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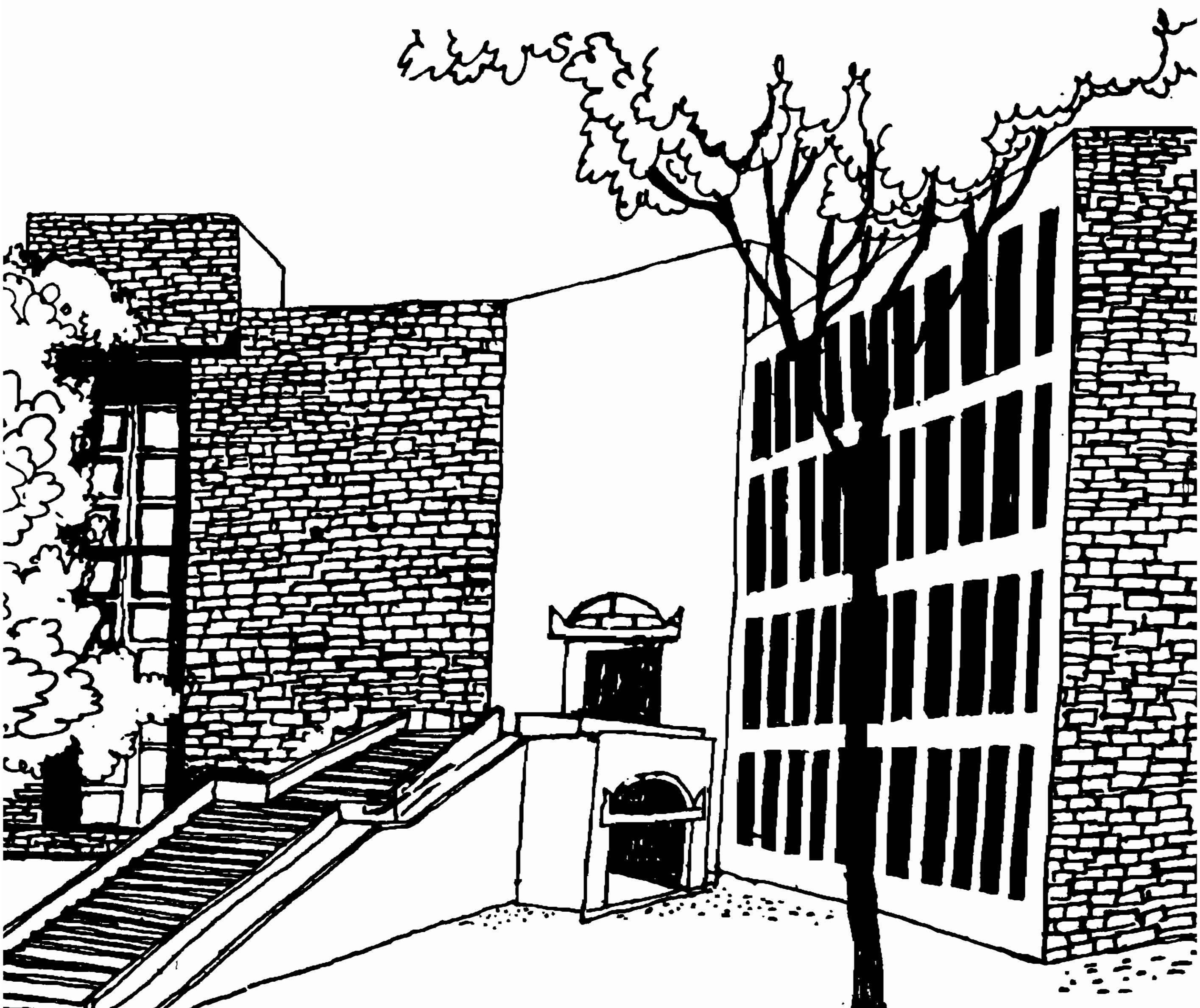

NEED FOR BACK-UP IN BOX SOLAR COOKER

By

Girja Sharan

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Girja Sharan

Centre for Management in Agriculture,
Indian Institute of Management,
Vastrapur, Ahmedabad 380015, Gujarat, INDIA

Abstract

Systematic efforts to promote box solar cookers in Gujarat (India) began in Gujarat is characterised by high insolation, high ambient temperatures, clear sky and ii parts, severe shortage of fuel-wood. In short, a region with high potential for use of cc In addition it has good entrepreneurial climate, an added positive feature.

Yet, only about 35,000 units have so far been sold and sales are levelling off. first-purchase-volume curve, often used by market research professionals to study product cycle, indicates that cooker is past maturity and is in decline. Significant improvement wo be essential for further diffusion.

A survey of users in and around Ahmedabad city indicated that they would like t present cooker made less vulnerable to climatic factors. Conjoint analysis indicated two oth features desired--doneness indicator, and stainless steel vessels. In this paper we present a analysis of back-up required in Ahmedabad region, which can make the cooker les vulnerable to climate.

Diffusion in Gujarat

Box solar cooker (cooker for short) was launched in Gujarat State (India) in the late seventies. Gujarat could be rated as a region of high potential for cookers, characterized as it is by high insolation, high ambient temperatures, low cloud cover, and widespread shortage of fuel-wood.

However, the total number of cookers sold till the year 1994 is only about 35,000 units, and sales appear to be levelling off. Diffusion curve is described by **Equation-1.**

$$N(t) = \frac{53700\ (1 - e^{-0.2t})}{1 + 10.3\ e^{-0.2t}} \qquad \textbf{(1)}$$

where $N(t)$ = cumulative sales (no.)
t = time (years), $t(0)=1979$

Cooker seems headed for a low saturation limit (54000). Also it is now past maturity and is in decline phase [1]. Significant improvements are now needed.

Desired New Features

In order to identify new features the users may desire and be willing to pay for, a survey was carried out in and around Ahmedabad city (Naik and Sharan [2]). Conjoint analysis revealed three features that may significantly enhance the acceptability--provision of back-up source, doneness indicator and stainless steel vessels.

Sample consisted of 50 owners of cookers, and another 50 neighbours of these who were knowledgeable about the cooker but did not own one. **Table-1** shows the summary results. It is seen that only 14 would be willing to buy the cooker as it is. Even this number will reduce, if price is raised. Addition of stipulated features increases the acceptability. Largest increment is made by the back-up, when the number of those willing to go for it increases from 14 to 24. Responses also indicate that new features should not be accompanied by a large increase in price.

Table 1
Acceptability: Simulated Results

Respondent Category	Features	No. of respondents likely to purchase at		
		Rs.600	Rs.900	Rs.1200
Non Owners	As it is	14	10	6
	With SS vessel	20	16	14
	With Indicator	17	15	11
	With Backup	24	13	8
	SS+Indicator	36	27	21
	SS+Backup	37	29	21
	SS+indicator+ Backup	45	38	30

Strength of Back-up for Ahmedabad Region

These findings led us to initiate a collaborative project with the Sardar Patel Renewable Energy Research Institute (SPRERI), Vallabh Vidyanagar, to develop a prototype with back-up. SPRERI team has contributed much to the design of cooker presently marketed in Gujarat [3]. It is easy to guess the strength of back-up needed. Indeed such cookers are already in market in certain parts. However, we think, in adding a back-up certain additional aspects need to be considered.

In rural areas of Gujarat, public grid is very erratic. Electrical back-up may not improve the dependability of cooker substantially in such areas. It is likely to do so more in and around urban centres. Provision of back-up may further skew the pattern of cooker use toward cities. Positive aspect, however, is that it will enable the owner to use the cooker more fully. Users in our survey had indicated that they used the cooker for 6 to 8 months. This may increase with back-up.

Strength of back-up will also depend on answers to following questions: Should it also be a supplementary source to raise temperatures sufficiently to permit frying? Should it also be a indoor device for days when it is not possible to go outdoors? Implications of these are examined below.

Consider a single glazed empty cooker without reflector. We shall do heat balance on two components--glass cover and absorber plate.

Let

I_h	insolation on horizontal surface (W/m^2)
T_p, T_g, T_a, T_s	temperatures of absorber plate, glass cover, ambient air and sky (°K)
α_p, e_p	absorptivity and emissivity of plate, dimensionless
α_g, e_g	absorptivity and emissivity of glass cover, dimensionless
τ	transmissivity (solar) of glass cover, dimensionless
$(mc)_p$,	heat capacity of absorber plate (J/°K)
$(mc)_g$	heat capacity of glass cover (J/°K)
h_1	convective heat transfer coefficient between plate and cover (W/m^{2}K)
h_2	convective heat transfer coefficient between glass top and atmosphere (W/m^{2}K)
U_b, U_s	bottom and side loss coefficient (W/m^{2}K)
σ	Stefan-Boltzmann constant (W/m^2-°K^4)
F_{p-g}	view factor from plate to cover, dimensionless
A_p, A_g	areas of absorber plate and glass cover (m^2)

Heat balance on plate

$$(mc)_p \frac{dT_p}{dt} = A_p \tau \alpha_p I_h - \frac{\sigma \left(T_p^4 - T_g^4\right)}{\left(\frac{1-e_p}{e_p A_p} + \frac{1}{F_{p-g} A_p} + \frac{1-e_g}{e_g A_g}\right)} - A_p h_1 \left(T_p - T_g\right) - A_b U_b \left(T_p - T_a\right) - A_s U_s \left(T_p - T_a\right) \qquad (2)$$

The first term on the right is heat gain by plate by absorption of radiation, the second is heat lost through radiation back to the glass, the third heat lost through the air between plate and cover by convection, the fourth heat lost through bottom and the fifth heat lost through sides by conduction. For radiative transfer from plate to glass cover, these two surfaces are treated as two aligned rectangles of finite dimension, the view factor for which can be obtained from the catalogue. Radiative and convective transfers from the sides and bottom are ignored.

Heat balance on cover

$$(mc)_g \frac{dT_g}{dt} = A_g \alpha_g I_h + \frac{\sigma \left(T_p^4 - T_g^4\right)}{\left(\frac{1-e_p}{e_p A_p} + \frac{1}{F_{p-g} A_p} + \frac{1-e_g}{e_g A_g}\right)} + A_p h_1 \left(T_p - T_g\right) - A_g e_g \sigma \left(T_g^4 - T_s^4\right) - A_g h_2 \left(T_g - T_a\right) \quad (3)$$

The first term on the right is heat absorbed by glass cover from sun, the second heat gained by radiation from plate, the third heat gained by convection from plate, the fourth heat lost to atmosphere by radiation and the fifth heat lost to surroundings by convection.

Parameters

Weight (kg)	13	Insulation thickness		
Outer dimension (cm)	52 X 52 X 19.5		bottom (cm)	5.2
Casing material	Aluminium sheet		side (cm)	4.5
Glass cover (cm)	45 X 45 X 0.30		material	glass wool
Absorber tray (cm)	43 X 43 X 8			
thickness (mm)	1			

A_g	0.202 m^2	A_p	0.185 m^2
A_b	0.185 m^2	A_s	0.1376 m^2
α_p	0.9	e_p	0.9
α_g	0.08	e_g	0.88
τ	0.8	$\tau\alpha_p$	0.73

Cooker presently in market has parameters close to these values.

Heat Transfer Coefficients

Estimates of the convective heat transfer coefficient between the plate and glass cover (h_1) can be made using correlations for natural convection available in literature. Holland's correlation yields a value of 2.7; those given in ASHRAE Handbook of Fundamentals a value of 6.2, that of Duffie and Beckman [4] 3.18. Latter has been used here.

As stated, for the radiative transfer from plate to glass cover, the two surfaces have been treated as aligned rectangular opaque and diffuse. Treating the glass cover as opaque simplifies the computation without introducing significant error since the transmissivity of glass in the infrared range is very small.

Convective heat transfer coefficient for top of glass.

$$h_2 = 5.7 + 3.8\ V$$

where V wind velocity (m/s), taken to be 5 m/s constant

$(mc)_p$	879 J/°K	$(mc)_g$	747 J/°K
h_1	3.18 $W/m^2/°K$	h_2	24.7 $W/m^2/°K$
U_b	0.5 $W/m^2/°K$	U_s	0.5 $W/m^2/°K$

Solar radiation in Ahmedabad reaches its lowest in August [5]. We therefore selected August for determination of back-up strength. Fourier coefficients [6] for ambient temperatures and global insolation for August are shown in **Tables 2 and 3**.

Table 2
Fourier Coefficients for Air Temperature Series: AHMEDABAD

	n	0	1	2	3	4	5	6
August	A	28.03	-1.12	0.12	0.02	0.03	0.01	-0.03
	B		-2.07	0.50	0.06	-0.10	-0.03	0.04

Table 3
Fourier Coefficients for Global Solar Radiation Series: AHMEDABAD

	n	0	1	2	3	4	5	6
August	A	185.88	-287.54	117.54	-2.73	-17.17	0.91	3.58
	B		-45.99	40.92	-5.92	-9.38	0.55	5.17

Results and Discussion

An empty cooker, with all its components at temperature equal to that of the ambient air, is placed outdoors at 8:00 A.M. **Equations 2 and 3** are integrated numerically to yield plate and cover temperatures. **Figure-1** shows the temperature and time graph of the plate on an average day in August. Note the maximum temperature achieved is only 82°C, not satisfactory. A good cooker is expected to produce stagnation temperature upwards of 120°C, considered necessary for satisfactory cooking. Addition of a reflector will improve this, but not enough.

Let us assume now that the cooker has been provided with a back-up source of strength, S. It is assumed to be automatically turned on when the plate temperature falls below a given level, say, T_d and is off otherwise. Presence of such a feedback controlled back-up can be accounted for by adding the following term on right hand side of Equation-2.

$$S = \frac{W}{2} + \frac{W}{2}\,\mathrm{Sign}(T_d - T_p)$$

where W — power of back-up source (W)
T_d — stagnation temperature desired, here 120°C
Sign — signum function

With a source of 100 W, plate temperature reaches (120°C) by 10:30 A.M. (**Figure-1**). Cooker users generally start cooking after 11:00 A.M. Thus, a back-up of 100 W is adequate to make the present cooker usable through out the year in Ahmedabad region, during the hours solar cooking is presently done. We shall call such cooker a `all-days-of-year device'.

If the graphs were plotted at finer intervals of time, it will be easily possible to see when the source was on and when off. This will enable one to compute the contribution of electricity. The 100 W source was turned off twice near noon for a total period of 12 minutes.

Increasing the strength of source above 100 W helps only in extending the span of time during the day when stagnation temperature of 120°C can be achieved and maintained. For instance, a strength of 150 W enables plate temperature to reach 120°C about 2 hours earlier in the morning (8:30 A.M.) and to be maintained till at least 4:00 P.M., as shown in the figure. Simulations were terminated at 4:00 P.M. We can call this a `all-hours-of-day device'.

Patel and Patel [7] modified a cooker by placing a heating element below absorber plate, and tested it in April at Vallabh Vidyanagar, about 80 km from Ahmedabad to determine the strength needed. They reported that it took 5 hours (11:00 A.M. to 4:00 P.M.) to cook 1 kg of rice in an unassisted cooker. With a 125 W heater, cooking could be done in 2.5 hours both in the morning (10:30 A.M. to 1:00 P.M.) and in the afternoon (1:00 to 2:30 P.M.). They repeated cooking test indoors and found that 208 W source was needed to do rice in 2.5 hours.

Although Vallabh Vidyanagar and Ahmedabad are not very far off, it is not quite appropriate to compare their results in entirety with ours. Their cooker had a slightly smaller aperture (0.16 m^2) than that used in simulation here. They report heater strength needed for cooking, we for reaching stagnation temperature of 120°C. Their test was done in April, our simulations are for August. Also, in simulation model thermal output of back-up is taken to be equal to electrical input. In experimental set-up some transport losses would be inevitable. Patel and Patel have treated these as negligible in interpreting the results.

It may not be as inappropriate however to compare the results of their indoor cooking with simulations of cooker placed inside. For, the results will then not have the effect of difference in month of test and small difference in aperture size.

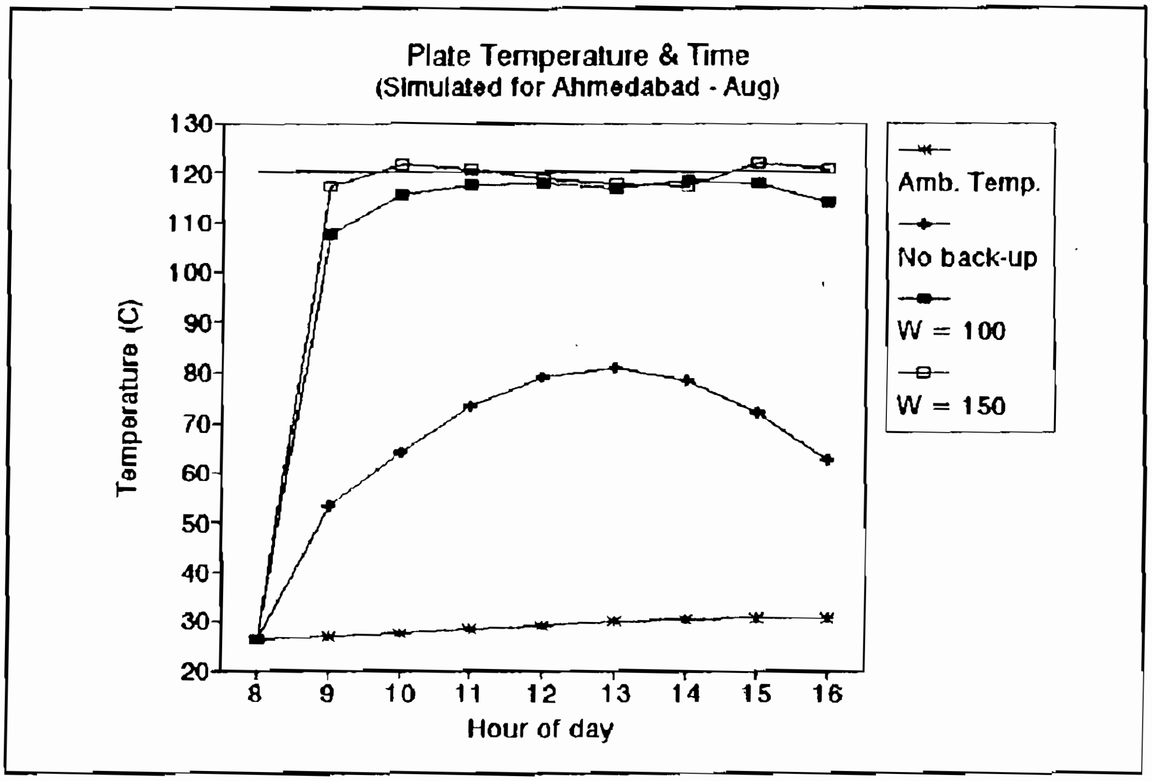

Figure 1

Cooker as Indoor Device

Accordingly, simulations were done with insolation reduced to zero ($I_h = 0$) and the ambient temperature set to a constant 26°C to mimic indoor conditions. Table-4 shows the temperature achieved with source strength from 100 W to 900 W.

It stagnation temperature of 120°C is taken to be necessary for satisfactory cooking, it would take a heater strength of about 200 W. This is quite close to the figure of 208 W reported by Patel and Patel for cooking rice, indoors.

We can also state that the cooker is comparatively a better oven than the (fully) electrical ovens available in the market which typically have heating elements upwards 1000 W and maximum temperature setting of 300°C. The box cooker being very well insulated device, can achieve such temperature at a lower heater strength. This was also noted by Patel and Patel.

Table 4
Cooker Indoors

Back-up Strength (W)	Max. Temperature Attained (°C)
100	86
200	133
300	170
400	202
500	229
600	253
700	275
900	312

Refinement of Model and Prototype Development

Model used in the above simulation is being refined and made more comprehensive to help in designing and reducing the need for extensive experimentation. Some of the models developed in the Indian context are by Chandra and Pandey [8], Mannan and Singh [9], Mullick *et al* [10], Yadav and Tiwari [11], Dang [12], and Thulasi Das *et al* [13].

Thulasi Das *et al* model is the most comprehensive so far. It has heat balance on glass cover, inside air, vessel cover, vessel, contents of the vessel, and plate. They consider all modes of heat transfer inside the box including radiative. Box is treated as a cylindrical enclosure. Suitability of using some of the recently published models to help design a cooker with back-up is being explored.

Summary and Conclusion

Gujarat is a region with apparently high potential for use of solar cooker. Yet, it seems to be headed for a low saturation limit. A user survey indicated that the acceptability of cooker may increase significantly if it can be made less vulnerable to climatic factors. One way of doing so is to provide an electrical back-up.

It is obvious, that the strength of back-up source will differ from region to region. A little less apparent is the fact that it will also depend on whether the cooker is to be all-days-of-year device and a (fall-back) indoor device for days when it is not possible to place it outdoors.

Present analysis suggests that a source of about 100 W can make the cooker all-days-of-year device around Ahmedabad. Increasing the strength to 150 W can enable the cooker to be used in the early mornings and late afternoons as well.

Strength will need to be increased further to about 200 W to make it a fall-back device when it is not possible to place the cooker outdoors. Our simulations support some of the published experimental measurements.

It may also be added that above estimates of back-up strength will keep the box cooker still essentially a slow cooking solar device and not turn it into a fast electrical oven.

Acknowledgement

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References

1. Sharan Girja. Product Planning and Diffusion Models-I. Working Paper No.1256, Indian Institute of Management, Ahmedabad, May 1995.

2. Naik G. and Girja Sharan. Assessing Consumer Preference for Product Features Selection: Solar Cookers. *Vikalpa*, January-March, 1997 (forthcoming).

3. Balasubramanian V., S.K. Philip, and A.K. Singhal. Performance Testing of Box-type Solar Cookers with Differing Cooker-Vessel Combinations. *SESI Journal*, 4(1), 1990.

4. Duffie J.A. and W.A. Beckman (1974). Solar Energy Thermal Processes. John Wiley and Sons. New York.

5. Mani A. (1980). Handbook of Solar Radiation Data for India. Allied.

6. Sharan Girja and M. Krishna Kumar. Fourier Representation of Ambient Temperature and Solar Radiation. *SESI Journal*, 5(2): 55-59, 1995.

7. Patel P.D. and Rekha S. Patel (1994). Electrically Boosted Solar Cooker, *SESI Journal*, 4(1).

8. Chandra P., M.M. Pandey (1987). Predicting the Temperature Inside on Empty Box-type Solar Cooker. *SESI Journal*, 1:2.

9. Mannan K.D. and Prempal Singh (1989). Computer simulation of box-type solar cooker. In Renewable Energy for Rural Development. New Delhi: Tata Mcgraw-Hill

10. Mullick S.C., T.C. Kandpal, and A.K. Saxena (1987). Thermal test procedure for box-type solar cookers. *SE*, 39:4, 353-360.

11. Yadav Y.P. and G.N. Tiwari (1987). Transient analytical study of box-type solar cooker. *SE*, 27:2, 121-125.

12. Dang Aman (1985). An analytical study of a solar cooker with a booster mirror using PCM as storage. *Energy Conversion Management*, 25:3, 255-261.

13. Thulasi Das T.C., S. Karmakar, and D.P. Rao (1994). Solar box-cooker: Part I - Modelling. SE 52:3, 265-272; Part II -Analysis and Simulation. *SE*, 52:3, 273-282.