4CBLA00 Energy Storage and Transport

Self-Study Assignment
Group 16

SSA No.	Description
1	Preliminary Designs and Research
SSA Owner	
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Introduction

As concluded in the last meeting, the reference system (Intex Solar Heating Mat) needs to be researched to come up with preferences. After this, preliminary designs need to be devised to outperform the given reference system

Goal

- To research the given reference system (Intex Solar Mat)
- To devise preliminary designs of thermal collectors
- Argument each design with pros and cons, as well as some back of the envelope calculations.

Conclusion

- After performing research on the reference system, the following areas of improvements were found (as seen in table 1)
- 2 designs (Telescopic fig. 1,2 and Sand Heat Sink fig. 3) have been devised
- Both designs have been argumented as seen in tables 2 and 3

Recommendations

- It is recommended that amongst the telescopic and sand heat sink, the sand heat sink is a preferred choice, since it is less complex, performs better and doesn't compromise in creativity and/or recyclability

1 Elaboration

1.1 Understanding and Researching the Reference System (Intex Solar Mat)

Along with link [6] provided in the project manual, additional research was also done to understand the limitations of the system. Information found in website [4] was also used to list the following parameters. These parameters can be potentially improved when designing a new system.

Parameter	Reference System Property Value	Recommendation/Note
Weight	2.69 kg	Can be made more lightweight
Surface area	120 x 120 cm	Can be reduced further to be more compact
Materials	Polyurethene [1]	Tough to re-cycle since it is a thermoset
	PVC [1]	Recycling is plausible, however it is difficult due to presence of additives, plasticizers, evolution of HCl gases (in chemical recycling), and other dioxins [5]
Compactness and Portability	The mat can fold up and be transported fairly easily [4]	This area is difficult to improve on much more
Convenience	The solar mat needs to be placed on a flat surface near the pool and **cannot** be placed on a roof [4]	The convenience can be further enhanced by allowing for placement on roofs, surfaces which are not flat, and surfaces that are not nearby the pool
Price	22.95 Euros [4]	A cheaper system can be devised
Automation and temperature control	The temperature cannot be controlled precisely [4], the mat can be plugged in and out	The devised system can be automated (or have scope for automation) such that the temperature of the water can be controlled better

Table 1: Areas of Improvement

Keeping all of these things in mind, now preliminary designs can be devised.

1.2 Preliminary Designs

1.2.1 The Telescopic Heater

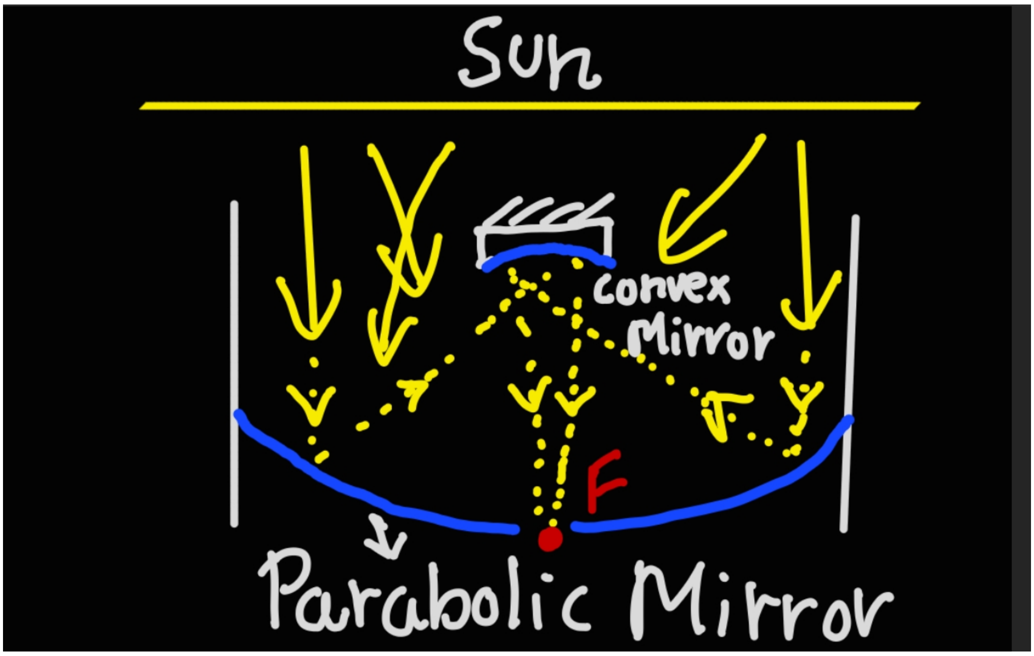

Figure 1: Telescopic Heater, Telescope Section and Labelling (not to scale)

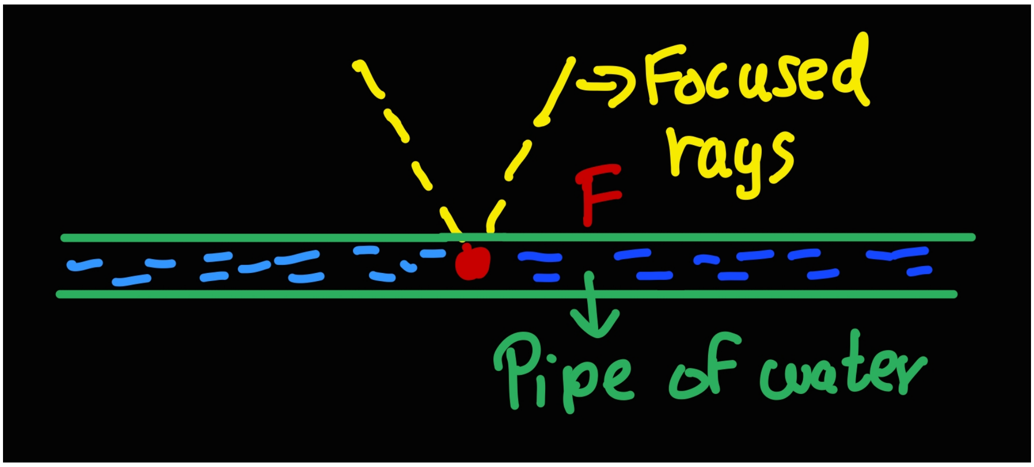

Figure 2: Telescopic heater, Heating and Pipe Section (not to scale)

To give a short explanation of this design, the system uses the 20 % of parallel light rays from the artificial sun, and focuses them to point F (in red, see fig. 1). This is done using a big parabolic mirror with a very small puncture at the centre and a convex mirror placed opposite to it (in blue, see fig. 1). At the point of focus, the pipe carrying the cold water from the pump will be placed (as seen in fig. 2). The section of the pipe within the focus of the telescope, can be made transparent, hence allowing the light rays to pass through and heat the water directly.

To perform some back-of-the-envelope calculations, a few assumptions are made and the system has been vastly simplified.

- Knowing that only 20 percent of the light rays are parallel (and hence usable in this case), it is assumed that this translates into 20 percent of usable energy from the artifical sun. This would result in a total irradiance of 200 W/m^2 (Total irradiance being 1000W/m^2).
- The water in the pipe is assumed to be flowing slowly, ie; the water stream can be divided into multiple pockets of static water which are progressively, individually heated under focus.

- The mirrors are perfect and have no reflective or optical faults, ie; the telescope functions perfectly
- The pipe in the system is assumed to be made of steel
- The pipe has a window/glass piece at the surface near the focus of the telescope, to allow the light rays to pass through
- Based on the Project Manual, the length x width of the design space is 720 x 670 mm, and at this stage, it is assumed that the telescope spans this area and fits withing the height constriction of 365 mm.
- The heat capacity of water is 4184 J/kg K, its density is 10^3, and the initial temperature (before heating) is 20 degree Celcius

Following these assumptions, the temperature of the 2 L water in the storage tanks after 30 minutes of heating can be calculated simply as follows:

$$\begin{aligned}
E_{usable} &= \frac{20}{100} * 1000W/m^2 \\
&= 200W/m^2 \\
\\
P &= E_{usable} * l * b \\
&= 200 * 720 * 670 * 10^{-6} \\
&= 96.48W \\
\\
P &= \frac{m_{water} * c_{water} * \Delta T}{t} \\
&= \frac{\rho_{water} * V_{water} * c_{water} * (T_{final} - T_{initial})}{t} \\
&= \frac{10^3 * 2 * 10^{-3} * 4184 * (T_{final} - 293)}{1800} \\
\\
T_{final} &= 313.75K \\
&= 40^{\circ}C
\end{aligned} \tag{1}$$

Where, E_{usable} is the usable irradiance from the artificial sun, P is the power generated by the sun, V_{water} is the volume of water being heated and T_{final} is the final temperature achieved by the water

The back of the hand calculations suggest that the water will be heated from 20 °C to 40 °C in a time interval of 30 minutes. For quick comparison, the solar mat takes nearly 36 minutes to achieve the same result. Keeping in mind the assumptions made during the calculations, it is possible that the telescopic heater matches or potentially underperforms with respect to the solar mat in this comparison. Below is a table of concrete pros and cons of the telescopic heater:

Pros	**Cons**
It is more creative than an aluminium solar mat	It could be hard to assemble and build within the given time limit
The losses due to radiative heat emissions from the pipes (that transport the water to and from the focus) can be vastly reduced compared to the solar mat, in which a lot of heat is lost by radiative emission due to the black coating of the mat	The telescopic heater could potentially underperform at matching heat performance of the solar mat under the artifical sun
This system would work at a much higher efficiency under real sunlight, where light rays are nearly 90% direct (non-diffused) and can be assumed to be largely parallel (maximum angle difference being only 0.53 degrees [7])	This system is currently incapable of converting the non-parallel sunlight rays into usable heat energy
This system could be placed on a roof or slanted surfaces	This system needs to be calibrated to face the sun at all times, otherwise it will not function
This system can heat up water at a very quick rate due to its concentrating nature paired with its scope to minimize heat loss to the environment	In reality (under a real sun), this heater could cause stagnation in the water flow and cause evaporation of the water in the pipes due to the high concentration of heat
The mirrors of the telescope can be downcycled. They would rarely need replacing or cleaning and if the telescope is made using proper techniques. Even in a case of replacement, mirrors are usually inexpensive to replace. There are also opportunities for these mirrors to be recycled if the mirrors are kept clean and unbroken. Apart from that, the pipes are assumed to be of steel, and hence these pipes can be recycled fairly easily. The frame of the telescope can be made with a wood/-plywood to create insulation (prevent heat escaping the telescope) and make for easy recycling.	

Table 2: Pros and cons of the proposed telescopic solar water heater.

Keeping these pros and cons in mind, and matching them with the RPCs (once they are formulated), this design can be considered for selection and further analysis.

1.2.2 The Sand Heat Sink

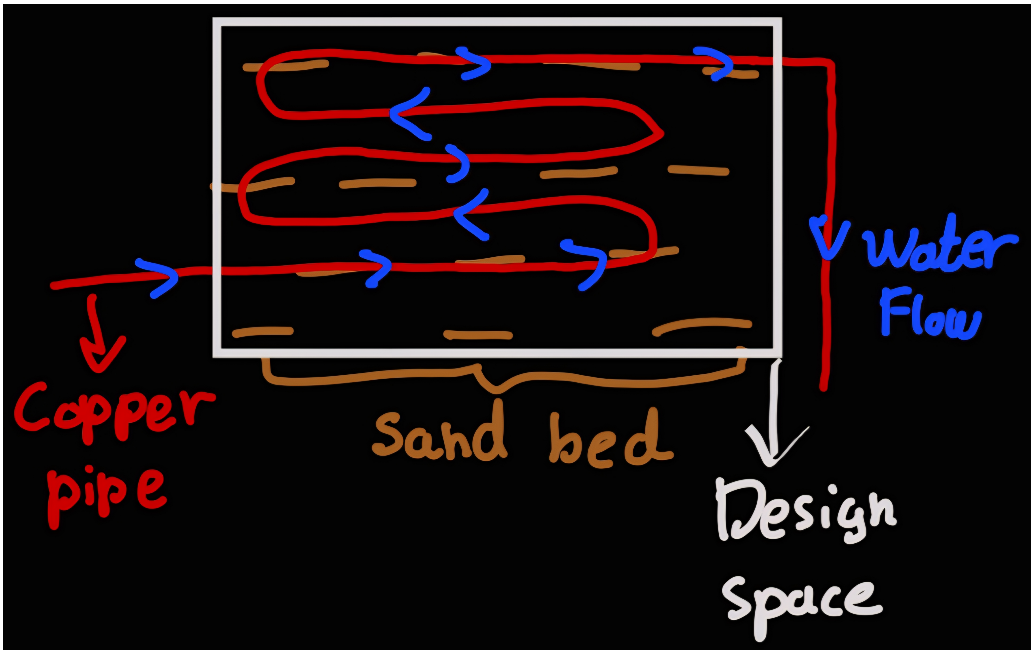

Figure 3: The Sand Heat Sink (not to scale)

This design is sand-based solar mat. The sand heats up under the heat of the artificial sun. Due to the low heat capacity of sand, it requires lesser energy to produce an increase in temperature. This is useful in creating good heat flow between the heated sand and thin copper tubes, within which the water is flowing. Sand stores the heat produced by the sun and hence stays hotter for longer, preventing the system from cooling down during small phases of cloud cover or other sunlight disruptions. It might be more effecient to have a low height bed of sand, than a taller bed of sand, since the thermal conductivity of sand is fairly small (around 0.15-0.25 W/m K), meaning that layers of sand further from the heat of the sun will be cooler. The figure is a top view of the system, such that the sun is directly above and parallel to the plane used in the figure.

To perform some back-of-the-envelope calculations, the following assumptions are made:

- The sand bed is uniformly heated, ie; the sand bed is a really thin layer (in height) and hence there is no temperature gradient
- The copper tube has 9 turns (giving 10 straight sections in the sand bed), each straight section with a length of 700 mm, resulting in a total length of approximately 7000 mm. The tube has a wall thickness of 1 mm, and an inner diameter of 10 mm,
- No energy is lost to the environment from the sand bed, it is perfectly insulated by wood.
- The sand used in this case is dry and its heat capacity is 840 J/kg K [2]
- The thermal conductivity of copper is nearly 400 W/m K [3]
- It is assumed roughly 10 kg of sand (at 20 °Celcius initially) is used in the sand bed
- The flow rate of the water in the copper pipe is assumed to be the same as for the reference system in the experimental data (around 1.5 L/min), and hence a weak laminar flow (Reynold's number comes up to 3200) is assumed for ease of calculation
- Following the previous assumption, the convective heat flow coeffecient of water is assumed to be nearly 300 W/m^2 K

Following these assumptions, the following equations are used to find the temperature to which 2 L of water (at 20 °Celcius initially) will heat up to, in a time period of 30 minutes.

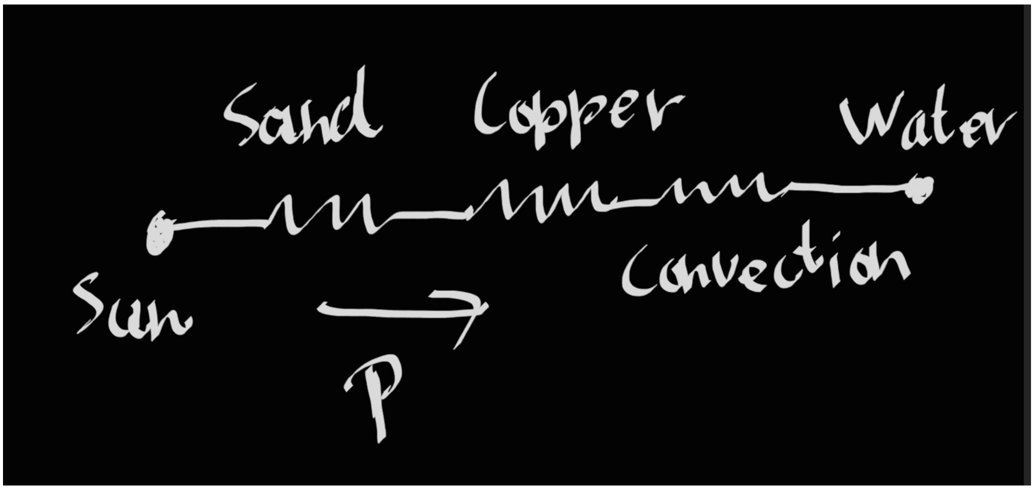

Figure 4: Thermal Resistances Arrangement Interpretation

$$E_{usable} = 1000W/m^2$$

$$\begin{aligned} P &= E_{usable} * l * b \\ &= 200 * 720 * 670 * 10^{-6} \\ &= 482.4\ W \end{aligned}$$

$$\begin{aligned} P &= \frac{m_{sand} * c_{sand} * \Delta T}{t} \\ &= \frac{m_{sand} * c_{sand} * (T_{final} - T_{initial})}{t} \\ &= \frac{10 * 840 * (T_{final} - 293)}{1800} \end{aligned} \tag{2}$$

$$\begin{aligned} T_{final} &= 396.37\ K \\ &= 123.37°C \end{aligned}$$

These first set of calculations indicate that the sand will be at a temperature of 123.27 °Celcius at the end of 30 minutes. It highlights the importance of insulation, without which the sand bed is too hot and unsafe for domestic use.

The thermal resistance provided by the copper tube can be described as the thermal resistance provided by a cylinder:

$$\begin{aligned} R_{thermal} &= \frac{ln(\frac{r_{outer}}{r_{inner}})}{2 * \pi * L * k_{copper}} \\ &= \frac{ln(\frac{6}{5})}{2 * \pi * 70 * 400} \\ &= 1.036 * 10^{-6}\ K/W \end{aligned} \tag{3}$$

When the sand discharges its energy in the form of heat into the copper pipe, it would result in the following temp. inside the copper pipe:

$$\begin{aligned} P_{discharged} &= -P_{stored} = -482.4\ W \\ P_{discharged} &= \frac{T_{inner} - T_{outer}}{R_{thermal}} \\ &= \frac{T_{inner} - 396.37}{1.036 * 10^{-6}} \\ T_{inner} &= 396.3695\ K \\ &= 123.3695°C \end{aligned} \tag{4}$$

Since copper has a high thermal conductivity and the selected tube has a very thin wall (only 1 mm), there is almost no temperature drop accross its walls.

Now, the temperature of the water depends on the heat transferred by convection, this is given by the following relation:

$$\begin{aligned} P_{received} &= -P_{stored} = -482.4\ W \\ P_{received} &= h_{water} * A_{Cylindrical} * (T_{water} - T_{inner}) \\ &= 300 * 2199.11 * (T_{water} - 396.3695) \end{aligned} \tag{5}$$

$$\begin{aligned} T_{water} &= 396.3687\ K \\ &= 123.3687°C \end{aligned} \tag{6}$$

Due to the numerous assumptions, this number may not be completely accurate, however this gives good insight into how the sand heat sink can transfer a maximal amount of heat into the water and outperform the reference system in that parameter if insulated well.

Following is a table describing the pros and cons of this system:

Pros	**Cons**
It outperforms the temperature parameter of the reference system by a factor of 3 (nearly)	The system can become really messy if the casing of the sand breaks
The system can function smoothly even with small gaps in sunlight	The water might vaporize and stagnate due to the high temperatures
This system is cheap to manufacture since sand and copper tubes are fairly cheap	This system cannot be placed on surfaces that are heavily slanted, such as some roofs
This system will be able to absorb energy from 100 % of the light rays provided by the artificial sun	Replacing the copper pipes in the system may be inconvenient
Sand can be easily recycled from this system into gardening purposes, to use in constructions, etc. The copper can also be recycled easily since it is a metal that can be repurposed with inexpensive mechanical treatment	It is difficult to make this system lightweight due to the weight of the sand
By adding or removing sand, the temperature of the water can be adjusted. More sand height would result in lower temperature water (due to low thermal conductivity of sand) and decreasing the height of the sand would result in high temperature water, assuming the copper tubing is flatly placed near the base of the sand bed This heat sink has scope to be designed to be smaller than the reference system	
The design is simple and not complex to build within the given time frame. It is possible to source all the materials using the gift-card stores and fit it easily within budget.	

Table 3: Pros and cons of the proposed sand heat sink

Overleaf Link to this SSA

https://www.overleaf.com/read/mxtycynychzp#53ca0a

References

[1] Solar Heat System 4CBL00. *Measurement Data on Reference System (Intex Solar Mat)*. 2025.

[2] *Heat Capacity and Energy Storage*. URL: https://www.e-education.psu.edu/earth103/node/1005#:~:text=Table_title:%20Trend:%20Table_content:%20header:%20%7C%20Substance%20%7C,Air%20%7C%20Heat%20Capacity%20(Jkg%2D1K%2D1):%201000%20%7C. (accessed: 05.09.2025).

[3] *Heat Capacity and Energy Storage*. URL: https://thermtest.com/thermal-resources/top-10-resources/top-10-thermally-conductive-materials#:~:text=Copper%20%E2%80%93%20398%20W/m%E2%80%A2K. (accessed: 05.09.2025).

[4] *Intex Pool Heater - Solar Mat - TOP,* URL: https://www.top-zwembadshop.nl/intex-zwembadverwarming-solar-mat. (accessed: 04.09.2025).

[5] *Intex Pool Heater - Solar Mat - TOP,* URL: https://www.front-materials.com/news/can-pvc-be-recycled/#:~:text=The%20short%20answer%20is%20yes,they%20cannot%20be%20processed%20together.. (accessed: 05.09.2025).

[6] *Product Information Intex*. URL: https://www.intex.eu/support/28685/productdetail?lst_lang=4. (accessed: 03.09.2025).

[7] *Sunrays are Practically Parallel, but not perfectly parallel*. URL: https://flatearth.ws/sunray-angle. (accessed: 05.09.2025).