# Patukattal – Advanced Indigenous Refrigeration System

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## Abstract

Refrigerator is a common house hold appliance that operates by reducing and maintaining the temperature of a space below the temperature of the surroundings. Refrigerators utilize harmful gases like Chlorofluorocarbons (CFCs) which depletes the Ozone layer along due to release of HFCs and HCFCs that contribute to the global warming potential as compared to water vapor which is natures unbiased greenhouse cloak. Secondly refrigerators run on electricity which is mostly produced by thermal power generation unit which produces the notorious gases like $CO_2$ & CO gases thereby increasing carbon footprint & contribute to global warming indirectly. Apart from all these environmental effects these storage devices are not affordable by poor people around the African and Asian countries due to the development cost.

Thus we come up with an eco-yet tech-friendly cooling system which uses water as the main refrigerant and the process of water evaporation to generate the cooling effect. Evaporation of water takes a lot of heat away about 540 calories per gram. The structure would be modular to meet specific goal based on requirements. The model would be stronger

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lighter and portable with outer layer made of thermocol and the inner layer made of conductive Aluminium sheets. The buffer material comprising of sand and wood chips are used in compliance with the light weight and portability requirements. To know the moisture integrity of the buffer, a moisture sensor, Seven Segment display with micro controller is used. The inner space of the device is partitioned into compartments to allow flexible storage. Apart from that device contains IR sensors to detect space availability for storage. Thus the user can know when he has to refill the system and available box space. A Solenoid valve is used to provide both auto and manual refilling mode for water in the buffer region. A Peltier device which is being controlled on the basis of temperature sensor is used for further enhanced cooling.

**Keywords:** Refrigerator, Moisture Sensor, Peltier Device, Evaporative Cooling.

## 1 Introduction to Refrigeration

Throughout mankind history science has searched into unknown realms. After Brazil and China India Stands at number three on the production of fruits and vegetables which account for 209.72 million tons (MT) of which 73.53 MT & 136.19 MT are fruits & vegetables respectively [1]. One of the persistent problems is storage of horticultural growth after harvest because of high moisture content due to which they are liable to spoil. During harvest, storage, packaging distribution and transport around 30 to 35% of total vegetables and fruits produced in India is lost in a year which reduces the growers share [7, 15].

Evaporative cooling is a phenomenon in which a liquid evaporates into surrounding air, resulting in a cooling effect to any object inn contact with it. Water evaporation produces a considerable cooling effect and the cooling is greater for a faster evaporation. During similar temperature, it results in no evaporation and simultaneously no cooling effect. The primary principle behind this system is when a enclosed space is conditioned at lower temperature than the ambient temperature moisture from the surrounding body, it maintains low temperature and elevated humidity in the space compared to the surrounding. This evaporative chamber fills these requirements and that makes it helpful to rural and small farmers [9].

Evaporative coolers provide conditioned environment by forcing dry hot air over a wet pad. The evaporation of water in pad, removes heat from air while

adding moisture to the environment. During evaporation of water it draws the surrounding energy which produces a cooling effect in considerable amount. When air is not much humid, passes over a wet surface evaporative cooling occurs; the cooling is greater based on faster evaporation. The evaporative cooler efficiency depends on the surrounding air's humidity. Extremely dry air allows a lot of moisture absorption so greater cooling occurs. In the extreme case where air that is totally saturated with water, no evaporation can take place and no cooling occurs. The evaporative cooling storage structures work on the principle of adiabatic cooling caused by water evaporation, by making the water to drip over the bricks or cooler pads [3].

## 2 Existing Methods

The mainstay of this project is to decrease the inner temperature with respect to the outside surrounding which is mandatory for implementation of efficient and better preservation. This work is an alternative for the existing methodology.

The different designs that will be looked into are as follows:

A. Zeer Pot or Pot-in-Pot Technique
B. Tin in Pot technique
C. Eco-Fridge
D. Mitti Cool Refrigerator
E. Evaptainer

Mohammed Bah Abba invented Zeer pot technique in 1995 mainly to support the poor farmers to preserve their agricultural produce. This process involves usage of two earthen pots of different sizes. The smaller pot is placed within the larger pot and the space between the two pots is filled with sand. The Sand acts as a buffer medium to hold water required for evaporation and also provides insulation to the inner pot from the external temperature. The opening is covered with a wet cloth. The water diffuses through the sand and permeates through the outer pot. The permeated water reaches the pot surface, it gets evaporated and thereby cooling the inner pot.

Tin in pots are similar to Zeer technique. But a tin pot is used to replace the smaller pot in pot-in-pot technique. It made the material requirement and fabrication easier as compared to Zeer pot technique [13]. Emily Cummins from UK came up with the idea of sustainable refrigerator. Its construction is similar to Pot-in-Pot technique. But the material here is not essentially of clay. The outer cylindrical material can be of varieties of solid material like

wood, plastic etc whichever is readily available. The outer concentric cylinder has multiple holes in it to facilitate water evaporation. The inner cylinder is metallic and good conductor, holes are absent in it. The top of the cylinder is enclosed with a lid. The space between the concentric cylinders can be filled with any easily available buffer material like wool, soil or sand which can retain water for evaporation.

Mitti Cool Refrigerator is the invention of Mansukhbhai Prajapati. The primary constituent is clay. There is no maintenance cost in this refrigerator as it does not use any power source or electricity. The water from the top chamber permeates through the walls surrounding food storage chamber and when these water particles evaporate it brings about cooling of the storage chambers [2]. Quang Truong and Spencer Taylor invented Evaptainer. The construction of an Evaptainer consists of two separate chambers. One is used for storing water required for evaporation and the other for storing food. The highly conducive Aluminium plates are run along the walls of the storage space. These plates are connected to special fabric which is always kept wet. The Aluminium plates draw heat from the inside and the evaporation of water from fabric keeps the storage space cooler. From the above comparison it is clear that the main problem with evaporative coolers unfortunately is one that really cannot be remedied. It is that they are really effective in dry climates. Evaporative coolers work by soaking pads of wood or other cellulous material with water and some absorbing material. Thus, they constantly add water to the air. They work great in dry climates where adding moisture to the air will actually cool it, but in wet climates, adding water moisture to the air only makes it seem hotter! This is not good and a large portion of the country cannot use evaporative coolers efficiently. However, in dry areas of the western India, they work wonderfully. They can keep the system about 15 degrees cooler than it is outside on hot days.

## 3 Proposed Design

The prime objective of this project is to focus on the design and working of an affordable refrigeration system with no harmful effects. The prime purpose of this project is to provide street vendors and village people an effective system which they can use easily in their day to day life. The proposed system is constructed with the principle of evaporative cooling and Peltier effect which can provide cooling up to 15 degree Celsius difference from outside temperature. It consists of three units one is the evaporative cooling unit which cools the inner compartment of the system by the evaporation of water in outer

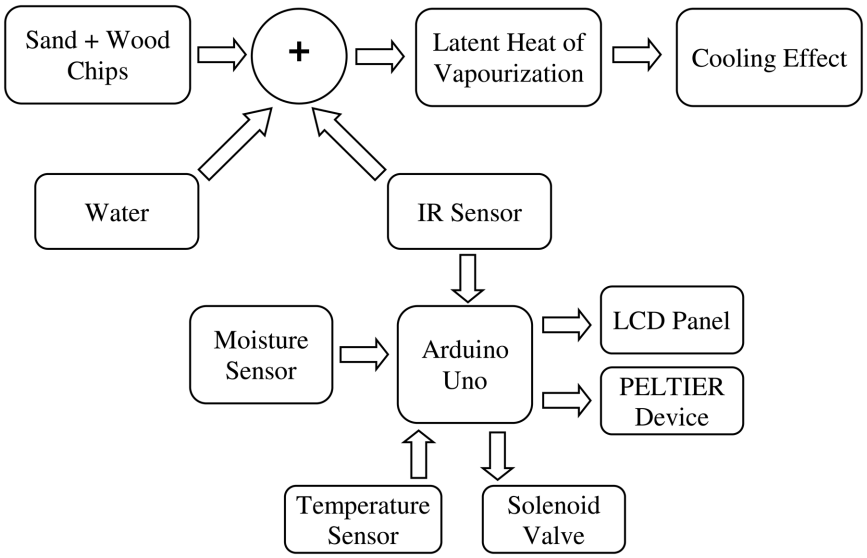


**Figure 1** Block Diagram of Patukattal system.

atmosphere the second unit is used to provide more cooling effect by using Peltier effect with Peltier plates and set of heat sink and fan to remove heat. To make it a smart device moisture sensor is used to read the moisture value and control the flow of water so that there is no wastage of water by adding it excess or depletion of water. IR sensor is used to check the inner compartment is full or not. This all sensor and system is controlled by Arduino Uno board.

The functional processor used in this system is Arduino Uno microcontroller. This project focuses on design and working of an affordable system for food preservation and utilizes multiple sensors based on which a smart yet non-conventional refrigeration system has been developed. The block diagram of the proposed system is shown in Figure 1.

## 4 Development and Operation

Here we put light on how the electronic circuitry is assembled as well the operation of the hardware model. The model is a culmination of two cooling systems, the evaporative cooling as well as the Peltier effect. Both play a vital role as per varying parameters in providing an effective cooling to extend the life of vegetables and fruits stored in it. The development consists of two phases

A) Development of the structure and
B) Interfacing of the electronic circuitry

### 4.1 Development of the Structure

The primary base is provided using a thermocol box that can be easily procured from fish vendors. The primary objective of choosing thermocol was due to its features of being lightweight yet formidable weight capacity along with its cheap availability. It also provides thermal insulation which primary requirement to refrigeration. Following to it the edges are measured and at gap of 3" from the vertex. Then these are cut and replaced by Aluminium plates about whose conductivity we have priory discussed. To provide support to them ridges are made within the cut edges and the Aluminium sheets are placed over there. To provide support to the Aluminium and thermocol box an additional set of Aluminium angular frames are attached to the box using nut and bolts. The development phase of structure is shown in Figure 2.

**Figure 2** Developing phase of the structure.

### 4.2 Interfacing of the Electronic Circuitry

In this system we have the following electronic modules.

- LCD module connection are made as follows
  RS- pin12 En- pin 11 D4- pin 5
  D5- pin 4 D6- pin 3 D7- pin 2
- Moisture Sensor is Connected to the A0 pin
- Temperature Sensor is connected to the A1 pin
- Solenoid valve is Connected via the relay to the output pin 13
- Peltier devices are connected via the relay to the A2, A3 pin

The Figure 3 shows the interfacing of sensor and i/o modules with Arduino uno. All the ground pins and voltage pins are synchronized via bread board. Separate 12 V supplies are provided to the solenoid valve and the Peltier modules that are controlled by the input pins of the relay [14].

First of all the LCD and serial monitor header call the library functions. Then the input and output pins are initialized. Following to it the display can be customized as the users preference. Then the IR sensor process is initiated. It sends the IR signal, and if the signal is deflected and received back it considers that the space is occupied or else it is not occupied is showed in Figures 4 and 6.

Followed by it the moisture sensor process is initiated which is for determining the moisture level. Based on that it compares it to a threshold value which is 655, if the moisture value reads greater than that it initiates

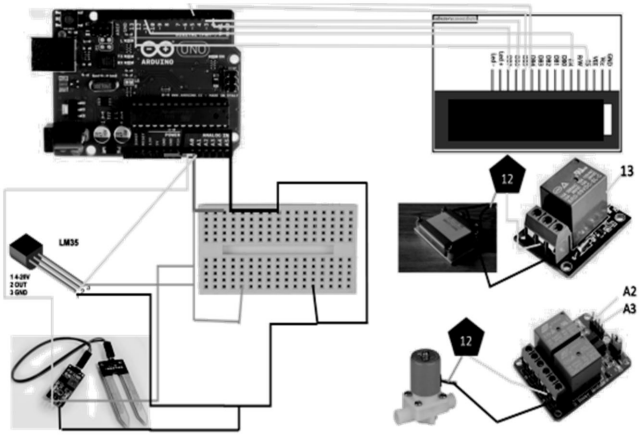


**Figure 3** Interfacing of the electronic circuitry.

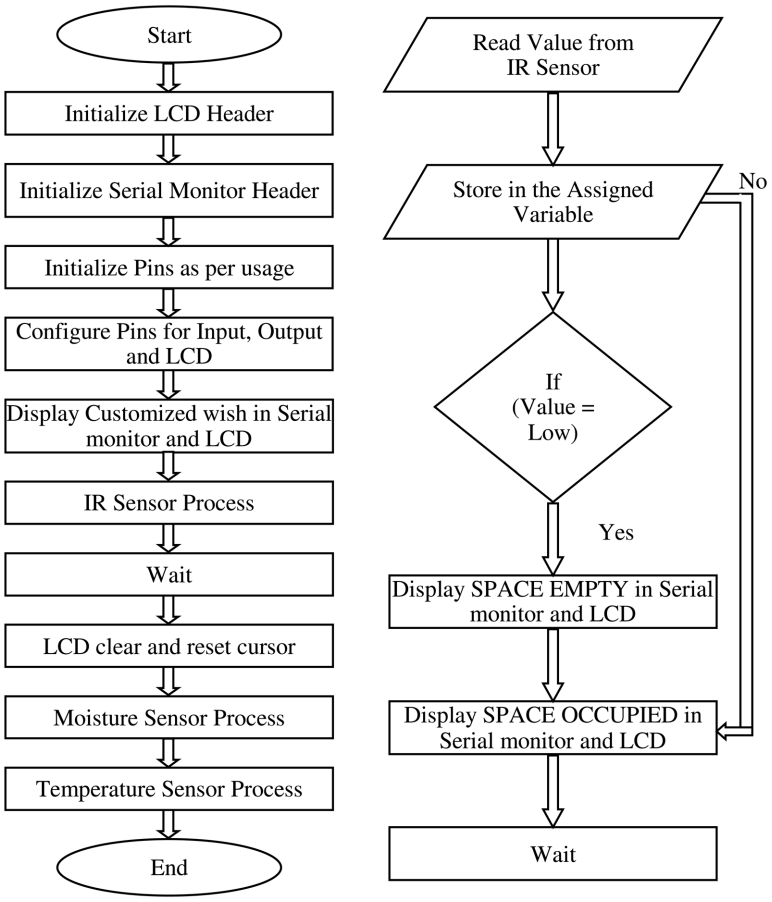


**Figure 4** Flow chart of Main Process & Space detection using IR Sensor.

the solenoid valve. There by the water is supplied to the sand and wood chips mixture ensuring they stay wet and allowing better evaporation. The procedure is displayed in the LCD module. After these the temperature sensor process starts. Here the temperature sensor LM-35 reads the temperature within the refrigerator if it is above the threshold value which is 21 degree Celsius then the Peltier devices are triggered allowing the cool functioning of the refrigerator as shown in Figures 5 and 7.

The process is repeated after a periodic interval of 13 seconds. The Arduino is constantly updated with the readings from the IR sensor, moisture sensor and temperature sensor based on which it alerts the customer of the available space followed by the valve action and then the cooling based on Peltier effect.

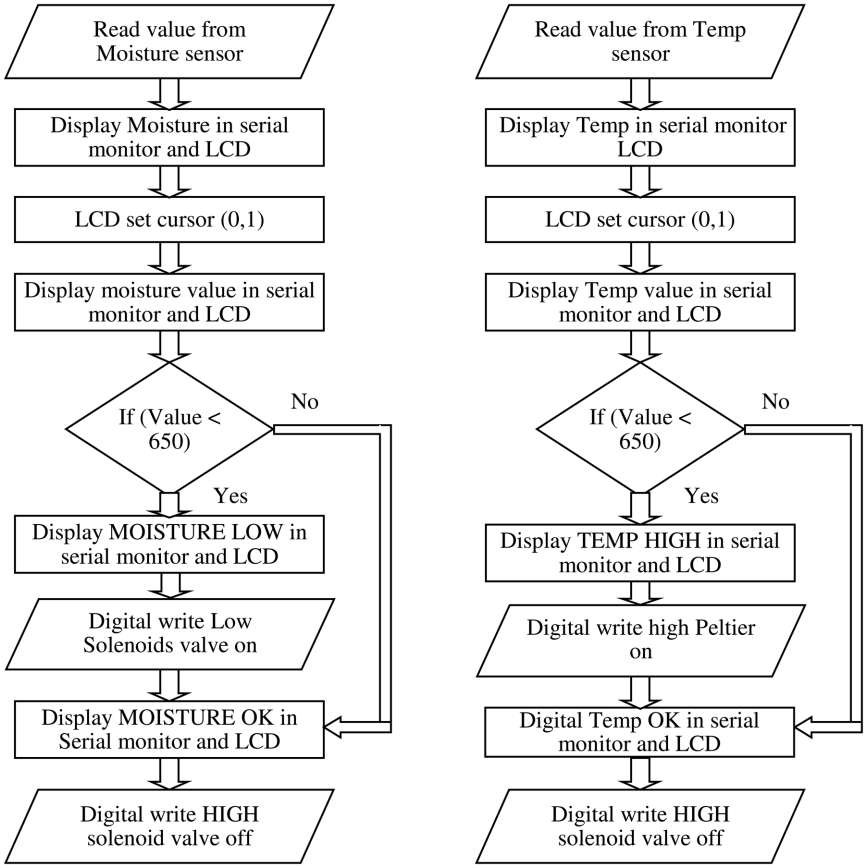


**Figure 5** Flow Chart Valve control based on moisture detection & Peltier Control Based on Temperature Sensor.

## 5 Results and Discussion

The proposed model is assembled as specified in the development and operation section. After that the model is scrutinized for errors and the results are validated using multi-stage evaluation methods.

The various evaluation techniques used are

- Serial Monitor Verification of the integrated device
- Evaluation of the Temperature and Humidity drop with respect to Time.
- Organoleptic measurements.


**Figure 6** Results of space detecting circuitry.


**Figure 7** Results of moisture circuitry.

## 5.1 Serial Monitor Verification

### 5.1.1 Sketch Editing and Compiling

This is the foremost test to ensure and verify the functioning of the interfaced embedded system. Initially the sketch in edited using the Arduino IDE. After the sketch is edited in .ino extension then it is compiled. The compilation starts only if the board is connected to the respective com port. During the compilation the IDE checks for syntax errors, followed by proper implementation of the declared variables and functions.

### 5.1.2 Sketch Uploading

After the compilation is finished the sketch is uploaded to the Arduino Uno Atmega328. Once it uploads the sketch to the Arduino Uno the Arduino IDE analyses the amount of space utilization in the program storage. It displays that the program uses about 18% of the available memory and occupies 5910 bytes of the available 32256 bytes. It further analyzes the amount of memory used by the global variables and local variables which is 416 bytes and 1632 bytes from the available memory.

### 5.1.3 Serial Monitor Display

Once the code is fed it is runs automatically whenever the Arduino is powered up. Initially for the developer the output is displayed in the serial monitor where we obtain the customized greeting for the user, followed by the availability of space, then it shows the available moisture level a depending on the threshold setup takes a desirable action to switch on the valve. This is further followed by the temperature readings from the temperature sensor LM-35 then based on it the Peltier device is triggered on or off. The entire process takes odd 15 seconds to run by the microcontroller and is repeated hence of to maintain the accuracy in the automated results.

The moisture sensor in Figure 7 will detect the moisture level of the side pads in digital format to the LCD panel if the moisture level is below 650 it trips the solenoid valve ON and the water starts flowing unit it reaches 650 plus to maintain the water level at its sides and it trips OFF the solenoid valve.

In this Figure 8 the temperature inside the system is determined and according to that the following steps occurred. As the temperature inside the system is high the peltier module is on by the use of relay module. The heat sink will drain the heat generated by the peltier module to make the inner atmosphere cool as the temperature inside the system starts decreasing to a desired value the relay module will automatically trip the peltier module. The above output shows the well-functioning of the electronic Circuitry in the refrigerator.

## 5.2 Evaluation of the Temperature and Humidity Drop with Respect to Time

A comprehensive analysis is done on the effective reduction in the temperature in the refrigerator which is quintessential for the storage of eatables and extending their life span. For this different environmental location and setups are utilized along with organoleptic measurements.

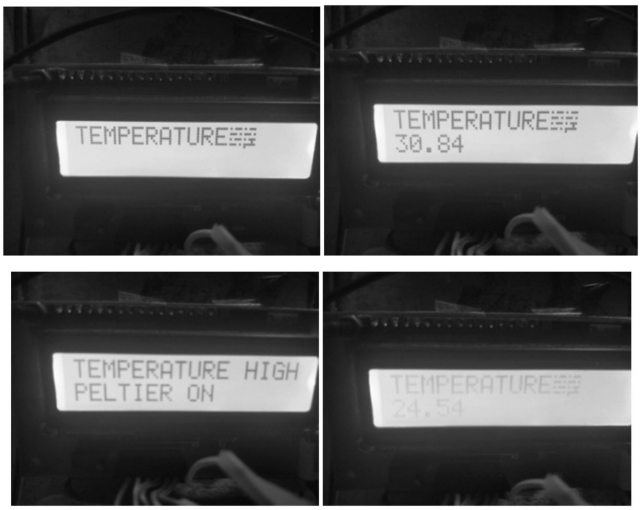


**Figure 8** Results of temperature circuitry.

Two environmental locations Bhilai, in the state of Chhattisgarh and Chennai in the state of Tamil Nadu a selected as places for the case studies and experimentation of the refrigerator. Both of these places have diversified climatic conditions Bhilai with high temperature and minimal humidity and Chennai with high temperature and high humidity. Three parameters are adjudged in both the places

- Temperature within the refrigerator
- Environmental temperature
- Humidity

It was noticed that humidity inside and outside the refrigerator stayed almost same varying by a minute range and hence forth are considered equal. The time span for the readings ranged from morning 6 till night 12 am.

### 5.2.1 Case Study at Bhilai, Chhattisgarh

Initially the temperature inside is higher than the environmental temperature but with the increase in the gross time the temperature increases outside with a gradual reduction in the temperature inside. By mid noon the temperature difference goes up to 11 degree Celsius where in the inner temperature is 19 degree Celsius and outside temperature is 31 degree Celsius. Initially on the addition of water there was increase in the humidity level increases to 75 percentage nearby the refrigerator but then it makes a steep fall to 16 percentage.

**Table 1** Temperature and Humidity with respect to Time (Dry Area)/Bhilai

| S. No | Time | Temperature (in Celsius) Inside | Humidity (in %) | Temperature (in Celsius) Outside |
|---|---|---|---|---|
| 1 | 6:00 am | 24 | 51 | 20 |
| 2 | 8:00 am | 23 | 75 | 25 |
| 3 | 10:00 am | 21 | 30 | 28 |
| 4 | 12:00 pm | 19 | 21 | 31 |
| 5 | 14:00 pm | 18 | 16 | 33 |
| 6 | 16:00 pm | 17 | 18 | 33.6 |
| 7 | 18:00 pm | 19 | 23 | 33 |
| 8 | 20:00 pm | 20 | 27 | 28 |
| 9 | 22:00 pm | 21 | 32 | 25 |
| 10 | 00:00 pm | 22 | 34 | 24 |

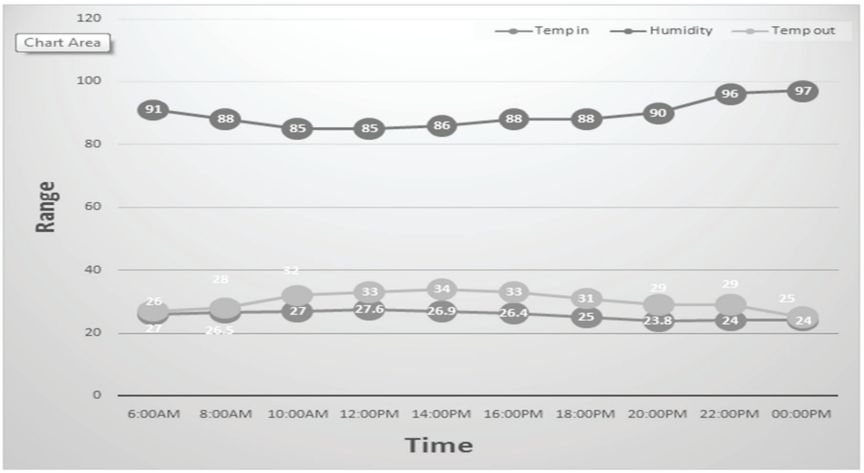


**Figure 9** Graphical representation of Temperature and Humidity with respect to time in Bhilai.

During night there is drop in the temperature outside with the increase in the humidity level. The inside temperature too increases and by midnight there lies only a difference of 2 degree Celsius where the outside temperature is 24 degree Celsius and the inside temperature is 22 degree Celsius.

### 5.2.2 Case Study at Chennai, Tamil Nadu

Initially the temperature inside is lower than the environmental temperature but with the increase in the gross time the temperature increases outside with

a gradual reduction in the temperature inside. By mid noon the temperature difference goes up to 5 degree Celsius where in the inner temperature is 27.6 degree Celsius and outside temperature is 33 degree Celsius. Initially on the addition of water there was increase in the humidity level increases to 91 percentage nearby the refrigerator and remains constant with an average of 89.4 percentage.

**Table 2** Temperature and Humidity with respect to Time (Humid Area)/Chennai (based on evaporative cooling)

| S. No. | Time | Temperature (in Celsius) Inside | Humidity (in %) | Temperature (in Celsius) Outside |
|---|---|---|---|---|
| 1 | 6:00 am | 26 | 91 | 27 |
| 2 | 8:00 am | 25.4 | 88 | 28 |
| 3 | 10:00 am | 25.3 | 85 | 32 |
| 4 | 12:00 pm | 23 | 85 | 33 |
| 5 | 14:00 pm | 21 | 86 | 34 |
| 6 | 16:00 pm | 20 | 88 | 33 |
| 7 | 18:00 pm | 19.9 | 88 | 31 |
| 8 | 20:00 pm | 21 | 90 | 29 |
| 9 | 22:00 pm | 21.5 | 96 | 29 |
| 10 | 00:00 pm | 22 | 97 | 28 |

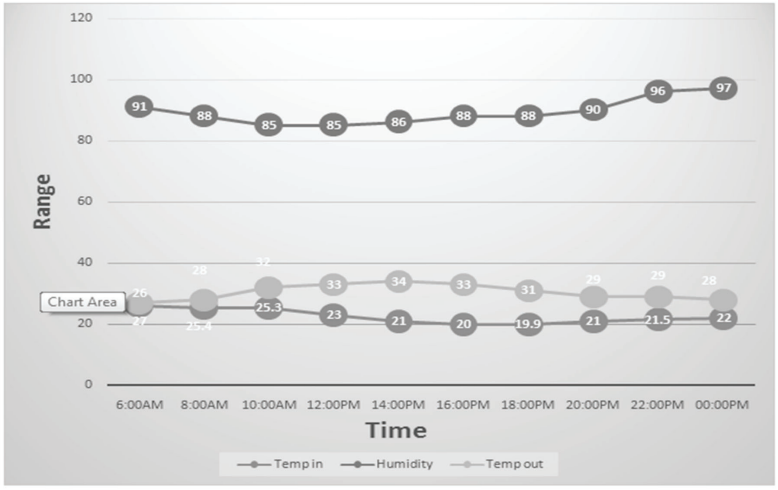


**Figure 10** Temperature and Humidity with respect to Time (Humid Area)/Chennai (based on evaporative cooling).

During night there is drop in the temperature outside with the increase in the humidity level. The inside temperature is further reduced and by midnight there lies only a difference of 4 degree Celsius where the outside temperature is 28 degree Celsius and the inside temperature is 24 degree Celsius.

### 5.2.3 Case Study at Chennai, Tamil Nadu (At the inclusion of Peltier device)

Initially the temperature inside is lower than the environmental temperature but with the increase in the gross time the temperature increases outside with a gradual reduction in the temperature inside. By mid noon the temperature difference goes up to 10 degree Celsius where in the inner temperature is 23 degree Celsius and outside temperature is 33 degree Celsius. Initially on the addition of water there was increase in the humidity level increases to 91 percentage nearby the refrigerator and remains constant with an average of 89.4 percentage.

During night there is drop in the temperature outside with the increase in the humidity level. The inside temperature is further reduced and by midnight there lies only a difference of 6 degree Celsius where the outside temperature is 28 degree Celsius and the inside temperature is 22 degree Celsius.

The below outputs and study clearly highlights the effect of the variance of humidity on the evaporative cooling. Here we can clearly understand that the temperature drop doesn't follow any sequential pattern within the refrigerator instead it varies as a function of the temperature outside and the humidity of the environment. With the increase in humidity the temperature difference as

**Table 3** Temperature and Humidity with respect to Time (Humid Area)/Chennai (based on evaporative cooling + Peltier effect)

| S. No. | Time | Temperature (in Celsius) Inside | Humidity (in %) | Temperature (in Celsius) Outside |
|---|---|---|---|---|
| 1 | 6:00 am | 26 | 91 | 27 |
| 2 | 8:00 am | 26.5 | 88 | 28 |
| 3 | 10:00 am | 27 | 85 | 32 |
| 4 | 12:00 pm | 27.6 | 85 | 33 |
| 5 | 14:00 pm | 26.9 | 86 | 34 |
| 6 | 16:00 pm | 26.4 | 88 | 33 |
| 7 | 18:00 pm | 25 | 88 | 31 |
| 8 | 20:00 pm | 23.8 | 90 | 29 |
| 9 | 22:00 pm | 24 | 96 | 29 |
| 10 | 00:00 pm | 24 | 97 | 28 |

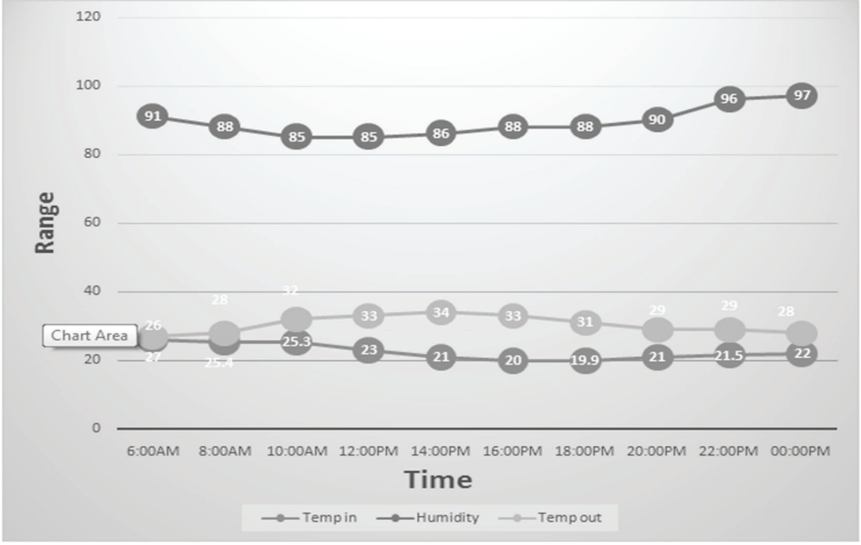


**Figure 11** Temperature and Humidity with respect to Time (Humid Area)/Chennai (based on evaporative cooling + Peltier effect).

well as the cooling effect drops as a result of which the device performance is reduced optimally in Chennai, which is a humid region. Then we go for storage of tomato for a span of 7 days to measure the organoleptic qualities.

## 5.3 Organoleptic Scores

### 5.3.1 Necessity of Organoleptic Scores

Objective tests are excellent in fields of research in which performance can be determined by objective tests. There are no objective tests for evaluating certain factors upon which acceptability depends in rating the variations between samples of meat or other foods. In addition, it seems unlikely that usable, valid objective tests for evaluating characteristics such as odour and taste of meat will be developed within a short time. Hence, it seems wise to use all objective tests that give useful information in evaluating scoring data and to spend time in elucidation of the complicating factors in organoleptic scoring.

The sample should be presented to the scorer in an attractive manner. All samples are coded. The scorer's first reaction is usually to the appearance of the sample.

### 5.3.2 Setup for Organoleptic Test

For experimentation purpose Tomato is chosen as it has low shelf life and would allow the easy study of the effective preservation made by our device. Three tomato samples are taken and each of them are suscepted to three different conditions

- Placed outside in normal vegetable shelf
- Placed within Refrigerator
- Placed within Patukattal

Then these tomatoes were stored for a period of 7 days. Each day these samples were judged by our scorers. Each scorer is given a sample, as nearly as possible, from the same anatomical location of each cut. This is important for different parts of the cut may vary in composition of fibre and connective tissue. The following scores were obtained on average from 3 scorers.

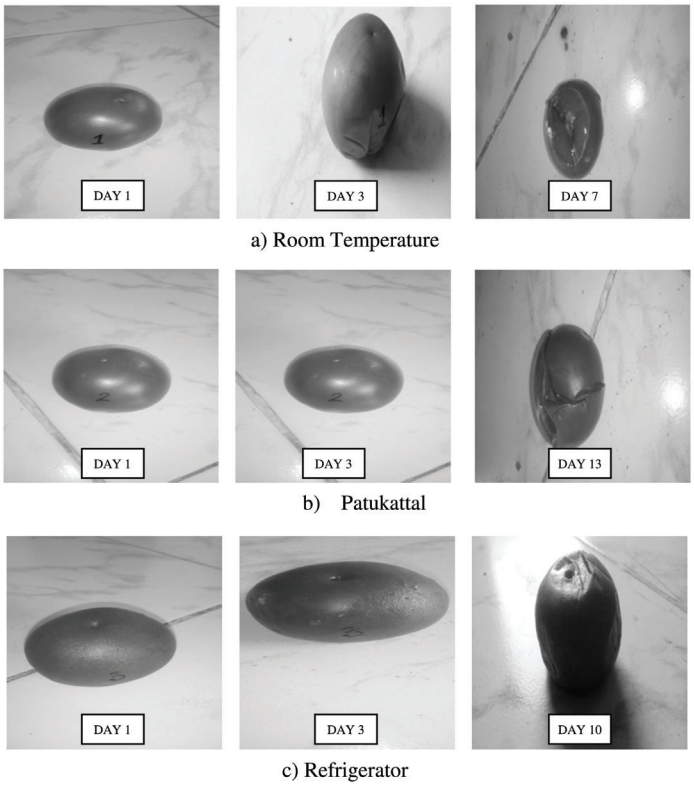


**Figure 12** Tomatoes placed in different conditions.

The scoring was undertaken from Day 0 to Day 7 and it varied from the scale of 0 to 10. It was done based on the following parameters:

- Skin Colour
- Flavour
- Odour

## 6 Conclusion and Future Scope

As per the primary objectives the motto was to develop a lightweight, low end yet tech-friendly refrigerator that could be of assistance to street vendors and the lower class people who don't have the budget to afford high end portable cooling system. Here with we undertake a comparative analysis between a conventional refrigerator and Patukattal.

As we see above there lies contrasting differences between the existing and the proposed system. What makes the proposed system significant is that it does not require a compressor system; apart from it has very minimal power consumption. On the better half it is automated and smart refrigeration system that could be produced at a low budget end below RS 1500.

**Table 4** Comparison Chart between Patukattal and Refrigerator

| Specifications | Refrigerator | Patukattal |
|---|---|---|
| Weight | 30–150 kg | 10.5 kg |
| Cooling system | Reciprocatory Compressor | Evaporative Cooling Peltier cooling |
| Number of Doors | 1 | 1 |
| Capacity | 80L–250L | 50L |
| Shelf Material | Wire Shelves, Toughened Glass | Aluminium, Thermocol |
| Requirements | Stabilizer | 12–15 v power supply |
| Power Consumption | 100–200 watts | 2–6 watts (based on phone may not be used) |
| Freezer | Yes | No |
| Min. Temperature | 4 to –20 degree Celsius | 15 degree difference from the environmental temperature |
| Environmental effect | Causes Global Warming | Eco-Friendly |
| Cost | RS 8500–25000 (Normal) RS 24000–150000 (Smart) | Below RS 1500 |

**Table 5** Organoleptic qualities of Tomato sample in different storage system

| Sl. No. | Nature of Storage | Characters of Samples | Storage of Tomato in Days | | | | | Overall Acceptability |
|---|---|---|---|---|---|---|---|---|
| | | | Day 0 | Day 1 | Day 3 | Day 5 | Day 7 | |
| 1 | Room Temperature | Skin Color | $10 \pm 1$ | $8 \pm 0.7$ | $6 \pm 0.4$ | $4 \pm 0.2$ | $4 \pm 0.2$ | $5.5 \pm 0.3$ |
| | | Flavour | | $8 \pm 0.6$ | $5 \pm 0.3$ | $3 \pm 0.1$ | $3 \pm 0.3$ | $5.25 \pm 0.4$ |
| | | Odour | | $8 \pm 0.5$ | $3 \pm 0.1$ | $2 \pm 0.2$ | $1 \pm 0.1$ | $3.5 \pm 0.2$ |
| 2 | Patukattal | Skin Color | $10 \pm 1$ | $8 \pm 0.5$ | $7 \pm 0.7$ | $5 \pm 0.8$ | $4 \pm 0.6$ | $6 \pm 0.6$ |
| | | Flavour | | $9 \pm 0.7$ | $8 \pm 0.5$ | $6 \pm 0.4$ | $5 \pm 0.2$ | $7 \pm 0.3$ |
| | | Odour | | $7 \pm 0.6$ | $7 \pm 0.4$ | $5 \pm 0.3$ | $3 \pm 0.3$ | $5.5 \pm 0.3$ |
| 3 | Refrigerator | Skin Color | $10 \pm 1$ | $8 \pm 0.6$ | $7 \pm 0.5$ | $4 \pm 0.3$ | $4 \pm 0.2$ | $5.75 \pm 0.3$ |
| | | Flavour | | $8 \pm 0.5$ | $6 \pm 0.4$ | $4 \pm 0.3$ | $4 \pm 0.1$ | $5.5 \pm 0.4$ |
| | | Odour | | $7 \pm 0.4$ | $5 \pm 0.3$ | $5 \pm 0.5$ | $4 \pm 0.3$ | $5.25 \pm 0.3$ |

The current refrigeration system can be further modified with the usage of desiccants, where in we can coat the buffer material (Sand and wood chips) with it. These would allow better water retention capacity, which would minimize the water seepage issue. Further the seepage water will be purified due to detoxifying nature of desiccants and can be used as a water filter along with refrigerator.

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