ROYAL OBSERVATORY, HONG KONG

TECHNICAL NOTE NO. 14

SOLAR DATA FOR HONG KONG

By

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First published	October	1955
Reprinted	November	1962
Revised Edition	October	1976
Revised Edition	October	1978

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1. TIME IN HONG KONG

The determination of the sun's position in the sky, relative to an observer at a station, is one of the fundamental methods for measuring time at the station. In Section 2 we are concerned with the position of the sun as seen from Hong Kong and so it is pertinent to define some of the systems by which time may be reckoned in Hong Kong.

Hong Kong Time †

This time system is specified in the Interpretation and General Clauses Ordinance. Cap. 1 of Laws of Hong Kong, Section 67 is quoted in full below:-

> 67. (1) Whenever any expression of time occurs in any Ordinance the time referred to is Hong Kong Time.
>
> (2) For the purposes of subsection (1), "Hong Kong Time" means the time used for general purposes throughout Hong Kong namely, 8 hours, or such other period as may be determined by the Legislative Council by resolution, in advance of Greenwich Mean Time.
>
> (3) A resolution of the Legislative Council under subsection (2) may determine Hong Kong Time for the whole or part of a year.
>
> (4) Nothing in this section shall affect the use of Greenwich Mean Time for the purposes of astronomy, meteorology, navigation or aviation, or affect the construction of any document mentioning or referring to a point of time in connexion with any of these purposes.

Local Mean Solar Time

This is a measure of time based on the position of the "mean sun" at Hong Kong. The mean sun is an imaginary point which moves uniformly eastwards in the celestial equator, completing its circuit in the same period at the true (or apparent) sun in the ecliptic. The mean solar day is of uniform length. On this system, noon (local mean time) occurs when the centre of the mean sun crosses the meridian through Hong Kong. 24 hours is equivalent to 360° of longitude. Since the longitude of Hong Kong is 114° 10' 18.75"E (at the Royal Observatory Trig-Station) and Hong Kong Time is the mean time of 120°E, Local Mean Solar Time is 23 min 18.75 s behind Hong Kong Time (or 7 h 36 min 41.25 s in advance of Greenwich Mean Time).

True (or Apparent) Solar Time

Apparent solar days are of irregular length. The two main causes of this are the eccentricity of the earth's orbit and the obliquity of the ecliptic. True Solar Time is defined by the position of the true sun. It may be obtained by adding the Equation of Time to the Local Mean Solar Time.

† See also Appendix

True Solar Time = (Local Mean Solar Time) + (Equation of Time)

= (Hong Kong Time) - (23 min 18.75 s) + (Equation of time)

= (Hong Kong Time) - H

where H = 23 min 18.75 s - (Equation of Time)

In Table 1 values of H are given to the nearest minute for each day of the year. The table is based on Equation of Time values for 1977 but may be used for any year if an accuracy of one or two minutes will suffice.

2. SOLAR ELEVATION AND AZIMUTH

The solar elevation above the celestial horizon, h, and azimuth from true north, z, may be expressed in terms of True Solar Time, the Apparent Declination of the sun, d, and the latitude, ϕ

$$\sin h = \sin \phi \sin d + \cos \phi \cos d \cos t$$

$$\sin z = -\sin t \cos d \sec h$$

where ϕ is the latitude;

t is the local hour angle of the sun. It is measured from the local meridian and increases as the day progresses. 15° is equivalent to one hour. At 0600 true solar time, $t = 270^{\circ}$; by noon, $t = 360^{\circ}$; and by 1800, $t = 90$.

The Apparent Declination of the sun (d) is the angular distance of its centre from the celestial equator as measured from the centre of the earth, and is considered to be positive to the north of the celestial equator. Table 2 gives the sun's Apparent Declination for each day of the year. Values are for 1977 but may be used for any year with a possible error of one or two degrees.

The Equinoxes ($d = 0^{\circ}$) occur on about 21 March (Vernal Equinox) and 23 September (Autumnal Equinox). The Solstices occur on about 22 June (Summer Solstice $d = 23^{\circ}\ 27'$) and 22 December (Winter Solstice; $d = -23^{\circ}\ 27'$). It is of interest to note that the sun at noon (True Solar Time) is in the north from about 3 June to 9 July; for during this period the sun's declination is greater than the latitude of Hong Kong ($22^{\circ}\ 18'\ 12.82''$N at the Royal Observatory Trig-Station).

If the True Solar Time and Apparent Declination are known then Table 3 or Fig. 1 may be used to find the elevation and azimuth of the sun.

In Fig. 1 the concentric circles are isopleths of equal elevation. The centre of the diagram represents the zenith ($h = 90^{\circ}$) and the outer circle the celestial horizon ($h = 0^{\circ}$). The straight lines radiating from the centre are isopleths of equal azimuth. The other two sets of lines are isopleths of True Solar Time (for each hour from 0600 to 1800) and Apparent Declination (for every 5° and the Solstices).

An example will illustrate how the tables and figure may be used:-

It is required to find the solar elevation and azimuth at 1516 Hong Kong Time on 14 December.

(i) From Table 1, 1516 Hong Kong Time is 1458 True Solar Time.

(ii) From Table 2, the Apparent Declination on 14 December is -23°.

(iii) Using Table 3 or Fig. 1, we obtain $h = 27^{\circ}$ and $z = 227^{\circ}$ corresponding to 1458 True Solar Time and an Apparent Declination of -23°. In other words the sun is 27° above the SW horizon at 1516 Hong Kong Time on 14 December.

The values of h and z are of little direct use to the architect in considering the relationship between the sun's position and the features of his design. Two derived functions are of more direct application.

The first is the <u>angle of incidence</u>, i, of the sun's rays falling on a vertical surface. The angle of incidence is measured from the normal to the surface, and other factors being equal, cos i gives a measure of the energy received by the vertical surface in the same way as sin h is related to the energy received by a horizontal surface. If the outward normal to the wall bears n degrees from true north then

$$\cos i = \cos h \cos (n - z)$$

The second function of interest we will call the <u>profile angle</u>, p. This is the angle between the component of the sun's rays that lies in the vertical plane normal to the vertical surface, and the horizontal. The profile angle may be used to give an indication of the depth of penetration of the sun's rays into a room after passing through a window. If p is small then the rays will penetrate well into the room. It is also useful to know how p varies when designing overhangs to provide shade.

$$\tan p = \tan h \sec (n - z)$$

Isopleths of i and p have been plotted on transparent paper using h and (n - z) as polar co-ordinates in the same manner as h and z are used in Fig. 1. This plot may then be used as a transparent overlay in conjunction with Fig. 1 to read off i or p at any time of year and day. The overlay is enclosed inside the back cover of this Note. An example will indicate how it may be used to help in the design of overhangs:-

> A building has a wall facing 70° from true North (i.e. approximately east-northeast) in which there is a window whose sill is 2000 millimetres below the undersurface of an intended overhang outside the building. The architect wants to know how deep the overhang should be to provide shade on the window in the morning by the time the sun has risen high enough to make the heat and glare undesirable. He should place the overlay on Fig. 1 with the "outward normal to surface" arrow (for isopleths of profile angle, p) pointing in a direction 70°. It will be seen that the profile angle reaches about 49° by 0900 True Solar Time. An overhang designed with this profile angle will give shade on the window by 0923 local mean

solar time throughout the year. A deeper overhang having a smaller design profile angle would give shade earlier in the winter and earlier still in the summer. A narrower overhang would start to give shade later in the winter and later still in the summer.

For a design profile angle of 49° the overhang would be ($1800 \times$ cotangent 49°)mm, that is 1565 mm, deep.

3. SUNRISE, SUNSET AND TWILIGHT

(a) Sunrise and Sunset

Sunrise and sunset occur when the upper edge of the sun's disc appears on an unobstructed celestial horizon, with normal atmospheric refraction. Assuming a constant horizontal refraction of 34' and semi-diameter of the sun of 16', sunrise and sunset will take place when the sun's centre is 50' below the horizon.

The full lines on Fig. 2 give the Hong Kong Times of sunrise and sunset throughout the year at Hong Kong. Times vary a little from year to year but the figure may be used to obtain the times of sunrise and sunset within one or two minutes for any year. Tables of sunrise and sunset times are included in an annual publication of the Royal Observatory entitled "Astronomical Tables and Star Charts for Hong Kong".

(b) Twilight

When the sun is not too far below the horizon, light reflected and scattered by the upper atmosphere reaches the earth. The period during which this occurs is known as twilight, and is usually considered to begin (in the morning) or end (in the evening) when the true position of the centre of the sun is 18° below the horizon. At the times this occurs, known as the times of <u>Astronomical Twilight</u>, stars of the sixth magnitude will be visible near the zenith. Generally there will be no trace on the horizon of the twilight glow.

The duration of twilight varies with the seasons of the year but any degree of indirect illumination (neglecting moonlight, and the variation of cloud amount) will always be associated with the same depression of the sun below the horizon.

<u>Civil Twilight</u> is defined as the time when the depression of the sun's centre below the horizon is 6°. At this time ordinary outdoor activities are difficult without artificial light, although there will be ample light to make possible large scale operations requiring outline only. The brightest planets and stars (first magnitude) will be visible to the eye.

Nautical Twilight occurs when the depression of the sun's centre is 12°. At this time general outlines will be visible although the horizon probably cannot be distinguished; all detailed operations are impossible, and all the brighter stars are to be seen.

The times of Astronomical and Civil Twilight have been plotted on Fig. 2. The times of Nautical Twilight have been omitted but they lie approximately midway between those of Astronomical and Civil Twilight.

4. DURATION OF SUNSHINE

Daily values of the maximum possible duration of sunshine, S_o, were obtained by subtracting the times of sunrise from the times of sunset and are shown on Fig. 3.

Average daily values of the duration of sunshine, S, recorded in the period 1958-1975 were smoothed by a 33-point binomial smoothing function and the results plotted on Fig. 3. Until the end of 1960 the Campbell-Stokes sunshine recorder was located at the Royal Observatory Headquarters but it was then removed to the King's Park Meteorological Station.

The climatological spell of cloudy weather in first half of June corresponds closely with the maximum of the annual daily rainfall curve (Peacock 1972). While the maximum in the sunshine duration curve occurs early in July it will be seen that in terms of the percentage of possible hours of sunshine autumn is, on average, the sunniest time of the year.

5. SOLAR RADIATION

Fig. 3 also shows the daily total amount of direct solar radiation, I_o, falling on a horizontal surface at the top of the atmosphere above Hong Kong.

$$I_o = \int (J_o \sin h)/r^2 \, dt$$

where J_o is the solar constant and has a generally accepted value of 1 396 W/m^2;

h is the elevation of the sun's centre above the celestial horizon;

r is the radius vector of the earth, i.e. the distance of the earth from the sun.

The integration is carried out from sunrise to sunset during which time it may be assumed that r is constant.

Global solar radiation, I, is the amount of direct and scattered solar energy which reaches the surface of the earth. It is affected by:-

(i) variation in the length of the atmospheric path traversed by the sun's rays for different values of h,

(ii) absorption by water vapour, ozone, carbon dioxide, oxygen and water droplets,

(iii) scattering by water droplets, water vapour, dust and by molecular scattering.

Measurements of global solar radiation are made at King's Park Meteorological Station by a thermo-electric pyranometer (or steel thermopile dome solarimeter) located close to the sunshine recorder at King's Park Meteorological Station. A bimetallic actinograph is also installed nearby for use as a standby unit to the thermo-electric pyranometer.

Average daily values of global solar radiation, I, recorded in the period 1958-75 were smoothed by a 33-point binomial smoothing function and the results plotted on Fig. 3. It will be seen that the curve is very similar to the plot of mean daily duration of sunshine. Sham (1964) gives the following regression equation based on monthly values of sunshine duration and global solar radiation recorded in Hong Kong during the period June 1958 - August 1962.

$$I/I_0 = 0.220 + 0.575\ S/S_0$$

REFERENCES

Peacock, J.E.	1972	Markov chains and sequences of wet and dry days in Hong Kong, Royal Observatory Technical Note No. 32.
Sham, P.	1964	Total solar and sky radiation in Hong Kong, Royal Observatory Technical Note No. 22.

TABLE 1. CONVERSION OF HONG KONG TIME TO TRUE SOLAR TIME

The table gives the number of minutes, H, to be subtracted from Hong Kong Time to obtain True Solar Time at the meridian through Hong Kong. Equation of Time values used were taken from the Nautical Almanac, 1977.

H (minutes)

Month \ Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
January	27	27	28	28	29	29	30	30	30	31	31	32	32	32	33	33	33	34	34	34	35	35	35	35	36	36	36	36	36	37	37
February	37	37	37	37	37	37	37	38	38	38	38	38	38	38	38	37	37	37	37	37	37	37	37	37	36	36	36	36	-	-	-
March	36	36	35	35	35	35	34	34	34	34	33	33	33	33	32	32	32	32	31	31	31	30	30	30	29	29	29	29	28	28	28
April	28	27	27	26	26	26	26	25	25	25	24	24	24	24	23	23	23	23	22	22	22	22	22	21	21	21	21	21	21	21	-
May	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	21	21	21
June	21	21	21	21	22	22	22	22	22	22	23	23	23	23	24	24	24	24	24	25	25	25	25	26	26	26	26	26	27	27	-
July	27	27	27	28	28	28	28	28	28	29	29	29	29	29	29	29	29	29	30	30	30	30	30	30	30	30	30	30	30	30	30
August	30	30	29	29	29	29	29	29	29	29	29	28	28	28	28	28	27	27	27	27	27	26	26	26	25	25	25	25	24	24	24
September	23	23	23	22	22	22	21	21	21	20	20	20	19	19	19	18	18	18	17	17	17	16	16	15	15	15	14	14	14	13	-
October	13	13	12	12	12	12	11	11	11	11	10	10	10	9	9	9	9	9	8	8	8	8	8	8	7	7	7	7	7	7	7
November	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8	9	9	9	9	10	10	10	11	11	11	12	12	-
December	12	13	13	13	14	14	15	15	16	16	16	17	17	18	18	19	19	20	20	21	21	22	22	23	23	24	24	25	25	26	26

TABLE 2. APPARENT DECLINATION OF THE SUN THROUGH THE YEAR

The table gives the Apparent Declination of the Sun in degrees. Values have been extracted from the Nautical Almanac, 1977 and approximated to the nearest degree.

Apparent Declination (degrees)

Month \ Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
January	-23	-23	-23	-23	-23	-23	-22	-22	-22	-22	-22	-22	-21	-21	-21	-21	-21	-21	-20	-20	-20	-20	-19	-19	-19	-19	-19	-18	-18	-18	-17
February	-17	-17	-17	-16	-16	-16	-15	-15	-15	-14	-14	-14	-13	-13	-13	-13	-12	-12	-11	-11	-11	-10	-10	-10	-9	-9	-8	-8	—	—	—
March	-8	-7	-7	-6	-6	-6	-5	-5	-5	-4	-4	-3	-3	-3	-2	-2	-1	-1	-1	0	0	+1	+1	+1	+2	+2	+3	+3	+3	+4	+4
April	+4	+5	+5	+6	+6	+6	+7	+7	+8	+8	+8	+9	+9	+9	+10	+10	+10	+11	+11	+11	+12	+12	+12	+13	+13	+13	+14	+14	+14	+15	—
May	+15	+15	+16	+16	+16	+16	+17	+17	+17	+18	+18	+18	+18	+19	+19	+19	+19	+20	+20	+20	+20	+20	+21	+21	+21	+21	+21	+21	+22	+22	+22
June	+22	+22	+22	+22	+23	+23	+23	+23	+23	+23	+23	+23	+23	+23	+23	+23	+23	+23	+23	+23	+23	+23	+23	+23	+23	+23	+23	+23	+23	+23	—
July	+23	+23	+23	+23	+23	+23	+23	+22	+22	+22	+22	+22	+22	+22	+22	+21	+21	+21	+21	+21	+21	+20	+20	+20	+20	+19	+19	+19	+19	+19	+18
August	+18	+18	+18	+17	+17	+17	+16	+16	+16	+16	+15	+15	+15	+14	+14	+14	+13	+13	+13	+13	+12	+12	+12	+11	+11	+10	+10	+10	+9	+9	+9
September	+8	+8	+8	+7	+7	+7	+6	+6	+5	+5	+5	+4	+4	+3	+3	+3	+2	+2	+2	+1	+1	0	0	0	-1	-1	-2	-2	-2	-3	—
October	-3	-4	-4	-4	-5	-5	-5	-6	-6	-7	-7	-7	-8	-8	-8	-9	-9	-10	-10	-10	-11	-11	-11	-12	-12	-12	-13	-13	-13	-14	-14
November	-14	-15	-15	-15	-16	-16	-16	-17	-17	-17	-17	-18	-18	-18	-18	-19	-19	-19	-19	-20	-20	-20	-20	-21	-21	-21	-21	-21	-21	-22	—
December	-22	-22	-22	-22	-22	-22	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23	-23

TABLE 3. THE ELEVATION AND AZIMUTH OF THE SUN'S CENTRE FROM HONG KONG

The table gives the values, to the nearest degree, of the sun's elevation, h, and azimuth measured from true north, z, for each hour of the day, True Solar Time, at selected values of the sun's declination. Also included are the azimuthal values of the sun's centre at the times (near sunrise and sunset) when it crosses the celestial horizon (h = 0°).

Elevation (degrees)
Azimuth (degrees)

Declination	Solar Time (hours)		06	07	08	09	10	11	Noon	13	14	15	16	17	18	
23° 27'	h	0	9	22	35	49	62	76	89	76	62	49	35	22	9	0
	z	65	68	73	76	79	82	82	0	278	278	281	284	287	292	295
20°	h	0	7	21	34	48	62	76	88	76	62	48	34	21	7	0
	z	68	71	76	80	84	89	96	180	264	271	276	280	284	289	292
15°	h	0	6	19	33	47	61	74	83	74	61	47	33	19	6	0
	z	74	76	81	86	92	99	115	180	245	261	268	274	279	284	286
10°	h	0	4	18	31	45	59	71	78	71	59	45	31	18	4	0
	z	79	81	86	92	98	108	128	180	232	252	262	268	274	279	281
5°	h	0	2	16	30	43	56	67	73	67	56	43	30	16	2	0
	z	85	85	91	97	105	116	138	180	222	244	255	263	269	275	275
0°	h	0	0	14	28	41	53	63	68	63	53	41	28	14	0	0
	z	90	90	96	102	111	123	145	180	215	237	249	258	264	270	270
-5°	h	0	—	12	25	38	50	59	63	59	50	38	25	12	—	0
	z	95	—	101	107	116	129	150	180	210	231	244	253	259	—	265
-10°	h	0	—	10	23	35	46	55	58	55	46	35	23	10	—	0
	z	101	—	105	112	121	135	154	180	206	225	239	248	255	—	259
-25°	h	0	—	8	20	32	43	50	53	50	43	32	20	8	—	0
	z	106	—	110	117	126	139	157	180	203	221	234	243	250	—	254
-20°	h	0	—	5	18	29	39	45	48	45	39	29	18	5	—	0
	z	112	—	114	121	131	143	160	180	200	217	229	239	246	—	248
-23° 27'	h	0	—	4	16	27	36	42	44	42	36	27	16	4	—	0
	z	115	—	117	124	133	146	161	180	199	214	227	236	243	—	245

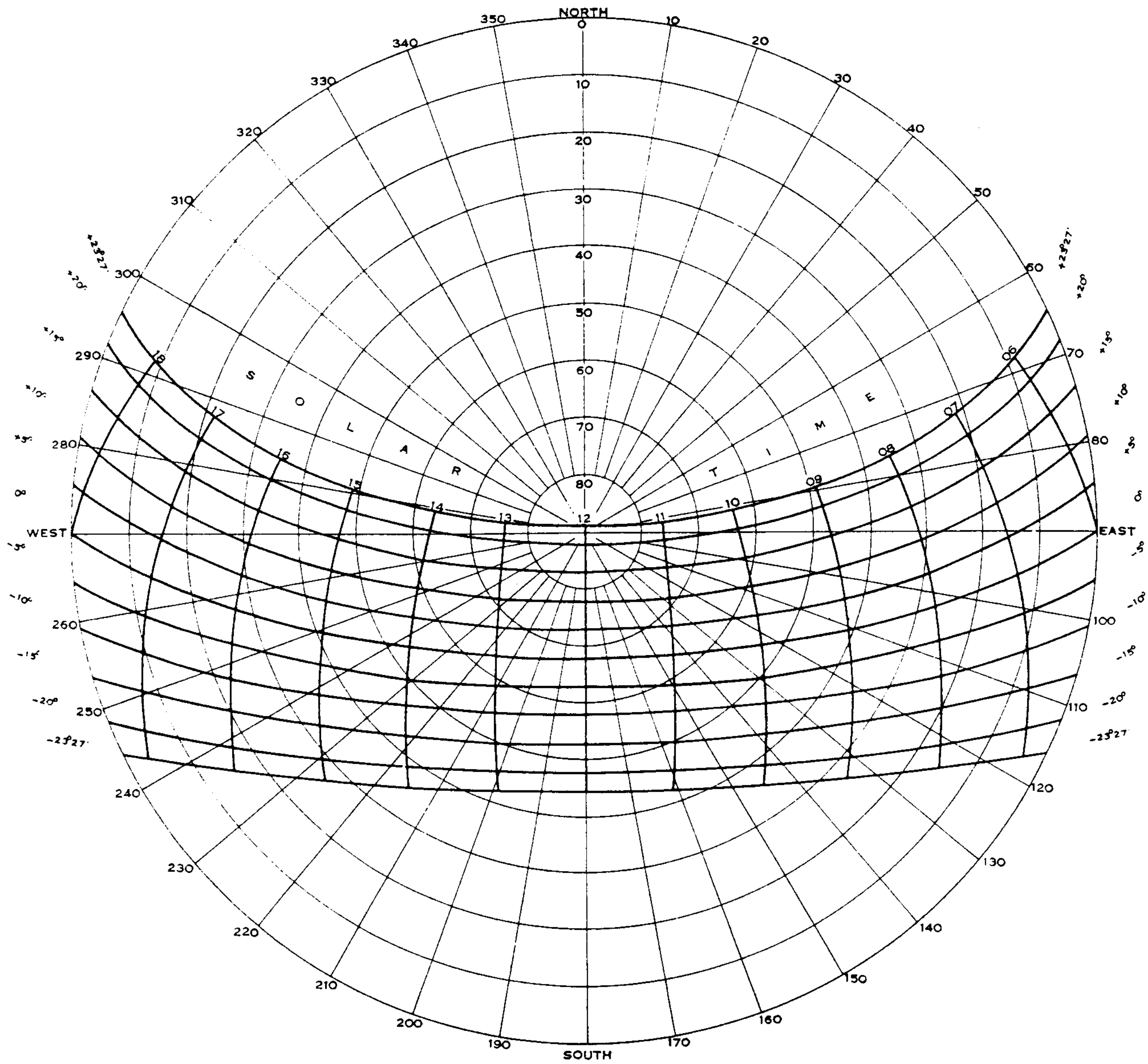

Fig. 1. **Solar Elevation and Azimuth for Hong Kong.**

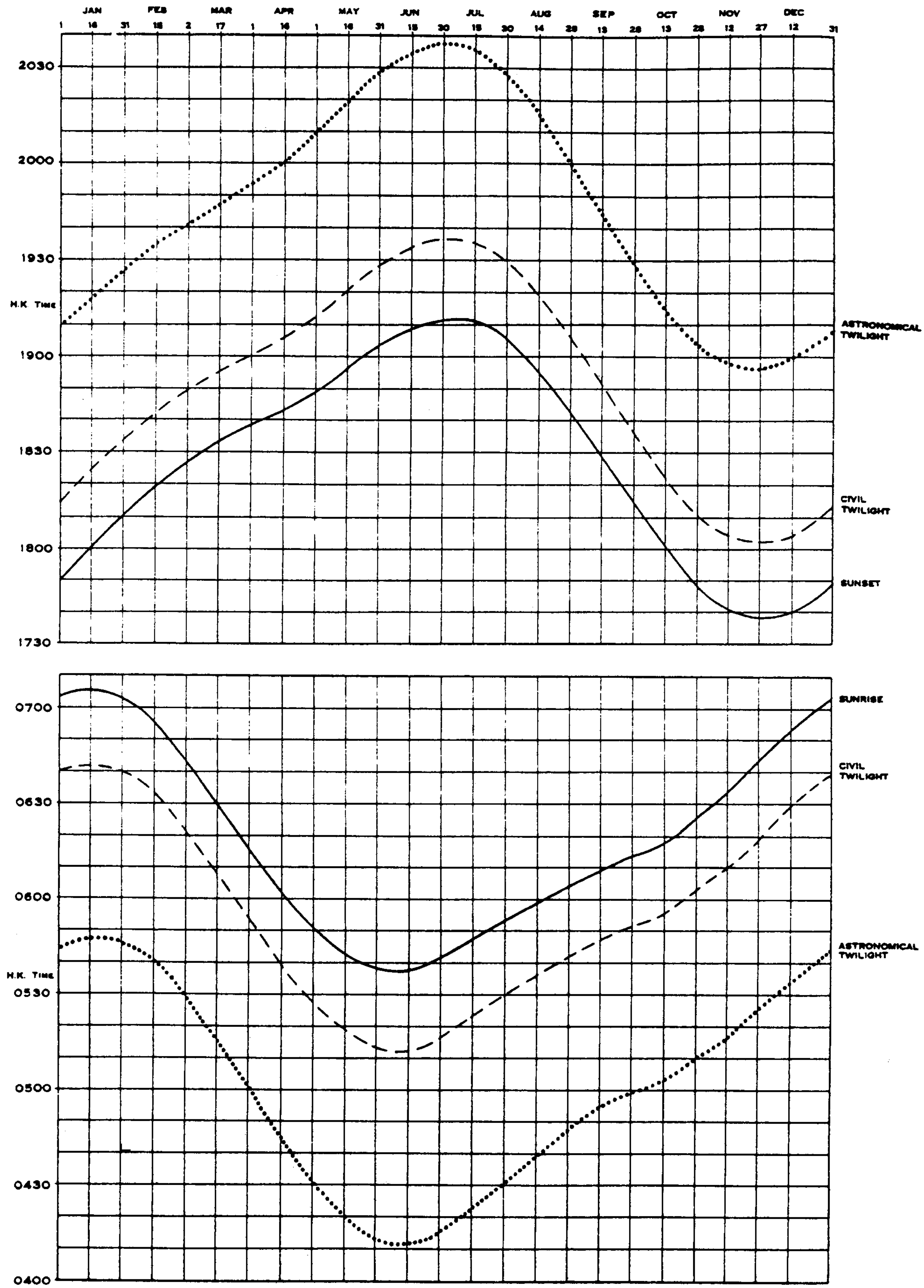

Fig. 2. Times of sunrise, sunset and of civil and astronomical twilight for Hong Kong.

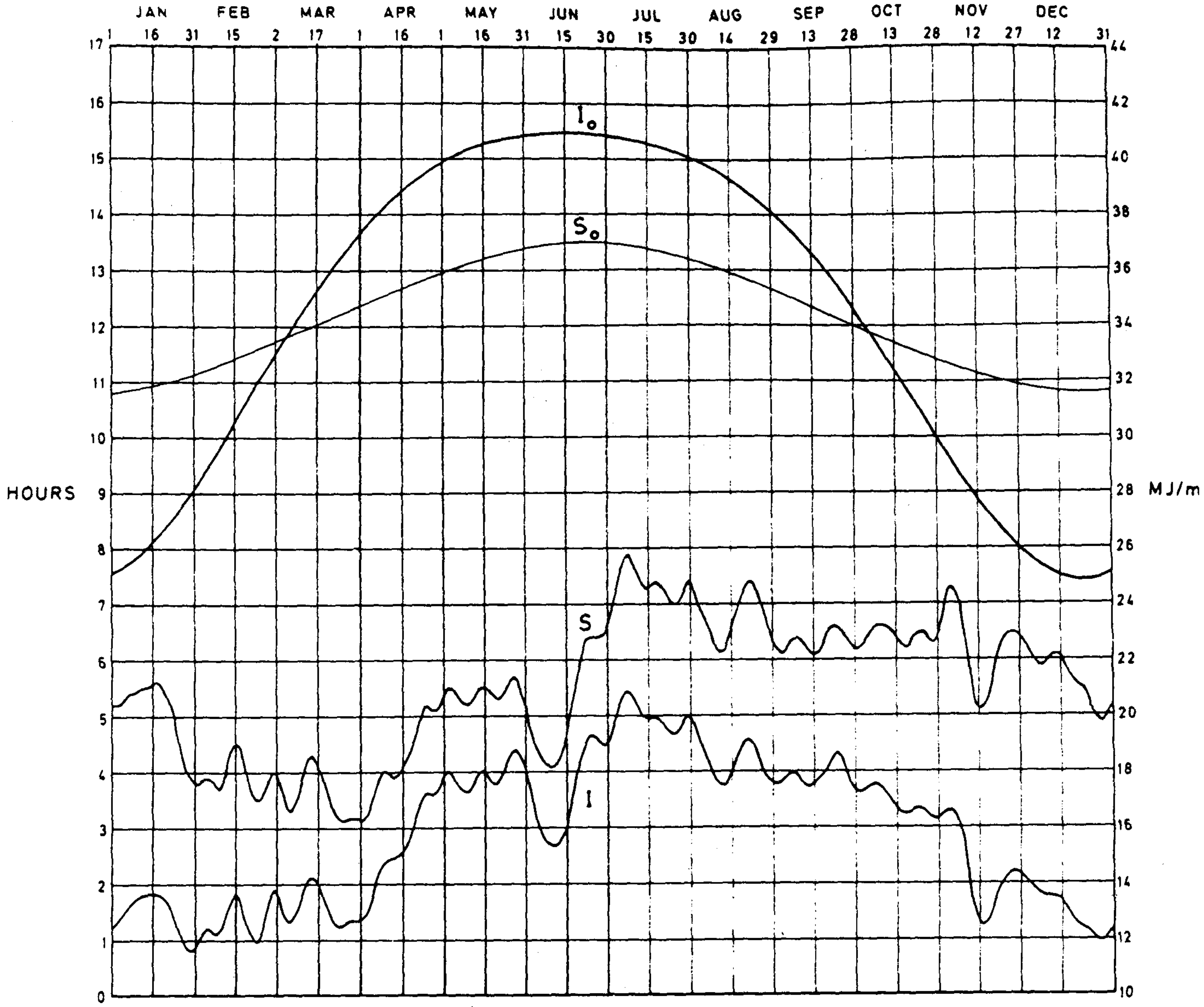

Fig. 3. Daily sunshine duration and solar radiation

I_o	Direct daily solar radiation at top of the atmosphere
I	Mean daily global solar radiation
S_o	Maximum possible daily duration of sunshine
S	Mean daily duration of sunhine

APPENDIX

BASIS FOR OFFICIAL TIME

Prior to 1972 the Hong Kong Time Service provided by the Royal Observatory was based on Universal Time, or Greenwich Mean Time as it is sometimes called. Any expression of time occurring in the Ordinances of Hong Kong is still legally defined as exactly eight hours in advance of Greenwich Mean Time. Whilst, in law, GMT thus remains the basis for time, the de facto basis for civil time in Hong Kong changed in 1972 and is no longer GMT.

Since 1 January 1972 the Hong Kong Time Service has been based on Co-ordinated Universal Time (UTC). This time now forms the basis for civil time and time signals all over the world and has been recommended for adoption as the basis for official time in all countries.

A full history of the subject of time scales would be too long for inclusion in this publication. However, some background information is given because the difference between UTC and GMT may approach 0.9 second and can be significant for some purposes.

GMT may be regarded as the general equivalent of Universal Time (UT). In applications in which an imprecision of a few hundredths of a second cannot be tolerated it is necessary to specify the form of UT which should be used;

> UTO is the mean solar time of the prime meridian obtained from direct astronomical observation;
>
> UT1 is UTO corrected for the effect of the small movements of the earth relative to the axis of rotation (polar variation). UT1 corresponds directly with the angular position of the Earth around its axis of diurnal rotation;
>
> UT2 is UT1 corrected for the effect of a small seasonal fluctuation in the rate of rotation of the Earth.

The base unit of time, the second, was originally defined in terms of the rate of rotation of the Earth (1/86 400 of a mean solar day). Earlier this century it became clear that there are small but measurable irregularities in the Earth's rate of rotation and time scales based on it are unsatisfactory for more precise astronomical purposes. The time scale based on the Earth's movement around the Sun, Ephemeris Time (ET), was established by astronomers to avoid this difficulty but it is unsuitable for general use because the reduction of astronomical observations to form it is necessarily a long process and the scale is accurately known only long after the event.

Research on atomic frequency standards indicated that an alternative basis for a definition of the second might be possible and in 1967 the Thirteenth General Conference of Weights and Measures adopted a resolution to replace the astronomical definition of the second by:-

> The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium-133 atom.

The International Atomic Time Scale (TAI) is the international reference scale of atomic time based on the second as defined above in the International System of Units (SI). It is in the form of a continuous scale, e.g. in days, hours, minutes and seconds from the origin 1958 January 1d 0h 0min 0s. The mean solar day is currently about 2.7 milliseconds longer than 24 hours, and TAI is gaining on UT by this amount each day. The rate is not constant, however.

At the beginning of 1972 a compromise time scale known as Coordinated Universal Time (UTC) was changed to a new standard so that 1972 January 1d 0h 0min 0s UTC coincided precisely with 1972 January 1d 0h 0min 10s TAI. This was accomplished by a step of 0.107 757 7 second being taken out of UTC. Also on 1 January 1972, the duration of 1 second UTC was shortened by about 30 nanoseconds so as to equal the second on the TAI scale. So that UTC and UT1 would never differ by more than 0.9 second, provision was made for the introduction from time to time of "leap-seconds" in the UTC scale. As TAI is currently gaining on UT1 positive leap-seconds are required. A positive leap-second was introduced to the end of June 1972 and again at the end of December each year from 1972 to 1977. As a result of these seven adjustments UTC was exactly 17 seconds behind TAI during 1978. A leap-second will again be inserted at the end of December 1978. Although UTC will differ from TAI by an integral number of seconds, its seconds "markers" always coincide with those of TAI.