

Storing Sunlight for the Evening Meal: A Phase Change Material Approach to Round-the-Clock Solar Cooking, with an Experimental Comparison of Erythritol, Wax, and Glucose

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Abstract: Cooking is one of the largest and least discussed energy demands in an Indian household, and roughly a third of household emissions arise from it. Solar cookers remove the fuel and the emissions, but they stop working when the sun goes down, which is precisely when most Indian families cook. This paper investigates whether a phase change material (PCM) can be used as a thermal battery to carry solar heat into the evening, and which material is best suited to the task. Five candidate materials were screened against seven selection criteria, and four thermal retention trials were carried out in which boiling water was held in contact with a candidate medium and its temperature logged over forty minutes. Plain water fell by 47°C over the trial; Glucose limited the fall to 28°C, wax to 35°C, and Erythritol to only 13°C, retaining 87°C at the end of the run. Erythritol also carries the highest latent heat of fusion among the candidates (about 340 J/g) and melts at 118 °C, a temperature that sits usefully close to normal cooking temperatures. A cooker built around a copper inner vessel, an erythritol-filled outer jacket, a metal foam matrix, parabolic reflectors, and a nichrome coil driven by a small solar battery is described, with a bill of materials of about ₹1,900. The design pays for itself against a conventional LPG set-up within the first year of use and emits nothing in operation. The study concludes that latent heat storage, not better insulation, is the decisive variable in making solar cooking practical and portable after sunset.

Keywords: solar cooking; phase change material; erythritol; latent heat of fusion; thermal energy storage; clean cooking; household emissions; appropriate technology.

1. Introduction

Cooking is the one energy demand that no household can postpone. It happens twice a day, in almost every home, during every season, and it is met almost entirely by burning something. In India that burning is done by roughly 300 million households, and the arithmetic of it is startling once written down. Taking a population of about 142 crore (1.42 billion), three rotis per person per meal, and two meals a day, the country produces on the order of 8.5 billion rotis every day, close to 3.1 trillion in a year. Every one of the rotis carries a fuel cost, and behind that fuel cost sits either a

gas cylinder, a kerosene stove, or a biomass fire.

The environmental consequence is not marginal. Roughly 34 per cent of emissions from Indian households arise from cooking alone, and this figure counts only the comparatively clean fuels. Where biomass and kerosene are still used, the picture worsens sharply: incomplete combustion in a closed kitchen releases Carbon Monoxide, oxides of Sulphur and Nitrogen, and fine particulate matter into the air that the cook breathes for several hours a day. Household air pollution is therefore both a climate problem and, more immediately, a respiratory and cardiovascular one.

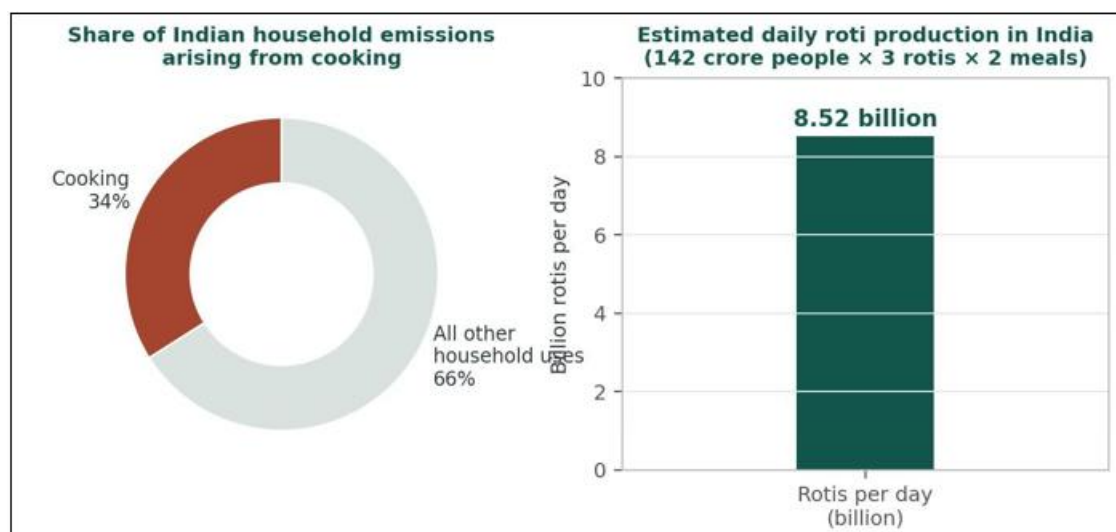


Figure 1: The scale of the problem: the share of Indian household emissions attributable to cooking and the estimated daily volume of roti production used here as an order-of-magnitude illustration.

Solar cooking is the obvious response, and it is not a new one. Box cookers, parabolic dishes, and evacuated tube collectors have all been built, sold, and studied for decades. Yet, adoption in India remains small, and the reason is easy to state: a solar cooker takes long to cook and works when the sun is overhead, and Indian families overwhelmingly cook the main meal after sunset. A technology that is unavailable at the exact hour it is needed will not replace a gas cylinder, however clean it is.

This paper takes that mismatch as its starting point. If solar energy can be captured during the day and released in the evening, the objection disappears. The question then becomes one of storage; specifically, what medium can hold a useful quantity of heat at a useful temperature, cheaply, safely, and repeatedly.

1.1 Aim and Objectives

The aim of this study is to design and evaluate a solar cooking system that remains usable after sunset by storing heat in a phase change material and to identify experimentally which material is best suited to the role.

- To review existing solar cooking technologies and identify the specific limitation that prevents their adoption.
- To compare the three principal modes of thermal energy storage and justify the choice of latent heat storage.

- To define selection criteria for a phase change material suitable for contact with food and for repeated melting and freezing.
- To measure experimentally the temperature retention of boiling water in the presence of glucose, wax, and erythritol against a plain water control.
- To propose a working assembly, cost it, and compare it with a conventional LPG cooking system.

1.2 Research questions

- Q1. Can a phase change material meaningfully extend the period over which a cooking vessel stays at cooking temperature?
- Q2. Which of the candidate materials, glucose, sucrose, wax, erythritol, or mannitol, best balances latent heat, melting point, cost, and food safety?
- Q3. Is a PCM-based cooker economically competitive with an LPG stove over a realistic period of use?

2. Review of Literature

2.1 Existing solar cookers and their limits

Three families of solar cooker dominate the field, and each fails in a different way. Their characteristics are summarized in Table 1.

Table 1: Comparison of Established Solar Cooker Designs

Design	Working Principle	Maximum Temperature	Principal Drawbacks
Parabolic solar cooker	Aluminum parabolic disc concentrates sunlight to a focal point	260-271 °C	Risk of eye damage from reflected glare; needs constant stirring and re-aiming
Evacuated tube cooker	Evacuated tube collectors absorb solar energy and store heat in a hot water Tank	About 290 °C	Fragile in extreme temperatures; unsuitable in very hot, cold, or humid climates; needs strong sun
Box oven	Glazed insulated box with reflective panels; traps radiation	121-204 °C	Slow; multiple collapsible reflectors make it bulky; low ceiling temperature

What unites all three is that they are collectors rather than stores. Each converts incident radiation into heat in real time and delivers it immediately. Remove the sun and the device becomes an insulated box. None of the three drawbacks listed above is as limiting as this shared one.

2.2 Modes of thermal energy storage

Three storage routes are available, and the choice between them determines the whole design.

- **Hot water tank (sensible heat).** The most common approach. Energy is stored as a rise in the temperature of water. It is simple and cheap, but the store cools continuously from the moment charging stops, and the energy density is low.
- **Solar cell and battery (electrical).** Sunlight is converted to electricity and stored chemically. Flexible and well understood, but the conversion path from light to electricity to heat wastes a large fraction of the

energy, and batteries are the most expensive component in any such system.

- **Phase change material (latent heat).** Energy is stored in the melting of a solid. Because the material absorbs a large quantity of heat at an almost constant temperature, the energy density is high and the discharge temperature is stable - the two properties that cooking actually requires.

2.3 The Physics of Latent Heat Storage

Anyone who has held ice and water at the same temperature has felt the principle at work. Ice feels colder because it must absorb a large quantity of heat, its latent heat of fusion, before its temperature can begin to rise at all. A phase change material exploits this in reverse: while it solidifies, it gives up that same store of energy at a fixed temperature rather than cooling gradually. The relevant relationships are given in Table 2.

Table 2: Governing Relationships Used in this Study

Quantity	Relationship	Meaning
Latent heat	$Q = mL$	Energy absorbed or released when a mass m changes phase, with L being the latent heat of fusion in kJ/kg. No temperature change occurs
Sensible heat	$Q = mc\Delta T$	Energy required to raise a mass m of specific heat c through a temperature change ΔT
Conduction	$Q/t = KA(\Delta T/L)$	Rate of heat transfer through a material of thermal conductivity K area A , and thickness L

2.4 Research Gap

The literature on PCMs is extensive in industrial and building applications - wall panels, cold chains, waste heat recovery - but comparatively thin on household cooking in Indian conditions and thinner still on the food-safety dimension. A material may store heat ideally and still be unusable if it corrodes its container, deforms on repeated cycling, or cannot safely sit next to food. This study is therefore organized around a comparison that treats storage performance and practical suitability as equally binding constraints.

3. Methodology

3.1 Research Design

The study is experimental and comparative. A single controlled trial, temperature retention of boiling water, was repeated across a plain water control and three candidate media, with temperature logged at fixed intervals over forty minutes. The slopes of the resulting cooling curves are the primary evidence. A parallel evaluation screened five candidate materials against physical and practical criteria.

3.2 Selection Criteria for the Phase Change Material

- It should store energy both through a temperature change and through a phase change.
- It must not deform its container as it melts and re-

solidifies.

- It must not corrode the vessel materials over repeated cycles.
- It should be light, so that the finished unit remains portable.
- It should be inexpensive and commercially available.
- Its melting point should lie close to cooking temperatures.
- It must be non-toxic and safe in proximity to food.
- Five materials were screened against these criteria: glucose, sucrose, wax, erythritol, and mannitol.

3.3 Experimental procedure

- Water was brought to its boiling point and its temperature confirmed at 100 °C.
- The vessel was placed in contact with the candidate medium under identical ambient conditions for every trial.
- Temperature was recorded every minute for the first fifteen minutes, then at five-minute intervals up to forty minutes.
- Plain water with no storage medium was used as the control, providing the benchmark cooling curve against which all other slopes are read.

3.4 Proposed system design

The working assembly combines a concentrating collector, a latent heat store and an electrical backup path for night use.

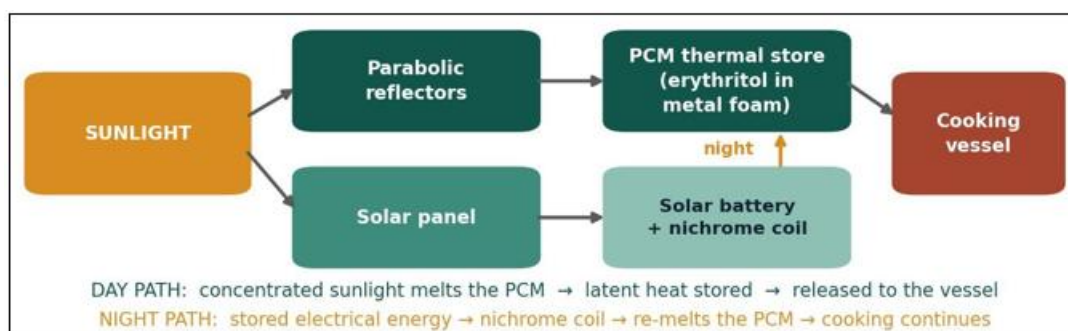


Figure 2: Working principle of the proposed cooker. The day path charges the phase change material directly with concentrated sunlight; the night path re-melts it using stored electrical energy through a nichrome coil.

In operation the sequence is as follows. Parabolic reflectors concentrate incident sunlight onto the outer jacket, raising the erythritol held within a metal foam matrix past its melting point. The material absorbs its latent heat of fusion and stores it at an almost constant temperature. As the inner copper vessel draws heat for cooking, the erythritol re-solidifies and releases that stored energy back at a stable temperature rather than cooling away gradually. The whole assembly is enclosed in an insulating wooden cylinder to limit conduction losses. After sunset, energy stored in melted erythritol or collected by the solar panel and held in the battery is passed through a nichrome coil embedded in

the store, re-melting the material and allowing cooking to continue.

4. Results and Analysis

4.1 Temperature retention trials

The four cooling curves are shown together in Figure 3, and the underlying readings in Table 3. The separation between them is large enough to be read without any statistical treatment.

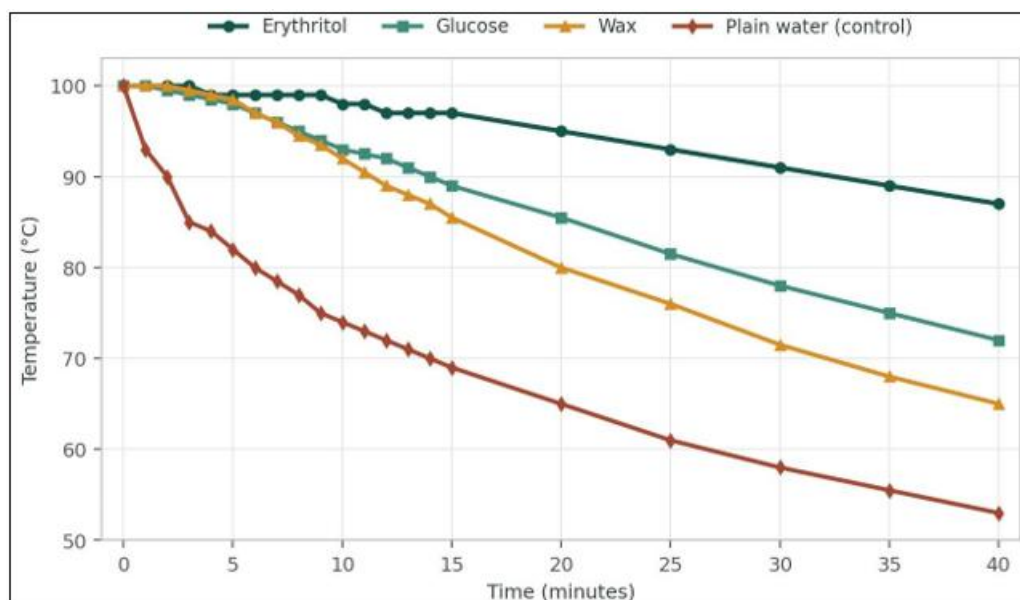


Figure 3: Temperature of boiling water over forty minutes in the presence of each storage medium, against a plain water control.

Table 3: Recorded Temperature (°C) against time for Each Medium

Time (min)	Plain water	Glucose	Wax	Erythritol
0	100	100	100	100
2	90	99.5	100	100
5	82	98	98.5	99
10	74	93	92	98
15	69	89	85.5	97
20	65	85.5	80	95
25	61	81.5	76	93
30	58	78	71.5	91
35	55.5	75	68	89
40	53	72	65	87

Total fall over 40 minutes · plain water 47°C · glucose 28°C
wax 35°C · erythritol 13°C

The control behaves as expected: plain water loses seven degrees in the first minute alone and forty-seven degrees over the full trial, ending at 53°C, well below any useful cooking temperature. Every storage medium improves on this, but not by comparable margins.

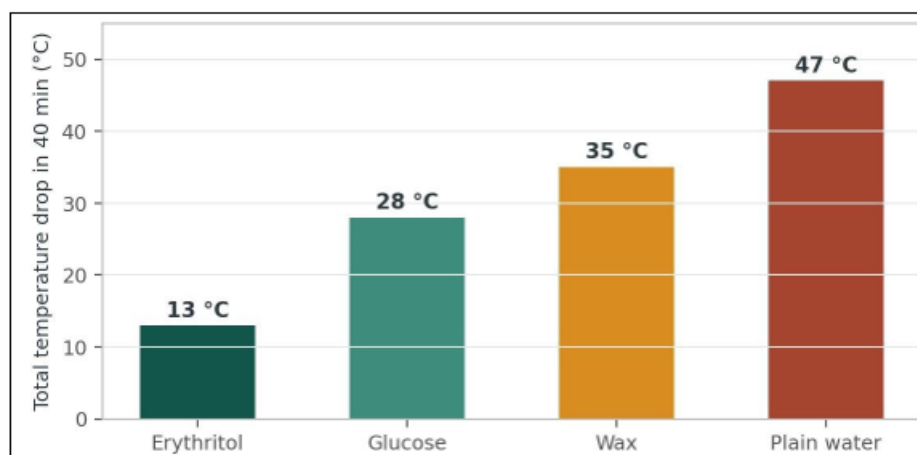


Figure 4: Total temperature drop over the forty-minute trial. Lower is better.

Erythritol is the clear outlier. It holds the vessel at 100°C for a full three minutes, is still at 97°C at the fifteen-minute mark, and finishes at 87°C, a total fall of thirteen degrees against forty-seven for the control. In practical terms, food in the erythritol-jacketed vessel remains at cooking temperature for the entire period over which the control has already become lukewarm.

4.2 Rate of Cooling

Reading the curves as rates rather than endpoints sharpens the finding. Figure 5 splits each trial into an early phase and a late phase.

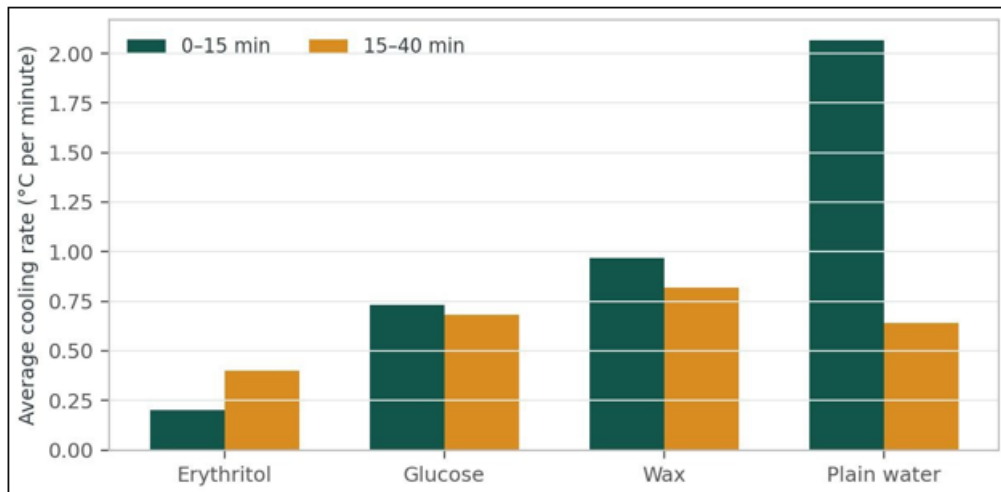


Figure 5: Average cooling rate in the first fifteen minutes and over the remaining twenty-five minutes.

The control loses over two degrees per minute in the early phase; erythritol loses one-fifth of a degree. More revealing is that erythritol's two phases are almost identical in slope, whereas the other media cool fastest at the start and then slow down. That flatness is the signature of latent heat: while the material is solidifying, it is giving up energy at a

nearly fixed temperature, so the curve refuses to bend. Glucose and wax, which store proportionally more of their energy as sensible heat over this range, show the ordinary decaying profile.

4.3 Material Properties and Final Selection

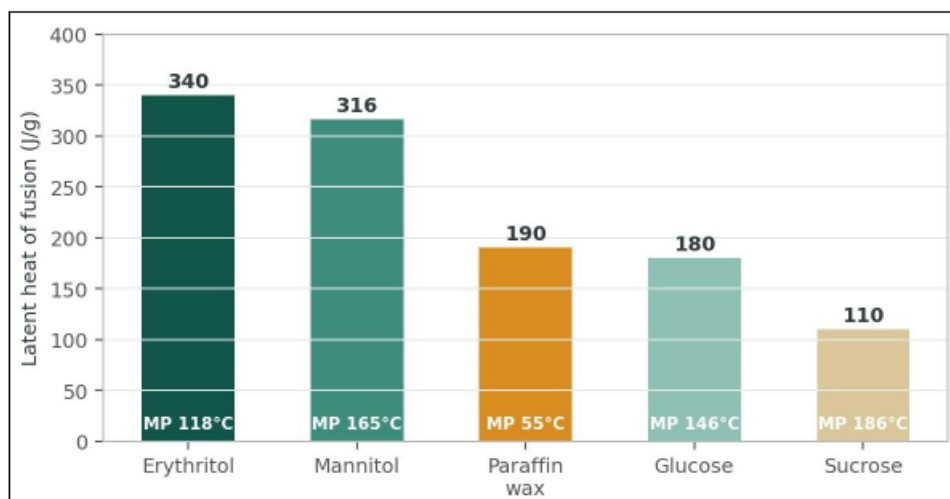


Figure 6: Latent heat of fusion and melting point of the five candidate materials (indicative values compiled from published literature)

The experimental result is consistent with the published thermophysical data. Erythritol carries the highest latent heat of fusion of the candidates at roughly 340 J/g, and its

melting point of 118 °C sits just above the boiling point of water, high enough to be useful for cooking, low enough to be reached by a modest concentrator.

Table 4: Properties of Erythritol Relevant to this Application

Property	Value	Why it matters here
Molecular formula	C ₄ H ₁₀ O ₄	A simple sugar alcohol already used widely in the food industry
Latent heat of fusion	≈ 340 J/g	Highest of the candidates; determines how much energy one kilogram can hold
Melting point	118 °C	Just above boiling point, so heat is released at a usable cooking temperature
Thermal conductivity	0.733 W/mK solid; 0.326 W/mK liquid	Conducts well when charging, insulates better once molten
Physical state	Odorless granular solid	Neutral in taste and smell; no contamination of food
Cost	About 50 paise per gram	Roughly ₹500 for the quantity used in the prototype
Other	Non-toxic, non-corrosive, non-hygroscopic, biodegradable	Safe near food, kind to the container, stable over repeated cycles

Sucrose and glucose caramelize and darken on repeated heating. Wax performs adequately but melts far too low, at around 55 °C, so it cannot hold a cooking temperature at all.

Mannitol is thermally attractive but more expensive and less freely available. Erythritol wins on every criterion simultaneously, which is unusual and is the reason for its

selection.

4.4 Energy stored in the thermal battery

The quantity of energy the store can hold follows directly from the latent heat relationship.

$$Q = mL$$

For 1 kg of erythritol: $Q = 1 \times 340 = 340 \text{ kJ}$ stored in the phase change alone

A further contribution comes from sensible heat as the molten material is raised above its melting point, given by $Q = mc\Delta T$. Figure 7 shows how the two components scale with the mass of material loaded into the jacket.

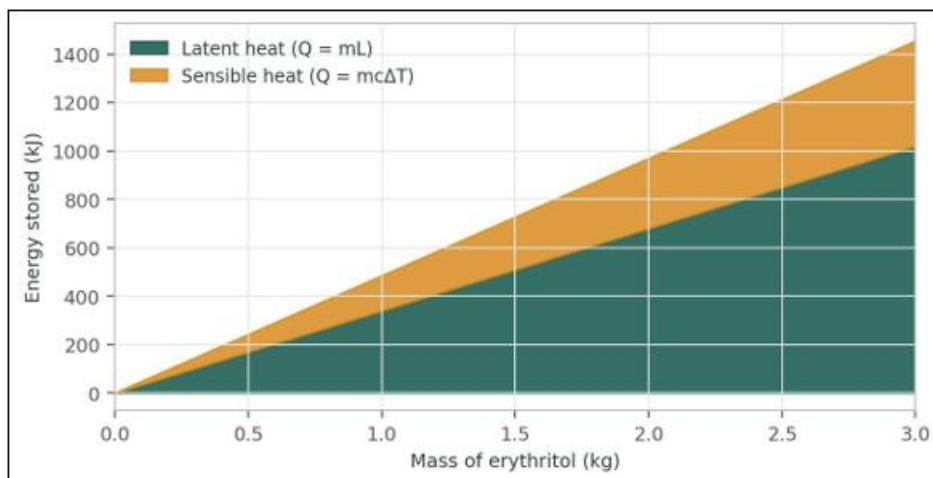


Figure 7: Energy stored against mass of erythritol, separated into the latent and sensible contributions

The latent component dominates throughout, which is precisely the design intention: a store that relies on sensible heat begins losing temperature immediately, while one that relies on latent heat holds its output steady until the phase change is complete.

4.5 Assembly and Costing

The prototype was specified from commonly available components. The bill of materials is given in Table 5.

Table 5: Components of the Proposed Cooker and Indicative Cost

Component	Function	Cost (₹)
Inner copper vessel (1 L)	Cooking vessel in direct contact with food	200
Outer vessel (3 L)	Jacket containing the erythritol store	1,000
Erythritol	Phase change material; stores and releases the latent heat	500
Metal foam	Perforated matrix holding the material and improving heat transfer	50
Nichrome coiled wire	Re-melts the erythritol at night using stored electrical energy	50
Concave reflectors	Concentrate incoming sunlight onto the store	100
Wooden cylinder	Outer insulation to limit conduction losses	Auxiliary
Solar panel and battery	Collect and store electrical energy for the night cycle	Auxiliary

Indicative bill of materials for the prototype · approximately ₹1,900 excluding auxiliary items

4.6 Comparison with a conventional system

A conventional set-up costs roughly ₹4,000 to acquire, about ₹3,000 for the stove and ₹1,000 for the cylinder, and then

continues to cost money for as long as it is used. A PCM based solar cooker costs about ₹2,000 once and nothing thereafter.

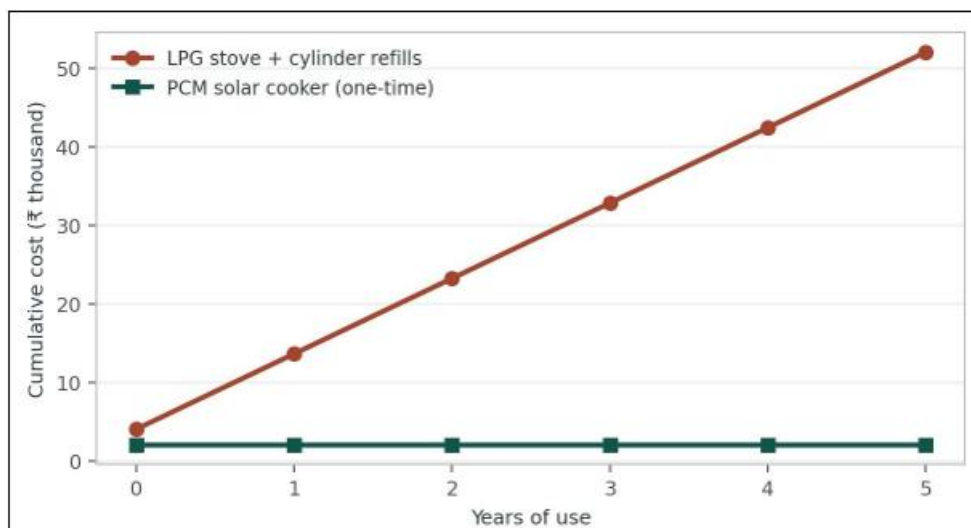


Figure 8: Cumulative cost of cooking over five years: an LPG set-up with recurring refills against a one-time PCM cooker

The lines diverge from the first year and never re-converge. Against a household using roughly one cylinder a month, the PCM cooker recovers its cost well inside the first year,

and every subsequent year is free. The running cost of sunlight does not rise with inflation.

Table 6: Qualitative Comparison with Existing Cooking Systems

Factor	Conventional systems	Proposed PCM system
Energy source	Biomass, LPG, kerosene or grid electricity, largely non-renewable	Sunlight, renewable and freely available
Emissions	CO ₂ , SO _x , NO _x and particulates; contributes to deforestation where biomass is used	None during operation
Residue	Soot and unburnt residue accumulate	No residue formed
Cost	Lower upfront cost but permanent fuel expenditure	One-time cost, no running expenditure
Portability	Bulky cylinders and fixed connections	Compact, self-contained, movable
Maintenance	Regular servicing and fuel procurement	Minimal; no fuel supply chain
Availability at night	Available on demand	Available through the stored latent heat and battery path

5. Discussion

5.1 Why latent heat is the decisive variable

The temptation in a project of this kind is to attribute better retention to better insulation. The data do not support that reading. All four trials were run under the same conditions in the same vessel; the only variable was the storage medium. Glucose and wax, both reasonable insulators, still lost twenty-eight and thirty-five degrees respectively. Erythritol lost thirteen. The difference is not in how slowly heat escaped but in how much energy was being released back into the vessel while it did.

This has a practical consequence worth stating plainly: improving the walls of a solar cooker yields diminishing returns, whereas adding a latent heat store changes the shape of the cooling curve itself. Insulation slows a decline; a phase change material postpones it.

5.2 Why erythritol rather than a better performer

Materials with higher latent heat exist, and industrial thermal stores routinely use salt hydrates that outperform any sugar alcohol. They are not appropriate here. A cooking appliance sits in a domestic kitchen, is handled by people with no technical training, and is likely to come into contact with food. Under those constraints, non-toxicity, non-

corrosiveness, and low-cost stop being desirable extras and become disqualifying requirements. Erythritol is not the best thermal store available; it is the best one that is also safe to have in a kitchen at fifty paise (₹0.50) a gram.

5.3 Implications

- **For Households:** The value of the design is not that it cooks with sunlight, many devices do, but that it decouples the moment of collection from the moment of cooking. That single change is what makes solar viable for a family that eats after dark.
- **For Emissions:** If even a modest share of households displaced a portion of their LPG use, the reduction in cooking emissions would be significant, given that cooking accounts for roughly a third of household emissions to begin with.
- **For Further Design Work:** The results point towards optimizing the mass of PCM against the intended cooking duration, rather than towards further insulation, as the most productive direction for improvement.

Principal Finding

Erythritol held the cooking vessel within thirteen degrees of boiling for forty minutes, against a forty-seven degree fall for plain water. The advantage comes from latent heat released at a constant temperature during solidification, not from insulation, which is why a phase change material, and

not a better-lagged box, is what makes solar cooking possible after sunset

6. Limitations and Future Scope

Several limitations should be stated honestly. The trials measured temperature retention in a laboratory-style set-up rather than the performance of a fully built cooker under field conditions, and each medium was tested once rather than replicated. Ambient temperature, humidity, and wind were not controlled instrument-wise, and no measurement of charging time under real sunlight was taken, although majority of these factors were kept similar by conducting the tests at the same place and time. The cost figures are indicative retail prices rather than a costed manufacturing estimate. The number of melt-freeze cycles the material can survive before its performance degrades was not tested physically, but degradation takes longer than other similar media. This is the single most important unknown for a device intended to last years.

Four extensions follow naturally. First, cycling the material several hundred times to establish durability. Second, building and instrumenting the full assembly to measure actual charging time and cooking capacity under Indian solar conditions across seasons. Third, testing composite stores, erythritol blended with a higher-conductivity filler, to speed up charging without losing storage capacity. Fourth, a field trial with real households to establish whether the design survives contact with everyday domestic use, which is where most appropriate-technology projects actually fail.

7. Conclusion

This paper asked whether a phase change material can make solar cooking practical at the hour when families actually cook. The experimental evidence says that it can. Erythritol held boiling water within thirteen degrees of its starting temperature over forty minutes, while an unassisted vessel fell by forty-seven degrees over the same period, and it did so while remaining non-toxic, non-corrosive, biodegradable, and cheap enough to be bought by the kilogram.

The wider point is about where the engineering effort belongs. Solar cookers have been refined for decades along the axis of collection, better reflectors, better glazing, and better insulation, while the limitation that actually blocks adoption lies along the axis of storage. A cooker that collects superbly and stores nothing is still useless at eight in the evening. Latent heat storage addresses the real constraint directly, and it does so with a material that costs fifty paise a gram and is already sold as a sweetener.

For a country making 8.5 billion rotis a day, a device that shifts even a fraction of that cooking from a cylinder to the sun is worth building. The physics is settled, the material is available, and the bill of materials comes to under two thousand rupees. What remains is the engineering of durability and the patient work of field testing.

Declaration: The experimental readings reported in this paper were recorded by the author during the project work described in Section 3. Thermophysical property values for

the candidate materials are indicative figures compiled from published literature and are included for comparison. Costs are indicative retail prices at the time of the study. This paper is submitted as academic work.

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