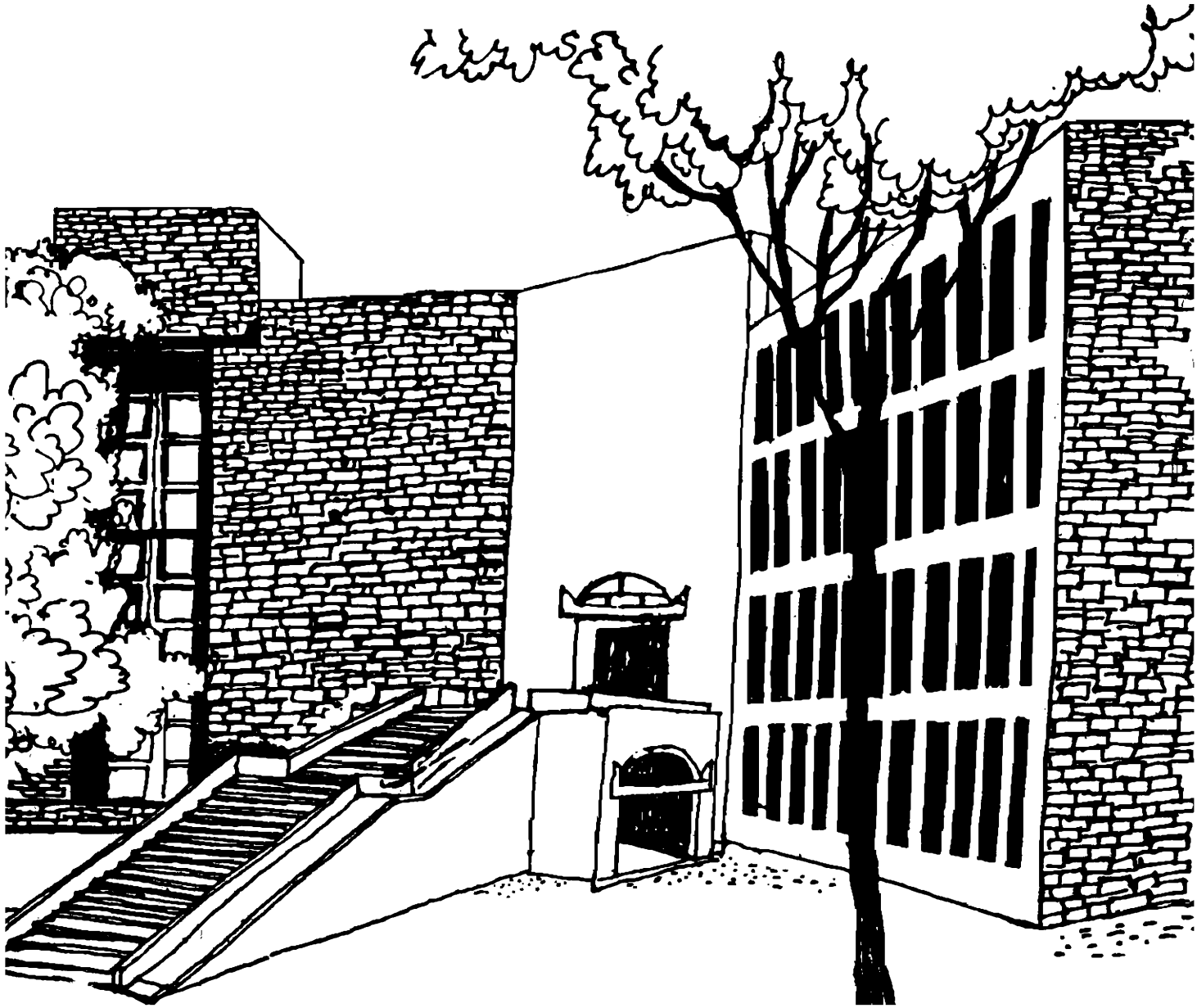
विद्याविनियोगाद्विकासः
IIM
AHMEDABAD

Working Paper



FOURIER REPRESENTATION OF AMBIENT TEMPERATURE AND SOLAR RADIATION

By

Girja Sharan
M. Krishna Kumar

W P NO.1239
March 1995

INDIAN INSTITUTE OF MANAGEMENT
AHMEDABAD - 380 015
INDIA

Fourier Representation of Ambient Temperature and Solar Radiation

Girja Sharan **M. Krishna Kumar**

Centre for Management in Agriculture
Indian Institute of Management, Ahmedabad

Introduction

In the course of constructing a transient simulation model of the box-type solar cooker, a need arose for analytic expressions of ambient temperatures during the day and global solar radiation. Mean hourly ambient temperature data for several places is given in the 'Handbook of Solar Radiation Data for India'(**1**). Locations in and immediate neighbourhood of Gujarat were of interest to us. These include Ahmedabad (23°04'N, 72°38'E), Bhavnagar (21°45'N, 72°11'E) Bombay (19°07'N, 72°51'E) and Jodhpur (26°18'N, 73°01'E). Accordingly, data of Ahmedabad, Bhavnagar, Bombay and Jodhpur (given in **Tables 16, 56, 78 and 150 respectively of Handbook**) were put through Fourier analysis. Temperature data in the Handbook is based on ten year observation for Ahmedabad, three years for Bhavnagar, ten years for Bombay and nine years for Jodhpur.

Mean hourly global solar radiation is available in the Handbook for each month at the above places (**Tables 1 to 12** for Ahmedabad, **42-53** :Bhavnagar, **64-75** :Bombay and **135-146** :Jodhpur). This data too has been subject to Fourier analysis. Results may be useful to those working on solar thermal appliances. These may also be useful to others working on crop growth models, green house models etc.

Ambient Air Temperatures

Equation 1 gives the Fourier series representation for ambient temperature.

$$T(t) = A_0 + \sum_{1}^{n} \left[A_m \cos\left(m \frac{\pi}{12} t\right) + B_m \sin\left(m \frac{\pi}{12} t\right) \right] \qquad \ldots(1)$$

where
- T — ambient temperature (°C)
- t — time in hours, midnight being the origin
- A_m, B_m — Fourier coefficients
- n — number of harmonics

Table A1 of appendix gives the first six harmonics for Ahmedabad and **Tables A2, A3 and A4** for Bhavnagar, Bombay and Jodhpur. Data from Handbook and computed values (using **equation 1**) with one and three harmonics is shown as illustration for January month at Ahmedabad (**Figure 1**). Visual examination suggests that the representation with three harmonics is quite good and would

Figure 1

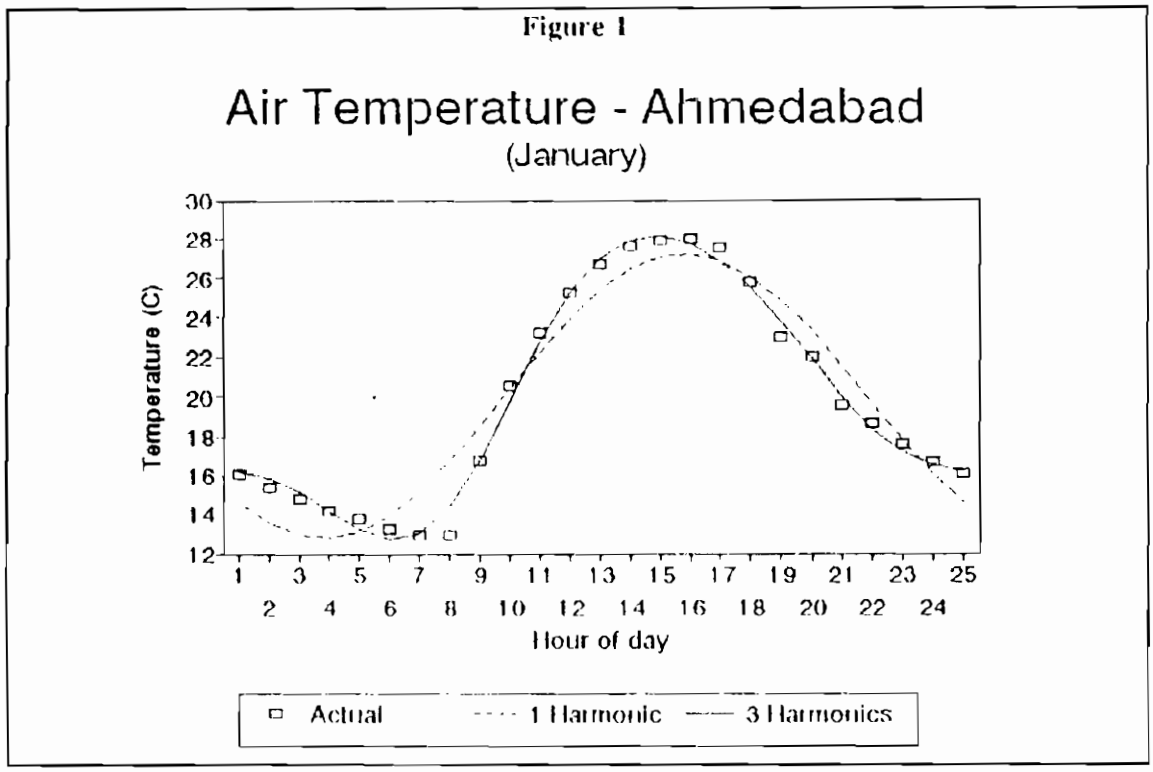
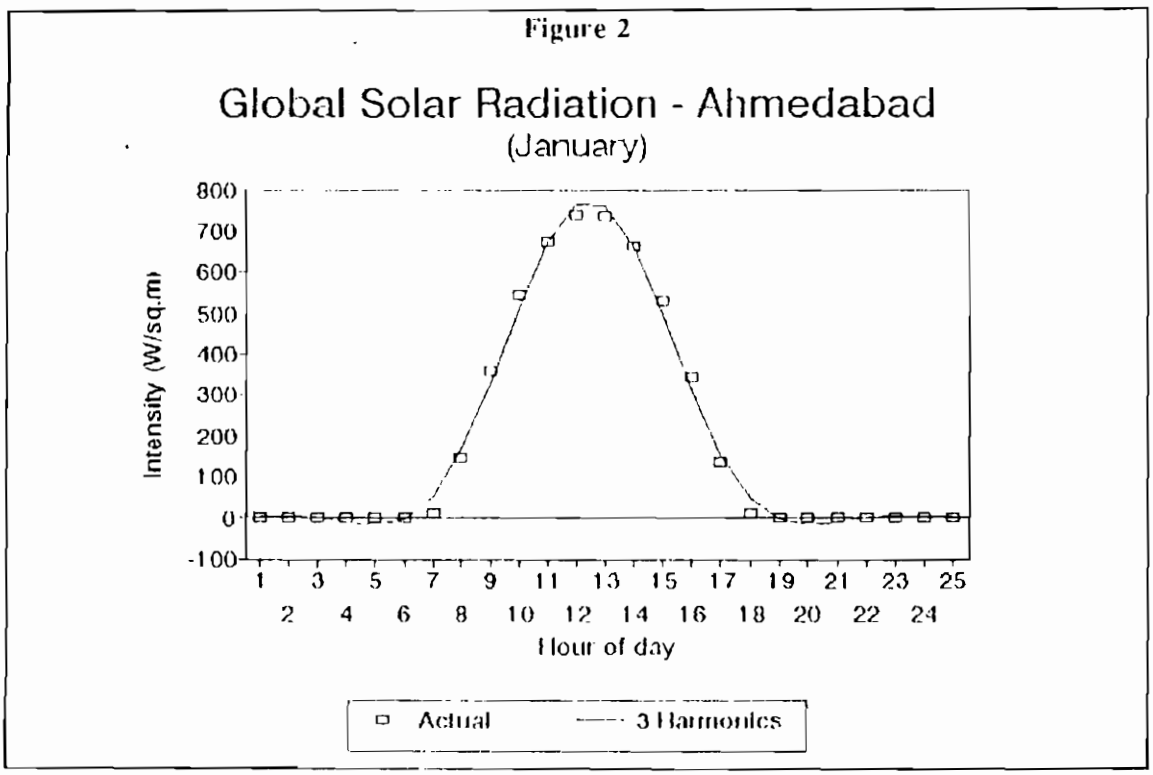


Figure 2



normally be sufficient. Inclusion of more terms will of course improve it further. That is why six terms are tabulated, in case needed. The maximum absolute deviation with three harmonics varied from 1 % to 11 % for Ahmedabad. The corresponding values for other locations were: Bhavnagar - 1 % to 4 %, Bombay - 1 % to 6 % and Jodhpur - 1 % to 5 %.

Global Solar Radiation

The Handbook gives the mean hourly global, diffuse and direct solar radiation separately. Radiation data is based on more than ten years observation. Here only global solar radiation has been analysed. **Equation 1** can again be used with left hand side replaced by global solar radiation (W/m^2).

Appendix **Tables A5 to A8** give the first six harmonics for Ahmedabad, Bhavnagar, Bombay and Jodhpur respectively. Again the representation with three harmonics is quite good. The maximum absolute deviation varied from 4 % to 16 % for Ahmedabad with three harmonics. The corresponding values for other cities were: Bhavnagar - 5 % to 11 %, Bombay - 5 % to 11 % and Jodhpur - 4 % to 23 %. High deviation occurs usually at sharp corners.

For illustration, graph of global solar radiation using three harmonics is given in **Figure 2** for January at Ahmedabad.

It may be mentioned here that those working on solar thermal systems will be interested only in day time values of temperature. It would be equally convenient to develop sine or cosine series in half interval, twelve hours starting with say 6 a.m. Those dealing with green house modelling, crop growth etc. will be interested in night time values as well. Expressions given here may be more convenient for them.

References

1. Mani Anna. Handbook of Solar Radiation Data for India. Allied, 1980.
2. Hildebrand F.B. Introduction to Numerical Analysis. Mcgraw Hill, 1956.

Appendices

Table A1
Fourier Coefficients for Air Temperature Series
Ahmedabad

	n	0	1	2	3	4	5	6
Jan	A	20.01	-3.92	0.89	-0.44	0.23	0.07	-0.18
	B		-6.07	1.63	0.35	-0.48	0.20	0.08
Feb	A	23.13	-3.97	0.98	-0.36	0.35	0.14	-0.27
	B		-6.70	1.67	0.60	-0.48	0.17	0.15
Mar	A	27.37	-3.54	0.79	-0.40	0.20	0.17	-0.18
	B		-6.42	1.36	0.59	-0.44	-0.05	0.09
Apr	A	31.55	-2.94	0.69	-0.30	0.16	0.13	-0.08
	B		-6.12	1.15	0.55	-0.31	-0.05	0.06
May	A	33.77	-2.53	0.31	-0.08	0.11	0.13	-0.04
	B		-5.90	1.20	0.39	-0.14	-0.09	0.03
Jun	A	31.83	-2.08	0.06	0.11	0.04	0.00	-0.08
	B		-3.74	1.07	0.20	-0.12	-0.08	0.06
Jul	A	28.74	-1.24	0.08	0.04	0.00	0.01	-0.04
	B		-2.07	0.54	0.10	-0.12	-0.03	0.06
Aug	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
Sep	A	28.00	-1.76	0.34	0.00	0.04	0.01	-0.08
	B		-2.60	0.71	0.13	-0.17	-0.03	0.08
Oct	A	27.69	-4.02	1.02	-0.13	0.03	0.07	-0.18
	B		-4.65	1.33	0.55	-0.51	0.01	0.19
Nov	A	24.27	-4.73	1.27	-0.26	0.03	0.07	-0.17
	B		-5.31	1.48	0.48	-0.65	0.11	0.23
Dec	A	21.03	-4.20	0.99	-0.26	0.20	0.00	-0.23
	B		-5.47	1.70	0.31	-0.58	0.08	0.16

Table A2
Fourier Coefficients for Air Temperature Series
Bhavnagar

	n	0	1	2	3	4	5	6
Jan	A	20.38	-1.89	0.73	-0.34	0.28	-0.09	-0.13
	B		-5.39	1.43	-0.22	-0.25	0.09	-0.03
Feb	A	23.58	-2.19	0.98	-0.36	0.24	-0.06	-0.11
	B		-5.17	1.06	0.05	-0.44	0.06	0.05
Mar	A	27.99	-2.37	0.98	-0.39	0.22	0.06	-0.11
	B		-5.30	1.07	0.17	-0.34	0.11	-0.04
Apr	A	30.60	-2.22	1.07	-0.18	0.13	0.00	-0.02
	B		-4.37	0.88	0.25	-0.19	-0.05	0.08
May	A	32.14	-2.56	0.96	-0.06	-0.12	0.11	-0.08
	B		-4.52	1.02	-0.15	-0.27	0.00	-0.01
Jun	A	29.74	-2.05	0.50	-0.11	0.10	0.02	-0.05
	B		-2.26	0.67	0.08	-0.09	0.06	-0.05
Jul	A	27.85	-1.52	0.46	-0.23	0.05	0.03	0.03
	B		-1.51	0.40	0.14	-0.11	0.08	0.02
Aug	A	27.31	-1.46	0.42	-0.13	0.01	0.04	0.02
	B		-1.95	0.52	0.06	-0.05	-0.04	0.08
Sep	A	27.38	-2.22	0.84	-0.17	0.05	0.07	-0.08
	B		-2.63	0.70	0.00	-0.14	-0.02	0.04
Oct	A	29.63	-2.65	1.07	-0.32	0.08	-0.05	-0.02
	B		-4.00	0.69	0.25	-0.39	0.17	0.04
Nov	A	26.93	-1.95	0.88	-0.28	0.05	0.06	-0.13
	B		-3.35	0.81	0.16	-0.37	0.09	0.06
Dec	A	22.41	-2.24	1.10	-0.33	0.22	-0.08	-0.08
	B		-4.89	1.08	0.03	-0.35	0.15	-0.02

Table A3
Fourier Coefficients for Air Temperature Series
Bombay

	n	0	1	2	3	4	5	6
Jan	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
Feb	A	24.55	-3.81	1.38	-0.65	0.05	0.09	-0.16
	B		-4.01	0.74	0.24	-0.48	0.14	0.10
Mar	A	26.44	-3.17	1.18	-0.43	-0.02	0.07	-0.08
	B		-3.10	0.45	0.35	-0.40	0.03	0.12
Apr	A	28.31	-2.58	0.99	-0.15	-0.10	0.07	0.00
	B		-2.34	0.14	0.40	-0.30	-0.03	0.12
May	A	29.75	-1.95	0.70	0.00	-0.11	0.05	0.01
	B		-1.48	0.20	0.25	-0.16	-0.04	0.08
Jun	A	28.71	-1.17	0.36	-0.01	-0.04	0.00	0.02
	B		-1.01	0.23	0.06	-0.04	-0.04	0.08
Jul	A	27.26	-0.68	0.19	-0.02	-0.04	0.03	-0.02
	B		-0.57	0.11	0.01	-0.06	0.00	0.02
Aug	A	26.80	-0.72	0.22	-0.06	0.03	0.01	0.00
	B		-0.59	0.18	0.06	-0.07	0.01	0.01
Spt	A	26.87	-1.18	0.35	-0.07	-0.04	0.03	-0.03
	B		-1.14	0.29	0.05	-0.10	-0.04	0.08
Oct	A	27.58	-2.64	0.84	-0.28	-0.08	0.05	-0.02
	B		-2.41	0.48	0.14	-0.24	0.05	0.13
Nov	A	26.64	-3.55	1.21	-0.27	-0.18	0.05	0.04
	B		-3.21	0.74	0.11	-0.36	0.17	0.11
Dec	A	24.68	-3.51	1.21	-0.39	-0.10	0.09	-0.06
	B		-3.43	0.74	0.00	-0.32	0.14	0.11

Table A4
Fourier Coefficients for Air Temperature Series
Jodhpur

	n	0	1	2	3	4	5	6
Jan	A	17.12	-2.53	0.67	-0.29	0.27	-0.08	-0.03
	B		-5.19	1.82	-0.27	-0.06	0.02	-0.06
Feb	A	20.64	-2.67	0.83	-0.40	0.42	-0.08	-0.09
	B		-5.84	1.71	0.05	-0.26	0.02	-0.05
Mar	A	26.29	-2.89	0.98	-0.49	0.23	0.10	-0.12
	B		-5.85	1.38	0.26	-0.28	0.03	0.05
Apr	A	31.37	-2.94	1.02	-0.50	0.09	0.15	-0.04
	B		-5.68	1.03	0.42	-0.25	-0.06	0.05
May	A	34.50	-2.32	0.78	-0.34	-0.03	0.23	-0.03
	B		-5.43	0.90	0.42	-0.22	-0.07	0.15
Jun	A	34.07	-1.08	0.32	-0.11	0.02	0.03	0.01
	B		-4.36	0.87	0.08	-0.05	0.01	0.00
Jul	A	31.06	-1.17	0.15	-0.07	0.01	0.00	-0.03
	B		-2.89	0.65	0.07	-0.05	-0.02	0.01
Aug	A	29.80	-1.21	0.23	-0.10	0.03	0.04	-0.05
	B		-2.66	0.64	0.03	-0.09	0.02	-0.01
Spt	A	29.06	-1.97	0.51	-0.14	0.02	0.05	-0.06
	B		-3.28	0.80	0.11	-0.14	0.00	0.05
Oct	A	27.92	-3.41	1.15	-0.39	0.20	0.02	-0.11
	B		-5.12	1.49	0.26	-0.38	0.07	0.08
Nov	A	22.58	-3.42	1.15	-0.41	0.23	-0.18	-0.05
	B		-5.18	1.80	-0.01	-0.30	0.06	0.07
Dec	A	18.46	-2.81	0.63	-0.24	0.22	-0.20	-0.03
	B		-5.12	1.92	-0.29	-0.14	0.05	0.15

Table A5
Fourier Coefficients for Global Solar Radiation Series
Ahmedabad

	n	0	1	2	3	4	5	6
Jan	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
Feb	A	240.63	-392.23	197.26	-35.04	-23.92	13.02	4.58
	B		-48.16	48.42	-11.77	-14.29	9.54	4.67
Mar	A	280.71	-448.12	207.89	-23.61	-28.71	8.56	7.25
	B		-54.54	50.50	-7.34	-16.09	5.54	7.17
Apr	A	305.33	-476.38	201.47	-9.08	-29.33	2.20	8.17
	B		-57.02	47.79	-1.48	-15.88	0.53	8.00
May	A	316.54	-485.23	191.02	-0.06	-26.46	-2.29	7.08
	B		-62.47	50.45	-0.85	-14.36	-1.55	6.50
Jun	A	265.71	-405.17	156.52	0.90	-20.75	-1.65	3.75
	B		-55.21	45.48	-3.41	-9.81	-1.78	4.50
Jul	A	201.42	-307.80	119.41	1.85	-18.12	-0.55	4.58
	B		-44.68	37.99	-4.22	-8.01	-0.59	3.75
Aug	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
Sep	A	230.83	-364.81	162.70	-13.87	-23.04	5.32	4.42
	B		-49.01	44.06	-4.69	-14.94	4.43	6.08
Oct	A	240.25	-388.49	189.58	-29.41	-23.54	9.85	5.83
	B		-47.73	46.29	-8.95	-15.08	8.26	5.33
Nov	A	207.21	-342.21	181.09	-40.68	-17.42	13.32	2.25
	B		-39.12	40.72	-11.58	-11.55	9.81	2.33
Dec	A	190.88	-318.26	174.50	-44.73	-13.92	14.03	0.58
	B		-38.45	42.04	-15.03	-9.38	10.78	0.67

Table A6
Fourier Coefficients for Global Solar Radiation Series
Bhavnagar

	n	0	1	2	3	4	5	6
Jan	A	213.92	-352.13	183.66	-38.05	-20.33	13.87	3.17
	B		-42.33	44.51	-13.65	-10.97	9.12	3.67
Feb	A	248.17	-402.51	198.52	-32.01	-25.00	11.35	6.25
	B		-46.65	45.48	-9.07	-14.58	7.80	5.75
Mar	A	286.29	-454.85	206.60	-19.37	-29.79	6.26	9.42
	B		-51.91	46.61	-4.83	-15.52	3.25	8.33
Apr	A	302.58	-470.94	196.67	-6.17	-29.62	0.87	9.08
	B		-50.08	40.35	0.93	-13.93	-1.37	7.42
May	A	316.25	-484.54	189.81	1.44	-26.83	-3.40	7.92
	B		-51.72	38.48	4.45	-13.42	-3.92	7.25
Jun	A	250.50	-377.93	137.34	10.74	-23.33	-3.16	6.83
	B		-42.83	29.01	7.86	-13.13	-2.47	4.83
Jul	A	191.75	-292.16	111.38	4.46	-19.50	1.33	3.17
	B		-24.63	12.61	11.87	-12.12	-1.64	3.67
Aug	A	179.21	-278.37	115.63	-3.48	-18.08	2.89	2.33
	B		-24.89	15.75	8.24	-11.84	-1.23	6.42
Sep	A	227.17	-359.83	161.89	-14.82	-22.42	4.28	6.83
	B		-33.69	25.45	6.24	-17.46	4.04	5.83
Oct	A	245.88	-396.34	190.75	-26.65	-25.92	10.51	5.83
	B		-44.66	42.28	-6.91	-13.86	5.45	6.92
Nov	A	216.96	-355.51	182.32	-35.28	-20.96	12.59	4.17
	B		-43.89	45.76	-13.79	-10.90	8.53	3.92
Dec	A	199.08	-329.21	174.69	-38.87	-18.08	13.96	2.17
	B		-40.65	43.47	-14.21	-10.54	10.19	2.17

Table A7
Fourier Coefficients for Global Solar Radiation Series
Bombay

	n	0	1	2	3	4	5	6
Jan	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
Feb	A	240.50	-388.68	189.37	-29.35	-23.33	9.83	5.58
	B		-61.22	62.97	-18.74	-13.57	9.84	4.92
Mar	A	267.79	-426.38	195.96	-21.50	-25.87	6.01	7.83
	B		-66.12	64.85	-15.93	-14.51	6.79	6.58
Apr	A	290.71	-455.87	197.70	-14.59	-25.00	1.91	6.92
	B		-74.85	70.68	-15.31	-14.43	4.15	6.33
May	A	299.13	-462.91	192.17	-12.68	-18.33	-2.45	4.42
	B		-78.79	70.59	-11.56	-15.59	4.22	3.17
Jun	A	213.17	-328.57	133.66	-5.44	-16.04	0.42	2.50
	B		-54.08	47.87	-7.58	-9.89	1.76	2.83
Jul	A	170.25	-264.30	111.21	-8.42	-10.62	-0.85	2.58
	B		-43.49	39.37	-7.25	-7.58	1.32	2.58
Aug	A	163.92	-258.19	115.25	-13.55	-10.54	0.77	3.33
	B		-36.68	32.99	-5.33	-7.00	0.03	4.67
Spt	A	203.46	-321.48	143.07	-11.19	-22.42	7.22	2.58
	B		-60.41	62.39	-22.29	-4.76	2.73	3.67
Oct	A	225.04	-360.99	170.51	-20.96	-25.33	11.16	3.33
	B		-59.73	61.80	-20.45	-8.95	6.04	4.92
Nov	A	209.50	-342.66	174.90	-33.96	-19.29	12.16	2.17
	B		-46.24	47.91	-14.11	-11.62	9.04	3.83
Dec	A	199.92	-329.35	172.87	-38.06	-16.42	12.03	2.17
	B		-45.98	49.05	-16.43	-10.54	10.05	2.67

Table A8
Fourier Coefficients for Global Solar Radiation Series
Jodhpur

	n	0	1	2	3	4	5	6
Jan	A	195.21	-324.65	176.18	-43.10	-15.96	15.07	0.17
	B		-41.52	45.45	-16.56	-9.31	10.57	1.42
Feb	A	231.13	-377.25	190.84	-34.74	-23.58	13.93	4.25
	B		-46.67	47.15	-12.21	-12.99	9.28	4.17
Mar	A	270.58	-431.99	200.24	-22.05	-28.62	8.29	8.25
	B		-49.97	45.85	-5.92	-15.37	5.02	7.25
Apr	A	298.50	-465.80	197.12	-8.94	-28.79	2.29	7.92
	B		-52.28	43.25	-0.71	-14.07	-0.96	8.25
May	A	313.04	-478.56	185.68	3.07	-27.71	-1.97	7.25
	B		-55.73	43.18	1.67	-12.92	-3.01	6.50
Jun	A	292.29	-443.03	167.19	2.56	-20.33	-4.49	6.17
	B		-56.65	43.06	1.36	-11.11	-2.94	3.75
Jul	A	247.54	-375.95	142.91	2.04	-18.37	-2.80	4.83
	B		-50.10	38.75	0.37	-9.31	-3.82	5.58
Aug	A	229.83	-354.50	143.35	-2.55	-20.67	0.21	5.67
	B		-47.62	39.25	-1.43	-11.40	-0.62	6.00
Spt	A	253.00	-400.18	179.02	-15.20	-26.46	6.64	6.25
	B		-48.27	42.68	-3.64	-14.94	3.91	6.58
Oct	A	242.67	-391.15	189.97	-29.68	-25.29	13.12	6.00
	B		-48.73	46.22	-9.96	-11.91	7.16	4.00
Nov	A	202.88	-335.10	177.08	-38.73	-18.87	14.51	1.83
	B		-41.54	43.97	-13.66	-11.33	10.32	2.58
Dec	A	183.38	-306.52	169.41	-44.03	-14.37	15.81	-1.33
	B		-39.66	44.44	-17.59	-8.30	11.52	-0.42