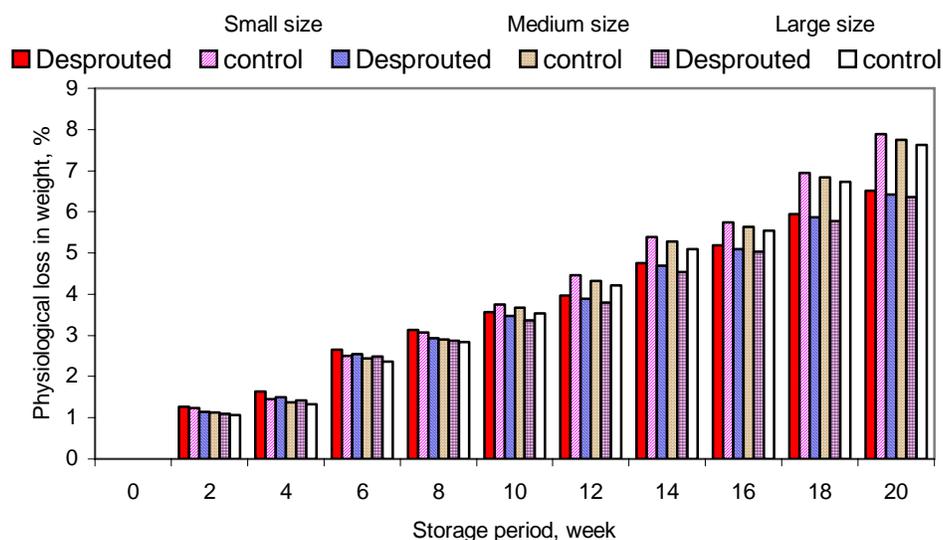


Figure 10. Physiological loss in weight as affected by manually desprouting and tubers size during storage period in summer 2001.

Figure 11 shows the effect of tubers size on sprouting capacity (sprout weight) during storage period. In case of manually desprouted tubers, the highest sprout weight was obtained at 12 weeks, and thereafter, it decreased. There are no internal sprouting and little tuber formation were observed in the present study in case of manually desprouted tubers. The sprout length and total sprout weight at the end of the storage period were highest in control tubers comparing with manually desprouted. This finding was in accordance with the observations recorded by Dayal and Sherma (1987). It interesting to note that with continuous desprouting, the weight of sprouts was decrease due to decrease number of sprouts.

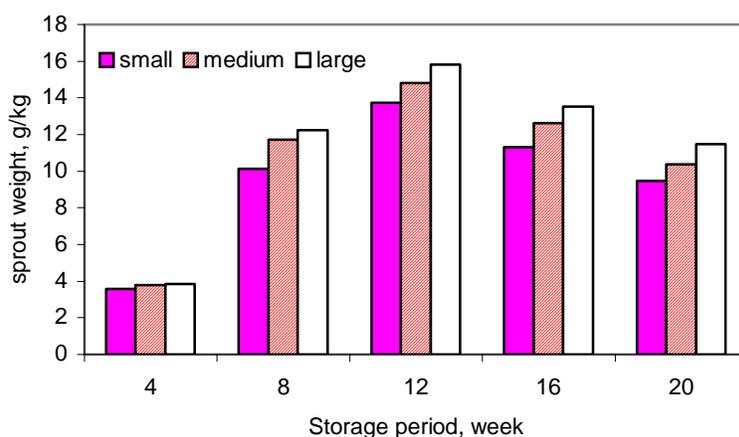


Figure 11. Effect of tubers size and storage period on sprouting capacity.

The rotten tubers as affected by tuber size and storage period is shown in Figure 12. The rotten tubers first noticed after 10 weeks and increased with storage period. The rotting was higher in manually desprouted tubers comparing with control. It was further observed that the maximum rotten tubers were 1.9, 2.2 and 2.6% for manually desprouted tubers and 1.7, 2.1 and 2.4% for control tubers with respect to small, medium and large tubers size, respectively, at the end of storage period. Smaller tubers suffered least from rottage.

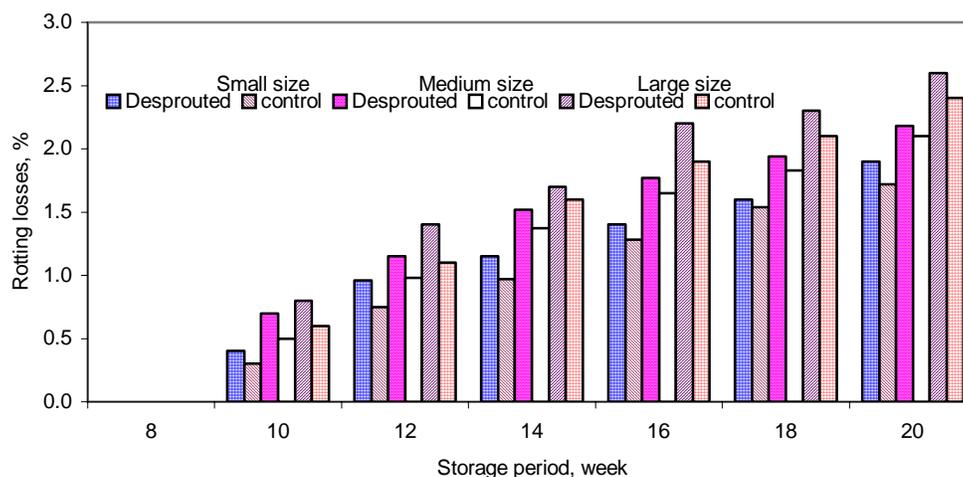


Figure 12. Rotting losses as affected by tubers size and storage period.

The control tuber showed shrivelling after 16 weeks while manually desprouted tubers showed slightly shrivelling at 18 weeks, and thereafter increased. At the end of storage period there were 17, 15 and 13.5% shriveled tubers for control and 6, 5, 3.5% for desprouted tubers with respect to small, medium and large size tubers, respectively, at the end of storage period. The higher moisture loss the higher shrivelling of control tubers comparing with that of manually desprouted ones. The shrivelling appeared due to transpiration and respiration, which carried out by the sprouts resulting in loss of turgidity in the tissue.

Observation on potato tubers stored in the maintained conditions indicated that, there was no black heart appeared during storage upto 18 weeks. But at the end of storage period (20 weeks) the control tubers showed few percent (3.3%) of slightly blue-grey discolouration of the potato tissue on cutting. This discolouration was displayed just below the skin around the vascular bundle tissue. The discolouration occurred principally at the stem end. The lower percentage appearing of discolouration may be attributed to proper and sufficient air renewal and decreasing CO₂ concentration (Meijers, 1987).

3.8 Physico-Chemical Properties

Observations on stored tubers revealed that with increasing storage period, the dry matter content (DM) and specific gravity (SG) of potato tubers increased. The average SG of 1.082 and 1.081, and DM content of 21.37 and 21.57% were recorded for manually desprouted and control potato tubers, respectively during storage period. While the average corresponding inside temperature

and humidity were 283.27 K and 86.58%, respectively. Analysis of data indicated that the DM content of tubers had affected significantly by temperature and relative humidity inside the store, and storage period. The DM content was higher in control tubers comparing with manually desprouted ones (Figure 13). However, control and manually desprouted tubers did not differ significantly with respect to specific gravity throughout the storage period. It was observed that in general, with increase in SG, the DM also increased in control and manually desprouted potato tubers. The close relation between SG and DM content was in conformity with the observations recorded by Mehta and Kaul (1988) and van Es and Hartmans (1987).

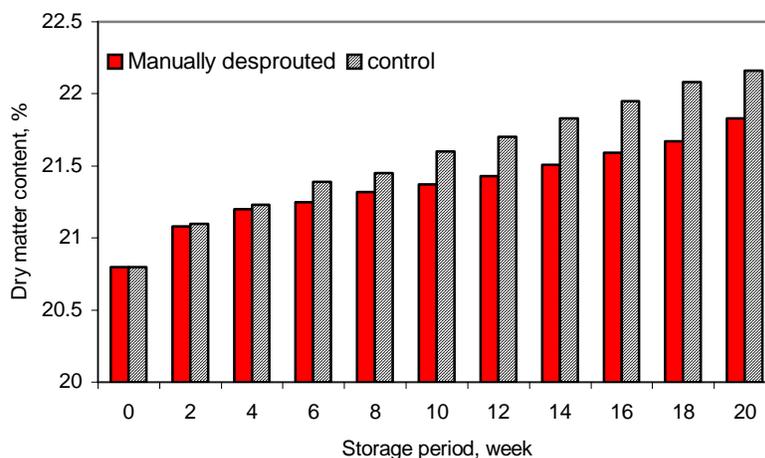


Figure 13. Dry matter content of potato tubers as affected by method of sprout control during storage period.

The little change in SG indicates that shrivelling was due to less of solids and more loss of water. The increase in DM of the tubers was a result of greater loss of water by evaporation than loss of solids by respiration. The DM content of large tubers is usually lower than that of small tubers, as the latter contain relatively less of the water-rich inner medullary tissue. Possible departures from this rule may be due to immaturity of the tubers (Burton, 1966). In summing up, the potato tubers, which had high specific gravity and dry matter content, were most suitable for making potato chips and other dehydrated products.

The effect of sprout control method on starch during storage period is shown in Figure 14. It was observed that there was an overall decrease in starch content with increase in storage period in all treatments. The manually desprouted tubers showed higher starch content comparing with control ones. The average starch content of potato tubers during storage period was 13.19 and 12.84% of fresh weight for manually desprouted and control tubers, respectively. At the end of storage period (20 weeks), it was found that the loss in starch content was about 19.97 and 15.76% for control and manually desprouted tubers, respectively. The degradation of starch in cold stored tubers is mainly phosphorolytic, and activities of phosphorylases are correlated to the accumulation of sugars in stored tubers (Claassen et al., 1993; and Morrel, and Rees ap, 1986), and so starch was decreased with storage period.

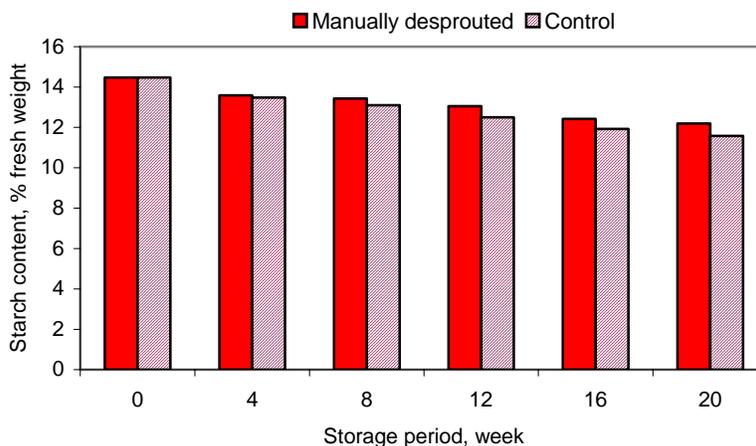


Figure 14. Starch content of potato tubers as affected by method of sprout control during storage period.

Figure 15 shows the effect of sprout control method on reducing sugar during storage period. It was observed that the reducing sugar increased after potato tubers entered to the store, then decreased and thereafter increased with increasing storage period. The manually desprouted tubers showed lower reducing sugar content comparing with control ones. The average reducing sugar of potato tubers during storage period was 342.33 and 366.50 g/100 g fresh weight for manually desprouted and control tubers, respectively. At the end of storage period (20 weeks), it was found that the increase in reducing sugar content was about 41.92 and 58.76% for manually desprouted and control tubers, respectively. Analysis of the data indicated that the storage period affects significantly the reducing sugar content for different treatment. Regular removal of sprouts manually caused the levels of reducing

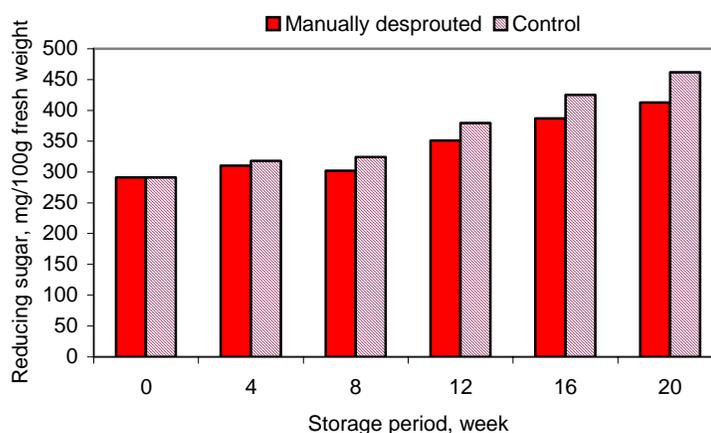


Figure 15. Reducing sugar content of potato tubers as affected by method of sprout control during storage period.

sugar to continue to increase slowly, whereas, in control tubers there was a higher increase in reducing sugar. Similar observations were also recorded by [Hughes and Fuller, \(1984\)](#). The removal of sprouts might be caused a loss of mobilized and transported sugar, which resulted in low levels of sugars at the end of the storage period.

It was found that potato Kufri Chandramukhi stored under maintained conditions had an acceptable level of dry matter and reducing sugar, and it could be considered a suitable variety for chip making ([Rai and Verma, 1989](#)).

3.9 Reconditioning

Reconditioning of potato tuber for one week after 20 weeks cold storage indicated that there was a reduction in reducing sugar by 11.32 and 16.08% i.e. from 413 to 371 and from 462 to 398 mg/100g fresh wt. for manually desprouted and control tubers, respectively. The starch content of potato tubers was increased by 7.46 and 8.38% i.e from 12.19 to 13.10 and 11.58 to 12.55%. As the potato warmed up, the moisture loss was increased and caused shrivelling, which accompanied by increasing DM content by 1.14 and 1.26% i.e. from 21.83 to 22.08 and 22.16 to 22.44%.

4. CONCLUSION

The energy supply from the solar panel (490W) is charged the battery for overnight operation of the cooling system. The average temperature and relative humidity maintained inside empty, insulated and air circulated cold storage structure were 280.94 K and 81.21%, respectively. The averages degrees of temperature and relative humidity maintained inside the loaded and air circulated storage structure during storage period were 283.13 K and 86 %, respectively. While, the average temperature and relative humidity maintained inside empty, insulated and non-air circulated cold store without storing potatoes were 285.39 K and 73.94%, respectively. The average daily actual COP of the empty and non-air circulated cold storage structure was 3.44, respectively. While, the average daily actual COP for loaded and air circulated cold storage structure was 3.25.

In summing up the overall discussion, it could be concluded that the maintained conditions by the designed systems can maintain potato tubers in their most edible, marketable conditions and acceptable level of dry matter and reducing sugar by preventing large moisture losses, spoilage by pathogens, attack by insects and animals, and sprout growth. The loss in weight was minimized by storing cured sound potatoes in cold store.

Solar panel can serve as an alternative source of energy for powering cooling system. It is recommended that the government should sponsor projects like this and give long loans to the farmers to do the same; hence we can minimize the losses of horticultural produce.

Acknowledgements: The authors would like to thank professor D. S. Khurद्या, Ex-Head of Post Harvest Technology Division, IARI, New Delhi, for providing the Lab facilities to test physico-chemical properties of potato tubers.

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