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# Design and Fabrication of Solar Heat Cell Using Phase Change Materials

M. A. A. Noon[1], B. Anwar[2], H. Koten[3]

[1,2]*Mechanical Engineering Department, International Islamic University, Islamabad*
[3]*Mechanical Engineering Department, Istanbul Medeniyet University, Istanbul, Turkey*

[1]adnan.aslam@iiu.edu.pk

***Abstract***- Thermal comfort as well as lower cooling and heating loads are need of the world today. Various studies have shown that thermal energy storage (TES) is a way to accomplish this goal. The salient findings of the paper are to seek for suitable phase change materials and design of cells for heat storage. The aim of this study is to store heat energy in a cylinder (called cell) from the sun light and to use the stored heat in absence of sunlight for cooking and other heating purposes. Estimates are made for designing a cell, capable of storing heat from sunlight, required to boil a cup of water. Focused sunlight is used to charge the cell from sunlight. The focused light is produced by focusing plate. The cell is kept at the focal point of focusing plate. After some time, the cell stores this heat by specific type of materials inside it. These materials are called phase change materials (PCM). Initially PCM heat up by concentrated beam of sunlight and store sensible heat. When the temperature of PCM reach its melting point, it starts melting and store latent heat energy. At this stage, PCM contain both sensible and latent heat energy. The PCM, upon cooling, provides this energy with minor heat losses. The cell, keeping PCM, is well insulated and could store heat for 8 hours after charging. The charging time of the cell varies from 16 to 24 minutes depending upon the sunshine hours. Beside this, smaller heat cells are also designed for use in insulated stove. So, heat is stored by cells at the day time and could be used at the night time for heating and cooking purposes. In this way heat is stored for prolonged time at very low cast. Minimum cost and prolonged heat storage are the key features of the research.

***Keywords-*** Renewable Energy, Phase change Materials, Solar heat Cell, Thermal Energy, Latent Heat, sensible heat

## I. INTRODUCTION

A substantial amount of energy is required for cooking all over the world. According to an estimation, 60 % of this energy comes from fossil fuels which are very costly [1]. Beside the high cost, fossil fuels are environmentally unfriendly and 40 % of the world's population use fuel for cooking [2]. Woods are also used for cooking which cause rapid deforestation of 16 million hectares per year [3]. The energy consumed by developed countries in producing food items is 8-16 % of their total annual energy consumption [4]. So, a continuous struggle is made by scientists to shift this load to solar thermal and thereby to reduce pollution and to save energy.

Solar thermal energy gives us a cleaner, drier, more comfortable environment with no fuel consumption or no electricity. Temperature of the sun is 6000° centigrade and solar intensity reaching the earth is ranging from 300 to 1100 watts/m$^2$ for different countries at different times of the day [5]. This heat can be harnessed with various ways and one among them is heat storage through concentrated solar power technology. Sunlight is focused on a point where we want to store energy. Molten nitrate salts, commonly called as phase change materials (PCM$_s$) are generally used as energy storing materials. PCM$_s$ having low density, stable at high temperature, moderate thermal conductivity and heat capacity are able to store thermal energy. Moreover, their stability at elevated temperature have increased working range and due to high heat capacity, they have high energy storage density [6]. PCM$_s$ are placed in special cylinders called as heat cells. These cells are insulated and can store heat for 8 hours. Later on, this stored heat can be used for heating and cooking purposes. The purpose of this study is to design, fabricate and test a solar heat cell capable of storing renewable energy in the form of solar thermal energy at the day time and to deliver that energy at the night time for cooking and heating purposes.

## II. DISCUSSION

### 2.1 PCM Selection

The selection of $PCM_s$ is based on its, melting point, heat storage density, durability, heat density and heat transfer rate. For this purpose, PCM are studied over last four decades and a number of materials including paraffin waxes, organic compound, non-organic compound hydrated salts and polymers are considered to possess heat storage potential. Division of PCM is based on temperature and physical state [7].

Table 1. PCM classification based on temperature

| | |
|---|---|
| Low temperature PCM | Here phase transition temperature is below 15 °C. These materials are mainly used in air conditioning systems. |
| Medium temperature PCM | Here temperature range is 15-90°C. These materials are mainly used in medical, textile and electronic industries. |
| High temperature PCM | These materials are used for application requiring temperature above 90 °C. For example, cooking, aerospace industry etc. |

Table 2. PCM division based on its physical state [8].

| | |
|---|---|
| Gas-liquid | Here liquid to gas and vice versa conversion take place. |
| Solid-solid | Here phase of material is not changed. Only the crystalline form of materials is changed |
| Solid gas | These materials need large volume. Hence limited in application. |
| Solid-liquid | Here phase of materials is changed from solid to liquid and vice versa. |

Finally, an in-organic mixture of $KNO_3$ and $NaNO_3$, having the potential for energy storage was selected in the ratio of 40 to 60% respectively [9]. The mixture of $KNO_3$ and $NaNO_3$ has a melting point of 220°C [10]. The reasons for selecting these materials are their high latent heat of fusion, high specific heat, good thermal conductivity, stable at high temperature, cheap, non-corrosive and stable up to a temperature of 500°C [11]. Simulation of $KNO_3$ and $NaNO_3$ was performed by Tesfay in COMSOL. His simulation showed that PCM of 2kg melts in four and half hours by applying a power of 650 watts and can store that heat for about one day [12].

The thermal energy storage is achieved by heating and melting the PCM materials and the release of energy is achieved by solidifying the materials. Energy can be stored in the following ways.

Latent heat energy can be stored at nearly isothermal conditions and over a narrow range of temperature [13].

$$Q = \int_{T_i}^{T_m} mC_p dT + ma_m \Delta H_m + \int_{T_m}^{T_f} mC_p dT \qquad (2)$$

Sensible heat energy is stored by increasing the temperature of PCM [18].

$$Q = \int_{T_i}^{T_f} mC_p dT = mc_p(T_f - T_i) \qquad (3)$$

Mixture of $KNO_3$ and $NaNO_3$ can store both sensible and latent heat energy [14]. Initially, the temperature of the mixture increases and store sensible heat energy. After some time, the temperature remains constant and only state of the mixture changes from solid to liquid. Here mixture of PCM stores latent heat energy.

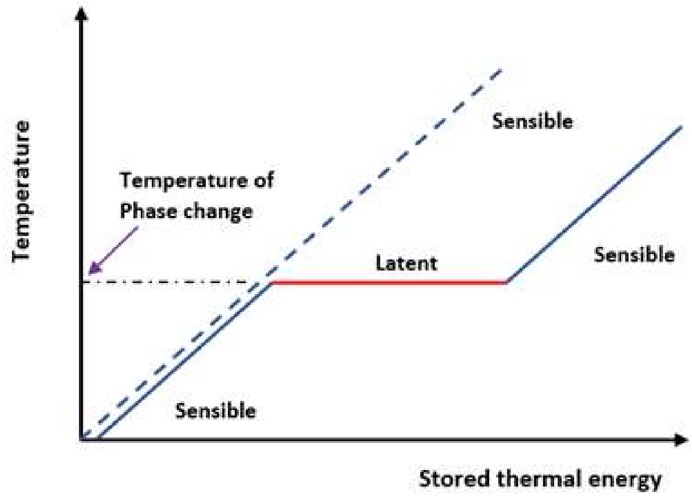


Figure 1. Thermal energy- Temperature Graph

*2.2 Solar Radiations*

The largest and free energy source of earth is the sun. Research reveals that 4 million Exa joules of energy reach the surface of earth annually of which 5×104 EJ of energy is harvestable [15]. The energy received per meter square of earth, called solar irradiance is 342 $Wm^{-2}$ of which around 30 % is reduced by scattering and reflection [16]. Energy received after scattering is called diffused solar radiations [17]. The remaining 70 % energy, called direct radiations, can be harvested in the form of solar thermal and solar photovoltaic energies [18]. A lot of new technologies are in practice to harvest this energy and are called renewable energy technologies. Solar photovoltaic (PV), solar thermal (ST) and concentrated solar power (CSP) are technologies used for harnessing solar energy. Each of these technologies use different component of sunlight. The daily, annual, monthly and seasonal data of a region and the type of energy requirement decide which technology to be used. The regions with direct irradiations are suitable for ST and CSP [19]. Solar insulation for a particular sunshine duration was first proposed by Angstrom and is given as [20].

$$\frac{H}{H_o} = a + b\frac{S}{S_o}$$

Solar energy potential of a specific region is proportional to sunshine hours, longitude, latitude and weather conditions of that region. Raja and Twidell calculated the average of daily diffused and direct solar radiation for a year in Pakistan. These values were ranging from 1.11 to 3.05 Kw/ $m^2$ for summer and 1.94 to 3.33 $kWh/m^2$ for winter [21].

*2.3 Solar Cooker*

Solar cookers, being environmentally friendly are used for cooking since several decades for harnessing solar irradiant energy. Box type solar cooker was the most common among them and was extensively studies and modified since eighties. The cooker was easy to manufacture, low in cost but was very time-consuming during cooking [22]. Box type cooker was then added with several reflector but cooking has must to be done out door and was slow. After this, parabolic cooker was used for fast cooking but they were also limited to the availability of sunlight and were hazard due to focused sun beams [23]. Split system solar cooker was proposed which has collector outdoor and cooking section inside the kitchen, with the pipes carrying the heat from collector to cooking section [24]. To increase the heat transfer rate, the cooker was added with collector having vacuum with heat pipes where heat was transferred by refrigerant [25]. For water purification, and hot water system, solar stills with phase change material (PCM) were used which showed significant increase in performance [26]. Finally, concentrated solar cell with good heat storing materials called PCM was selected for cooking.

The cell contains special chemicals called phase change materials. These materials have the ability to store heat energy for a long time and provide heat when needed. These materials have high melting point of about 217 degree centigrade. The cell is placed in specially designed parabolic collector for charging. This structure focuses sunlight on cell. After placing the cell in parabolic collector, the temperature of the materials reaches to its melting point and its phase changes from solid to liquid.

Here cell stores latent energy. When cell is fully charged, it is removed from the parabolic collector. Now heat is stored in cell for 8 hours. Energy stored in the cell can be used for cooking and heating. When the cell is used for cooking the temperature of cell start to reduce. Thus, state of materials changes from liquid to solid again so-called phase change materials. Consequently, upon charging, the state of materials is changed from solid to liquid and vice versa.

$NaNo_3$+ $KNO_3$ is nitrate mixture, having melting point of 221° **C** is used as storage medium for thermal energies [27]. The purpose of this study is to design, fabricate and test a solar heat cell capable of storing renewable energy in the form of solar thermal energy at the day time and to deliver that energy at the night time. The main purpose of the project is to make the solar energy able to be used at the night time when the sunlight is not present. This is achievable only when we store the heat and then use this heat for cooking and heating purposes. So, a composition called solar heat cell is made for storing heat. This cell is able to store heat during sunlight hours (called charging of cell) and to provide that heat during nighttime (called discharging of cell). This cell contains special chemicals called phase change materials. These materials have the ability to store heat energy for a long time and provide heat when needed. These materials have high melting point of about 217 degree centigrade. The cell is placed in specially designed parabolic collector for charging. This structure focuses sunlight on cell. After placing the cell in parabolic collector, the temperature of the materials reaches to its melting point and its phase changes from solid to liquid. Here cell stores latent energy. When cell is fully charged, it is removed from the parabolic collector. Now heat is stored in cell for 8 hours. Energy stored in the cell can be used for cooking and heating. When the cell is used for cooking the temperature of cell start to reduce. Thus, state of materials changes from liquid to solid again so-called phase change materials. Consequently, upon charging, the state of materials is changed from solid to liquid and vice versa.

## III. Methodology

The aim of the project is to design a cell capable of storing heat energy required to boil a cup of water with some basic calculations. The required energy is planned to be gained from concentrated sunlight at the day time and to be stored by PCM in the cell for use in the absence of light. The amount energy and PCM is calculated by heat transfer formula. The concentration of light is ensured by a parabolic dish called solar collector. The time required by the cell to store heat energy, called charging of the cell, is also calculated both mathematically and experimentally.

### *3.1 Cell design*

A larger and some smaller heat cells are designed to store heat energy. The amount of energy required to boil a cup of water is calculated from the formula $Q = mc\Delta T$ and found to be 47k joules and the mass of materials required is also calculated from the same formula and is 486 grams [13]. The volume of PCM is calculated from its mass by a formula $\rho = \frac{m}{v}$ and found to be 275 cm3. A cylinder is designed according to volume of PCM. The top of the cylinder is made of copper and painted with black chrome to increase heat absorption. 5 rods are attached to the back of the top to insure proper heat transfer toward and away from PCM. To avoid heat loss, the cylinder along with its top is insulated by fiber wool and thermal flask. A temperature sensor is installed at the bottom of the cell to display the PCM temperature. Moreover, smaller cells are also fabricated and are used for general cooking purposes in insulated stove.

Figure 2. Solar Heat Cell

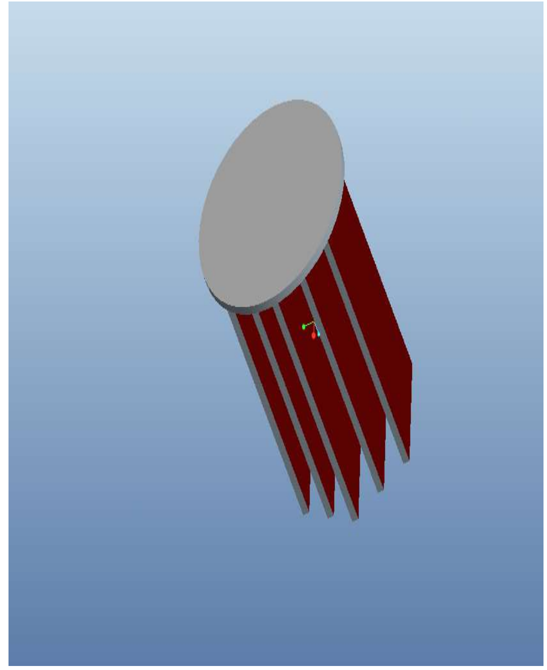

Figure 3. Head of cell with Inserting Plates

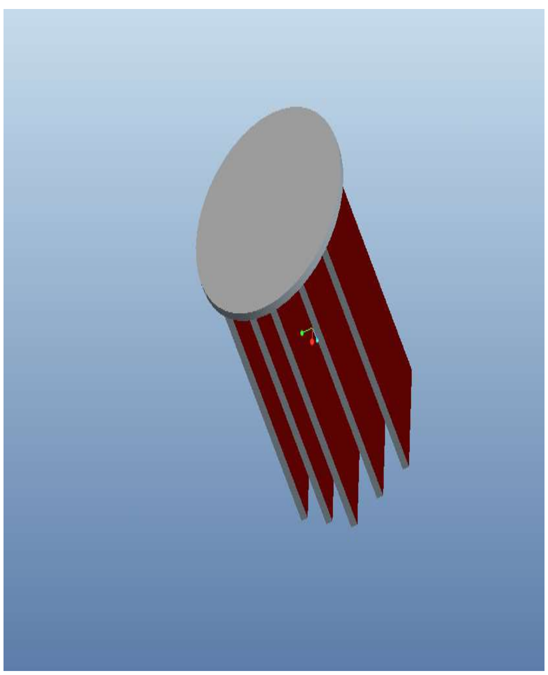

Figure 4. Smaller heat cells

Figure 5. Solar stove

Table 3. Specifications of cell

| | |
|---|---|
| Volume | 275 $cm^3$ |
| Diameter | 6 cm |
| Height | 10 cm |
| Top absorbing plate | Copper |
| Coating of top absorbing plate | Black chrome/ nickel/black paint |
| Insulating material | Ceramic wool and vacuum flask around the cell |
| Material of rods | Copper |
| Separations between rods | 0.95 cm |

*3.2 Solar collector*

This part is used to provide concentrated heat energy to the cell. It is actually a parabolic dish with aluminum covering. It concentrates light on the cell.

Figure 6. Parabolic Trough

The collector with 40 % efficiency, drops the power to 120 watts/$m^2$. According to the formula $t = \frac{Jouls}{power}$ time required to charge the cell is found to be 16 minutes [28].

*3.3 Heat source in the cell*

After designing the cell, arrangement is done for storing heat in the cell from sunlight. It is found that, at the average 600 watts/m$^2$ of power is available when the sky is clear and at cloudy weather this power drops to 300 watts/m$^3$ [29] . So, calculations are done for 300 watts/m$^2$.This power is focused on the top of the cell by using a parabolic collector plate. The parameters of collector plate are designed by the formula [30].

$$f = \frac{D \times D}{16d} \tag{4}$$

Table 4. Specifications of solar collector

| | |
|---|---|
| Diameter (D) | 1.5 m |
| Depth (d) | .39 m |
| Focal Length (f) | .36 m |

## IV. Fabrication & Testing

The project consists of cells and collector plate. The fabrication of each section consists of the following sections.

*4.1 Cell Fabrication*

Stainless steel container was selected for the cell and was filled from mixture of NaNO3 and KNO3. The head of the cell, made of copper, along with its inserting plates was placed on the top of cylinder and was welded on it. A temperature sensor was also installed at the bottom of the cell. External walls of the cell were insulated by fiber wools and a thermal flask.

*4.2 Solar collector installation*

A parabolic trough was selected to focus sunlight on cell. The trough was illuminated by aluminum sheet to increase the reflectivity of light. The focus point of the parabolic trough was specially designed for placing the cell.

*4.3 Testing*

The cell was placed at the focus point of the parabolic trough in sunlight and the results were obtained for different hours of the day.

Table 5. Cell Testing

| **Time (Hours)** | **Solar intensity (W/m$^2$)** | **Solar intensity After 60% optical loss in solar collector (W/m$^2$)** | **Cell Charging Time in minutes** $\boldsymbol{t = \frac{Jouls\ required\ i.e. 47000}{power\ available\ (solar\ intensity)}}$ **(W/m$^2$)** | **Cell Charging Time after heat loss (Minutes)** |
|---|---|---|---|---|
| 08:00 | 303 | 121 | 6 | 24 |
| 09:00 | 486 | 194 | 4 | 16 |
| 10:00 | 746 | 298 | 2.7 | 11 |
| 11:00 | 1050 | 420 | 2 | 8 |
| 12:00 | 1075 | 430 | 1.8 | 7.5 |
| 13:00 | 948 | 379 | 2 | 8 |
| 14:00 | 770 | 308 | 2.5 | 10 |
| 15:00 | 505 | 202 | 4 | 16 |

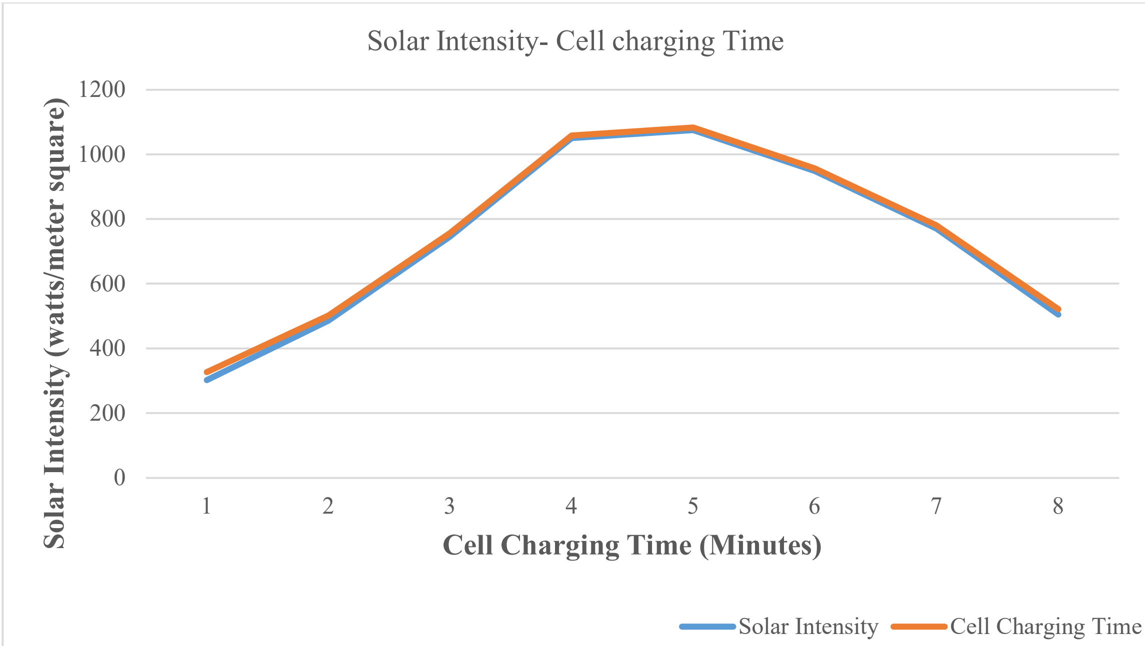


Figure 7. Solar Intensity Verses Cell's Charging Time

Table 6. Cell Discharging time

A cup of water (250 ml) was placed on charged cell and time for boiling water and discharging cell was noted. The rise of water temperature with time shows the validation of the research.

| Time (Hours) | Water Temperature (°C) | Cell temperature (°C) |
|---|---|---|
| 08:00 | 24 | 217 |
| 08:05 | 35 | 210 |
| 08:10 | 40 | 198 |
| 08:15 | 49 | 185 |
| 08:20 | 57 | 173 |
| 08:25 | 66 | 159 |
| 08:30 | 75 | 150 |
| 08:35 | 79 | 143 |
| 08:40 | 83 | 140 |
| 08:45 | 87 | 135 |
| 08:40 | 91 | 132 |
| 08:45 | 94 | 129 |
| 08:50 | 97 | 125 |
| 08:55 | 100 | 121 |

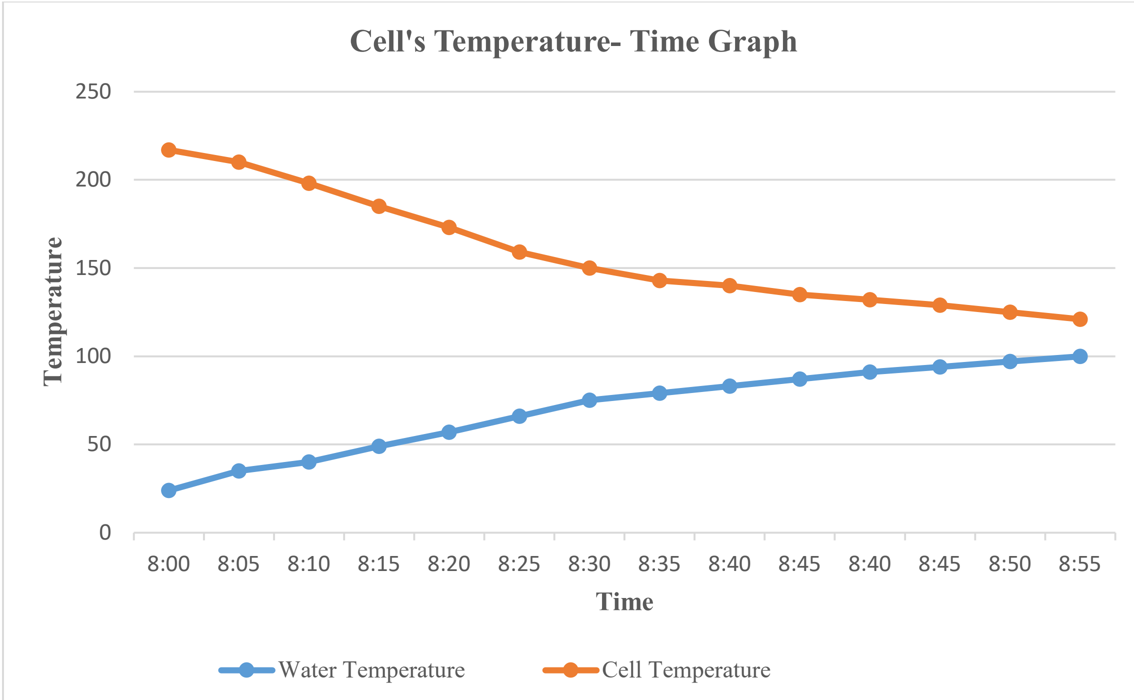


Figure 8. Temperature-Time Graph

## V. Conclusion

The current study shows the active and passive TES technologies which can be utilized in heating and cooking purposes. It also highlights the main advantages and drawbacks of each technology, including the materials used for sensible, latent and thermochemical heat storage. Some of the important parameters of the cell are durability, low capital and maintenance cost, easy to manufacture, small charging time, can provide heat for 3 hours etc. Through investigations, it is estimated that the cell was successfully charged in 8 minutes during solar peak hours but the theoretical or calculated time is 2 minutes. The time difference occurred due to convection and conduction hat losses. Similarly, transfer of heat from the cell to the food items take some additional time due to heat losses.

## VI. Nomenclature

| | | |
|---|---|---|
| **H** | **($Wh/m^2/day$)** | **Monthly average of daily insulation on horizontal surface** |
| $H_o$ | ($Wh/m2$ $/day$) | Monthly average daily extraterrestrial insulation on horizontal surface |
| **S** | **(Hours)** | Daily sushine hours |
| $S_o$ | **(Hours)** | Maximum possible dailysushine hours |
| **Q** | **(Jouls)** | Quantity of energy stored |
| **m** | **(Kg)** | Mass of PCM |
| **Cp** | **J/(kg·C)** | Specific heat capacity |
| **dT** | **(Degree Centigrade)** | Temperature difference |

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