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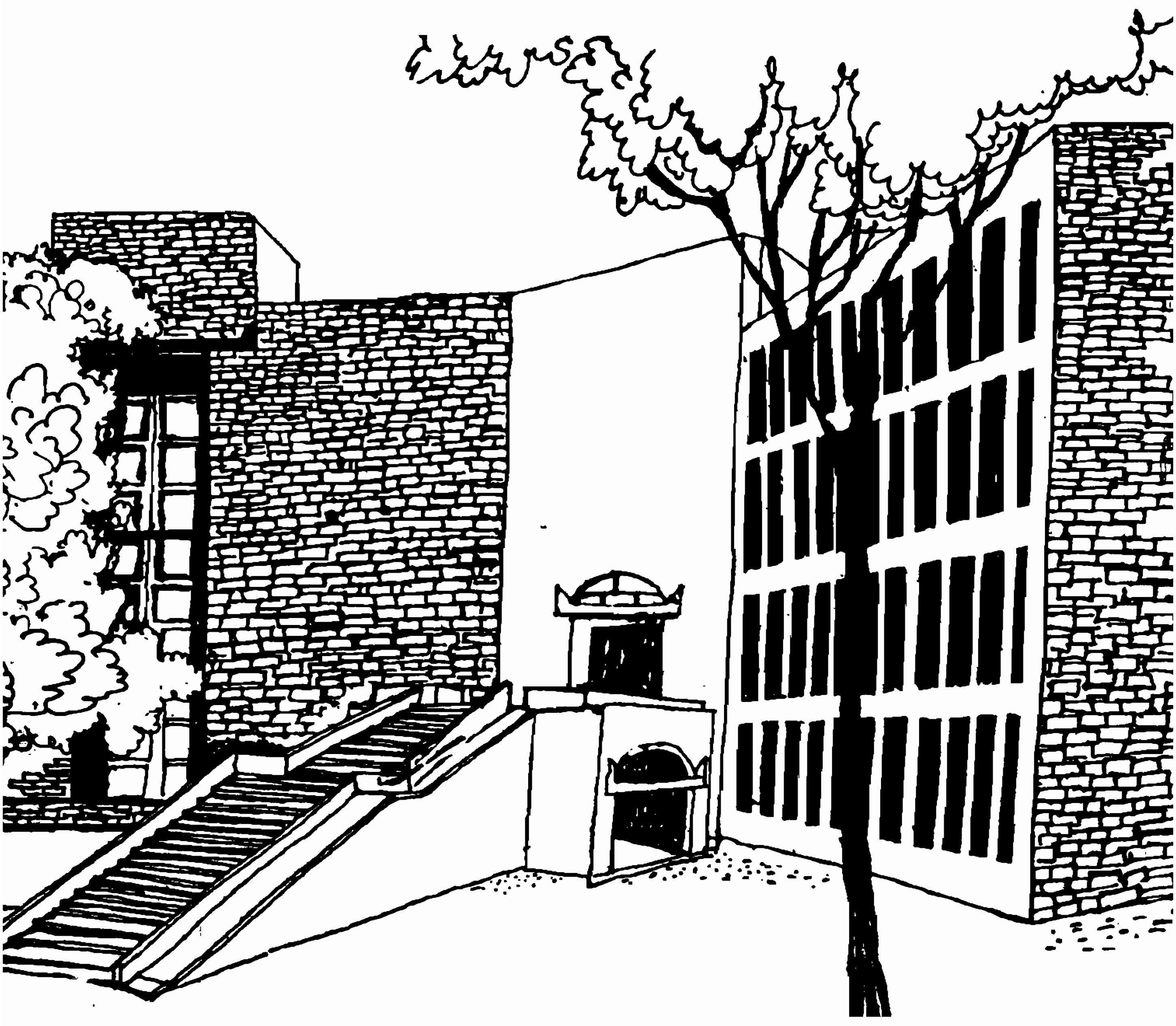

ESTIMATES OF BACK-UP NEEDED IN BOX COOKER IN DIFFERENT REGIONS USING SIMULATION

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Estimates of Back-up Needed in Box Cooker in Different Regions using Simulation

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Abstract

In this paper estimates of backup needed in eleven locations have been presented. Estimates were made using a duly validated mathematical model of box cooker and climatic conditions of each location.

Introduction

Cooker performance is affected by variation in climatic factors, primarily insolation and ambient temperature. When either of these is lower than the cooker is designed for, cooking may take long or not be feasible at all. Regular users of cooker in and around Ahmedabad reported that this happened in rainy season and then again in the middle of winter[1]. This problem may be more serious in cooler regions of the north where cookers with electrical backup have appeared in the market. Inspection of several models revealed that heating element used varied in rating, in some cases being as high as 500 W. It is clear that rating will differ from region to region. But it is not clear if the ratings were derived from or related to the climatic variations.

In this paper we present estimates of backup required in eleven locations including New Delhi in the north, Trivandrum in south, Ahmedabad in west, and Shillong in the east.

Method

1. Local data of global insolation on horizontal surface and ambient temperature was taken from Mani's handbook [2] and converted into analytical expressions using Fourier analysis. These are used as input to simulation model.

2. A mathematical model of box cooker made earlier [3] was modified and used for simulation.

3. In each of the eleven locations, two months were identified, one that is the coolest (lowest mean day temperatures) and other that has lowest insolation. Estimates of back-up strength required in these months are using the model and local climatic data (from `1'). Larger of the two values is selected as the appropriate backup for that location.

Specifications of Cooker used in Simulation

Figure 1 shows a schematic diagram of a double-glazed cooker. Specifications are given below. These specifications are of cookers marketed in Gujarat [4].

Weight (kg)	12.5	**Insulation thickness**	
Outer dimension (cm)	51.7 X 51.7 X 20.5	Bottom (cm)	4.6
Casing material	Aluminium sheet	Side (cm)	4.6
Glass covers		(Material: Glass-wool)	
- Second cover (cm)	47 X 47 X 0.30		
- First cover (cm)	43.5 X 43.5 X 0.30		
Gap between covers (cm)	2		
Absorber tray (cm)	42.5 X 42.5 X 8		
- Plate thickness (mm) 1			

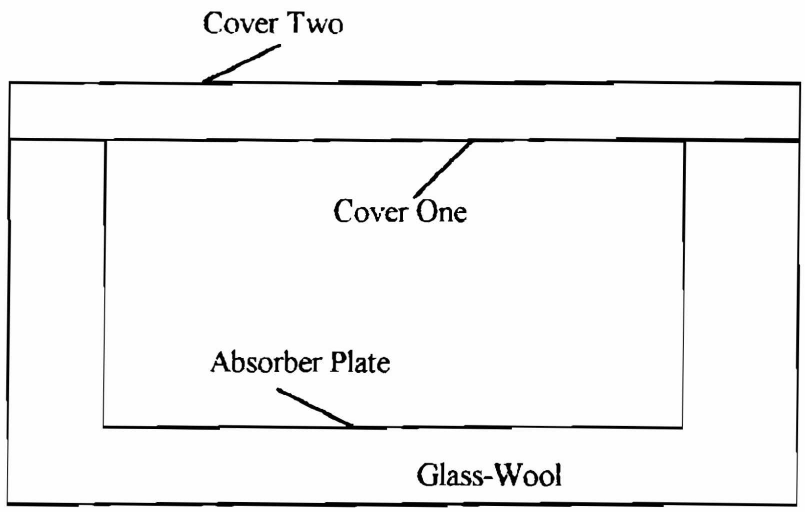

Figure 1: Schematic Section of Double-glazed Cooker

Model

Heat balance on plate

$$(mc)_p \frac{dT_p}{dt} = A_p(\tau\alpha)_e I_h - \frac{\sigma\left(T_p^4 - T_{c1}^4\right)}{\left(\frac{1-e_p}{e_p A_t} + \frac{1}{F_{t-c1} A_t} + \frac{1-e_{c1}}{e_{c1} A_{c1}}\right)} - A_p h_{pc1}\left(T_p - T_{c1}\right) - A_b U_b \left(T_p - T_a\right) - A_s U_s \left(T_p - T_a\right) \quad (1)$$

List of symbols is given in **table 1**. First term on the right is heat gain by plate by absorption of radiation coming through two-cover system, second heat loss through radiation from tray back to the first cover, third heat loss to first cover by convection, fourth heat loss through bottom and fifth heat loss through sides by conduction. Cooking chamber is treated as two surface enclosure.

First Cover

$$(mc)_c 1 \; dT_c \frac{1}{dt} = A_c 1 \tau \alpha_c 1 I_h + \frac{\sigma \left(T_p^4 - T_c 1^4\right)}{\left(\frac{1-e_p}{e_p A_t} + \frac{1}{F_{t-c1} A_t} + \frac{1-e_c 1}{e_c 1 A_c 1}\right)} + A_p h_{pc1} \left(T_p - T_c 1\right)$$

$$- A_c 1 h_{c1c2} \left(T_c 1 - T_c 2\right) - \frac{\sigma \left(T_c 1^4 - T_c 2^4\right)}{\left(\frac{1-e_c 1}{e_c 1 A_c 1} + \frac{1}{F_{c1-c2} A_c 1} + \frac{1-e_c 2}{e_c 2 A_c 2}\right)} \qquad (2)$$

First term on the right is heat gain by absorption of radiation passing through second cover, second heat gain through radiation from plate, third heat gain from plate by convection, fourth heat loss to top cover by convection, and fifth heat loss to top cover by radiation. For radiative transfer between covers, these are treated as aligned rectangles of finite dimension.

Second Cover

$$(mc)_c 2 \; dT_c \frac{2}{dt} = A_c 2 \alpha_c 2 I_h + \frac{\sigma \left(T_c 1^4 - T_c 2^4\right)}{\left(\frac{1-e_c 1}{e_c 1 A_c 1} + \frac{1}{F_{c1-c2} A_c 1} + \frac{1-e_c 2}{e_c 2 A_c 2}\right)} + A_c 2 h_{c1c2} \left(T_c 1 - T_c 2\right)$$

$$- A_c 2 e_c 2 \; \sigma \left(T_c 2^4 - T_s^4\right) - A_c 2 h_w \left(T_c 2 - T_s\right) \qquad (3)$$

First term on the right is heat absorbed by second cover from sun, second heat gain by radiation from first cover, third heat gain by convection from first cover, fourth heat loss to atmosphere by radiation and fifth heat loss to surroundings by convection.

Heat Transfer Coefficients

Estimates of the convective heat transfer coefficient between the plate and first glass cover, first

$$N_u = 1 + 1.44\left[1 - \frac{1708}{R_a}\right]^{+} + \left[\left(\frac{R_a}{5830}\right)^{1/3} - 1\right]^{+}$$

and second glass cover was made using Holland's correlation .

$$h = \frac{N_u\, k}{d}$$

Exponent (+) indicates that only positive values of the quantity in brackets is to be used, set to zero, if negative. 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 from second cover to atmosphere is obtained by following relation. Wind speed has been taken to be 1 m/s.

$$h_w = 5.7 + 3.8\ V$$

Table 2 lists all the parameters and coefficients used in simulation.

Feedback Control

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-1**.

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

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

Insolation and Ambient Temperature

Tables 3 and 4 show the list of eleven locations and also the Fourier Coefficient for global insolation and ambient temperature series computed using data from [2] and procedure followed in [5]. Month indicated in each is the one when higher back-up is needed.

Estimate of Back-up Strength

Figure 2 shows a typical hour- of- day and plate temperature graph. January is the coolest month in Ahmedabad. Although, insolation is lowest here in August, it is in January that higher back-up is needed. As seen , the plate temperature in an unassisted cooker will reach 120°C but only very near noon. making it infeasible to do the cooking. A back-up of 126 W would be needed to enable plate temperature to reach 120°C from 9:00 A.M. onwards. This value is arrived at by making several simulation runs, starting with a low value say 50 W and raising it by a small amount successively.

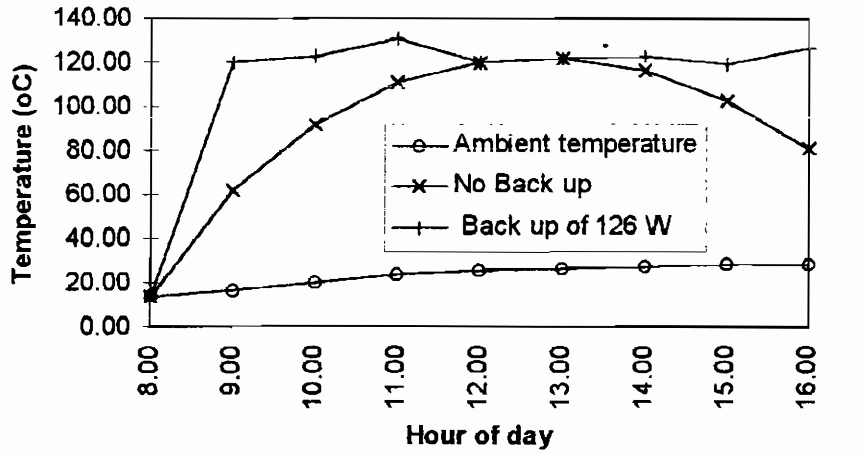

Plate Temperature
(Simulated for Ahmedabad-January)

Figure 2

Similar simulations were done for all the eleven locations. **Table 5** shows the estimates . In Delhi which is the northern most location among the eleven, the month of lowest insolation is December. January is the coolest month. Moreover, the conditions in both months are so close that, as shown in the first row of the table, a back up of 148 W is necessary to enable cooking in both.

As one moves towards south, the size of back-up tends to decrease. For instance, in Trivandrum it works out to just 110 W. Generally, at lower latitudes, size of back-up is lower unless the ambient temperatures are low.

Conclusion

Estimates of back-up source strength required have been made for eleven locations in the country. Estimates were made using a specially designed simulation model of the cooker and local climatic data.

A 148 W source would be needed in Delhi. In Trivandrum, the southern most location considered here, one would need a source of 100 W. All other locations fall between these two.

It must be kept in view that the estimates are for the power made available to absorber plate. In actual installation some losses will occur between the heater and plate. These will need to be taken into account in actual design.

Table 1

List of Symbols

I_h	Insolation (global) on horizontal surface (W/m^2)
T_p, T_{c1}, T_{c2}, T_a, T_s	Temperatures of absorber plate, glass covers, ambient air and sky (°K)
a_p, e_p	Absorptivity and emissivity of plate, dimensionless
a_{c1}, a_{c2}, e_{c1}, e_{c2}	Absorptivity and emissivity of glass covers, dimensionless
t	Transmissivity (solar) of glass, dimensionless
$(ta_p)_e$	Transmissivity-absorptivity product effective for two-cover system
$(mc)_p$,	Heat capacity of absorber plate (J/°K)
$(mc)_{c1}$, $(mc)_{c2}$	Heat capacity of glass covers (J/°K)
h_{pc1}	Convective heat transfer coefficient between plate and first cover (W/m^2K)
h_{c1c2}	Convective heat transfer coefficient between first and second cover (W/m^2K)
h_w	Convective heat transfer coefficient between top cover and atmosphere (W/m^2K)
U_b, U_s	Bottom and side loss coefficient (W/m^2K)
s	Stefan-Boltzman constant (W/m^2-$°K^4$)
$F_{p\text{-}c1}$	View factor from plate to first cover, dimensionless
$F_{c1\text{-}c2}$	View factor from first to second cover, dimensionless
$F_{t\text{-}c1}$	View factor between absorber tray and first cover; treated as two surface enclosure
A_p, A_{c1}, A_{c2}, A_b, A_s, A_t	Areas of absorber plate, glass covers, bottom side and tray (m^2) ($A_t = A_p + A_s$)
k	Thermal conductivity of insulation (W/m°K)
d	Thickness of insulation (m)
N_u, R_a	Nusselt and Rayleigh numbers, dimensionless
T	Time
V	Wind speed (m/s)

Table 2

Parameters used in Simulation

$(mc)_p$	396 J/°K (m = 450 g; c = 0.88 J/g°K)
$(mc)_{c1}$	931 J/°K (m = 1390 g; c = 0.67 J/g°K)
$(mc)_{c2}$	971 J/°K (m = 1450 g; c = 0.67 J/g°K)
A_p	0.1806 m^2 (42.5 X 42.5 cm)
A_t	0.3166 m^2
A_{c1}	0.1892 m^2 (43.5 X 43.5 cm)
A_{c2}	0.2209 m^2 (47 X 47 cm)
A_b	0.1806 m^2
A_s	0.136 m^2 (4 [42.5 X 8 cm])
t_g	0.85 (t_{c1}, t_{c2} = t_g)
a_g	0.08 (a_{c1}, a_{c2} = a_g)
e_g	0.88 (e_{c1}, e_{c2} = e_g)
a_p	0.93
e_p	0.93
$(ta)_e$	0.806 (for two-cover system, from Duffie and Beckman, p.231, equation 6.9.10)
s	5.669 X 10^{-8} $W/m^{2o}K^4$
h_{pc1}	2.31 $W/m^{2o}K$
h_{c1c2}	4.12 $W/m^{2o}K$
h_w	9.5 $W/m^{2o}K$
U_b	1.13 $W/m^{2o}K$
U_s	1.13 $W/m^{2o}K$
F_{pc1}	0.597 (from catalogue)
F_{c1c2}	1 (from catalogue)
k	0.052 W/m°K (glass wool)
d	4.6 cm (side and bottom equal)

Table-3
Fourier coefficient for air temperature series

Place, Design Month	n	0	1	2	3	4	5	6
Delhi, January	A	13.58	-2.83	0.69	-0.14	0.08	0.04	-0.18
	B		-4.24	1.38	0.17	-0.47	0.22	-0.07
Shillong, January	A	9.83	-2.89	1.13	-0.11	-0.26	0.12	0.05
	B		-1.17	0.08	0.24	-0.07	-0.03	0.08
Ahmedabad, January	A	20.01	-3.92	0.89	-0.44	0.23	0.07	-0.02
	B		-6.07	1.63	0.35	-0.48	0.20	0.08
Calcutta, December	A	18.90	-4.53	1.42	0.01	-0.32	0.10	0.05
	B		-3.16	0.85	0.29	-0.42	0.09	0.14
Bhavnagar, January	A	20.38	-1.89	0.73	-0.34	0.28	-0.09	-0.02
	B		-5.39	1.43	-0.22	-0.25	0.09	-0.02
Nagpur, December	A	19.36	-4.46	1.33	-0.13	-0.07	0.02	-0.08
	B		-4.38	1.40	0.38	-0.56	0.14	0.13
Bombay, January	A	23.40	-3.65	1.38	-0.54	0.03	0.07	-0.12
	B		-3.90	0.83	0.04	-0.38	0.13	0.12
Pune, January	A	21.13	-4.04	1.06	-0.51	0.15	0.17	-0.20
	B		-6.71	1.54	0.34	-0.45	0.13	0.01
Goa, July	A	26.22	-0.72	0.24	-0.04	0.03	0.00	0.00
	B		-0.55	0.22	-0.01	-0.03	0.01	0.02
Bangalore, December	A	20.36	-2.77	0.80	-0.07	-0.04	0.02	-0.06
	B		-2.94	0.98	0.11	-0.25	0.09	0.08
Trivandrum, November	A	26.23	-1.74	0.76	-0.22	-0.03	0.06	-0.04
	B		-1.49	0.29	0.12	-0.19	0.03	0.07

Table 4
Fourier coefficient for Global Solar Radiation series

Place, Design Month	n	0	1	2	3	4	5	6
Delhi, January	A	164.46	-275.54	154.03	-42.79	-9.62	12.18	-0.67
	B		-36.08	40.67	-16.75	-6.42	9.61	-0.42
Shillong, January	A	167.08	-282.59	163.18	-43.39	-9.21	15.61	-2.67
	B		-14.30	13.16	0.21	-9.74	7.19	0.50
Ahmedabad, January	A	204.00	-338.23	181.47	-42.61	-17.21	14.71	1.42
	B		-41.58	44.65	-14.90	-10.61	10.81	1.58
Calcutta, December	A	169.63	-283.45	156.93	-42.25	-10.37	11.67	0.25
	B		-38.25	43.26	-18.17	-6.28	9.89	-0.50
Bhavnagar, January	A	213.92	-352.13	183.66	-38.05	-20.33	13.87	3.17
	B		-42.34	44.51	-13.65	-10.97	9.12	3.67
Nagpur, December	A	194.33	-321.82	171.95	-39.98	-15.83	12.60	2.33
	B		-40.88	44.30	-15.63	-9.24	9.79	1.67
Bombay, January	A	209.33	-342.60	175.12	-33.88	-19.71	12.15	3.08
	B		-51.30	54.82	-18.97	-10.32	9.75	3.42
Pune, January	A	221.17	-363.57	189.30	-40.41	-18.37	12.54	2.83
	B		-47.73	50.26	-15.86	-11.62	10.27	2.83
Goa, July	A	165.33	-259.61	114.23	-11.63	-11.79	1.17	3.25
	B		-31.41	26.47	-1.24	-8.59	1.00	3.75
Bangalore, December	A	185.88	-302.81	153.13	-30.56	-13.79	8.57	0.58
	B		-40.15	40.04	-10.24	-9.17	3.82	6.33
Trivandrum, November	A	205.50	-330.76	158.11	-20.31	-24.71	13.08	1.08
	B		-40.40	39.43	-9.60	-7.87	1.27	7.75

Table 5

Estimates of Backup Strength required

Place	Latitude	Longitude	Month of Lowest radiation	Back up strength (Watts)	Month of lowest temp.	Back up strength (Watts)
Delhi	28° 35'	77° 12'	December	148	January	**148**
Shillong	25° 34'	91° 53'	September	106	January	**134**
Ahmedabad	23° 04'	72° 38'	August	100	January	**126**
Calcutta	22° 39'	88° 27'	December	**123**	January	123
Bhavnagar	21° 45'	72° 35'	August	95	January	**113**
Nagpur	21° 06'	79° 03'	August	95	December	**126**
Bombay	19° 07'	72° 51'	July	107	January	**117**
Pune	18° 32'	73° 51'	August	90	January	**118**
Goa	15° 29'	73° 49'	July	105	January	**105**
Bangalore	12° 58'	77° 35'	August	90	December	**113**
Trivandrum	8° 29'	76° 57'	November	**110**	July	100

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