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A MULTI-LAMP HELIODON FOR ARCHITECTURAL SCHOOLS

K.P. Cheung
Department of Architecture, The University of Hong Kong, Pokfulam Road, Hong Kong

H.M. Kam and C.F. Lam
Department of Electronic Engineering, Hong Kong Institute of Vocational Education, Tuen Mun campus
Tuen Mun, N.T., Hong Kong

ABSTRACT

Heliodons have been developed to simulate sunlight direction in relation to a building model. For placing the building model, heliodons can be divided into two categories. In one category, the model is to be tilted, and normally also rotated [1,2,3]. In the other category, the model is to be placed horizontally, and normally also stationary [4,5,6].

The later category of heliodons, with a horizontally placed building model, and with the simulated sunlight moving around it, will certainly help architectural students visualise the change of sunlight direction around a building and the related effect on insolation and shading.

Furthermore, in both categories, there are heliodons developed [7,8] to examine annual insolation/shading on massing models by putting red, green, blue lamps (i.e. dichromatic lamps) respectively at positions for June, September/ March, December, thus improving the capability of the heliodons.

In the pursuit of a heliodon capable of demonstrating solar movement, offering the speed of operation as demanded by architectural schools, and occupying a space generally affordable, and primarily suitable for use to test buildings of the climatic region of South China where Hong Kong is located, a multi-lamp heliodon has been developed.

This paper reports on this multi-lamp heliodon, which consists of 69 fixed quartz lamps, and 6 dichromatic lamps. It also has the capability of investigating the building model with dichromatic lamps, without the demand of additional space which is always a concern now in architectural schools.

1. INTRODUCTION

Heliodons are developed for testing of sunlight effect on physical building models, aiming at reproducing the actual direction of sunlight in relation to a building.

The variables to be adjusted are [3]:

- the latitude variable, which defines the sun-paths in relation to the geographical location.
- the seasonal variation, which relates to the declination of the sun on a given day, and
- hourly change of the sun from East to West.

The heliodons developed so far could be broadly categorised into two categories:

- a fixed light source (single lamp or multiple lamps) [2,9,10,11], or a moving light source [1,2], with the building model rotated and/or tilted
- the building model is placed horizontally, and the light source moves [4,5,6,12]

While each category or type is designed on different emphasis of its purpose of measuring certain variables, and for certain operation convenience, the type with horizontally placed models appear most easily understood to most people including students, professionals, building developers and purchasers and building users. A helidon of this type should be a basic equipment to architectural schools.

In designing a heliodon with horizontally placed building models, there exists a compromise amongst space available, convenience and speed of operation, and its applicability in testing building models of different latitudes.

Furthermore, teaching bonuses are gained if the heliodon can also give the students strong physical sense of the movement of the sun around the building, and if dichromatic lamps [7,8] can alternatively be used to test the building models. This paper reports on a multi-lamp heliodon consisting of 69 fixed quartz lamps, and 6 dichromatic lamps, capable of offering the speed of operation as demanded by architectural schools, and having the capability of investigating the building model with dichromatic lamps, without the demand of additional space which is always a concern now in architectural schools. The building models are horizontally placed for this heliodon.

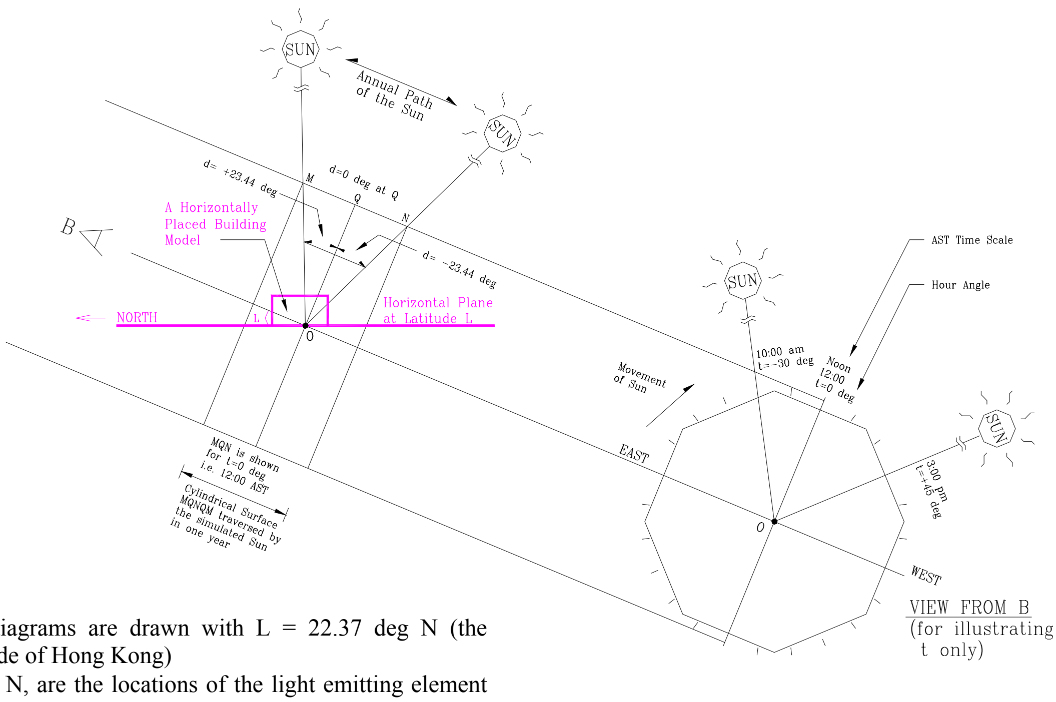
2. SIMULATING THE "SUNS" IN THE HELIODON – THE TWO EXISTING LIGHT TROUGHS

The sun is considered to travel with respect to an observer on the surface of the earth (i.e. topocentric observation) from d=+23.44 deg to -23.44 deg from Summer Solstice to Winter Solstice and vice versa, year by year (Fig. 1), on the assumption that there is practically no difference of topocentric observation and geocentric observation (i.e. observing the sun fictionally at the centre of the earth) in relation to simulating the variables of concern of the heliodon. This assumption is acceptable for architectural modelling, and is used in the design of the heliodon, because the distance between the sun and the earth far outweighs the diameter of the earth.

While it is common that this annual sun path is presented as part of an imaginary spherical surface, it can also be presented as part of an imaginary cylindrical surface [13] (Fig. 2).

This cylindrical surface presentation [13] was adopted for developing a heliodon with dichromatic lamps [8] travelling along a straight metal light trough for simulating the various angles of declination, i.e. different days of the year. (Fig. 1 & 2). The two light troughs, one for testing the model for AST a.m. period, and the other for p.m., were set slanting at 22.37 degree to the horizon in accordance with the imaginary cylindrical sky vault concept (Fig. 2) for the latitude of Hong Kong which is at 22.37 degree north.

These two existing light troughs are used for developing the heliodon presently reported.



Notes:

- The diagrams are drawn with L = 22.37 deg N (the Latitude of Hong Kong)
- M, Q, N, are the locations of the light emitting element Solstice, Spring/ Autumn Equinox, Winter Solstice
- is a fixed reference point on earth

Fig. 1: The principle of designing the heliodon for solar declination, latitude, and hours of the day (for Northern Hemisphere) [Adapted from 13]

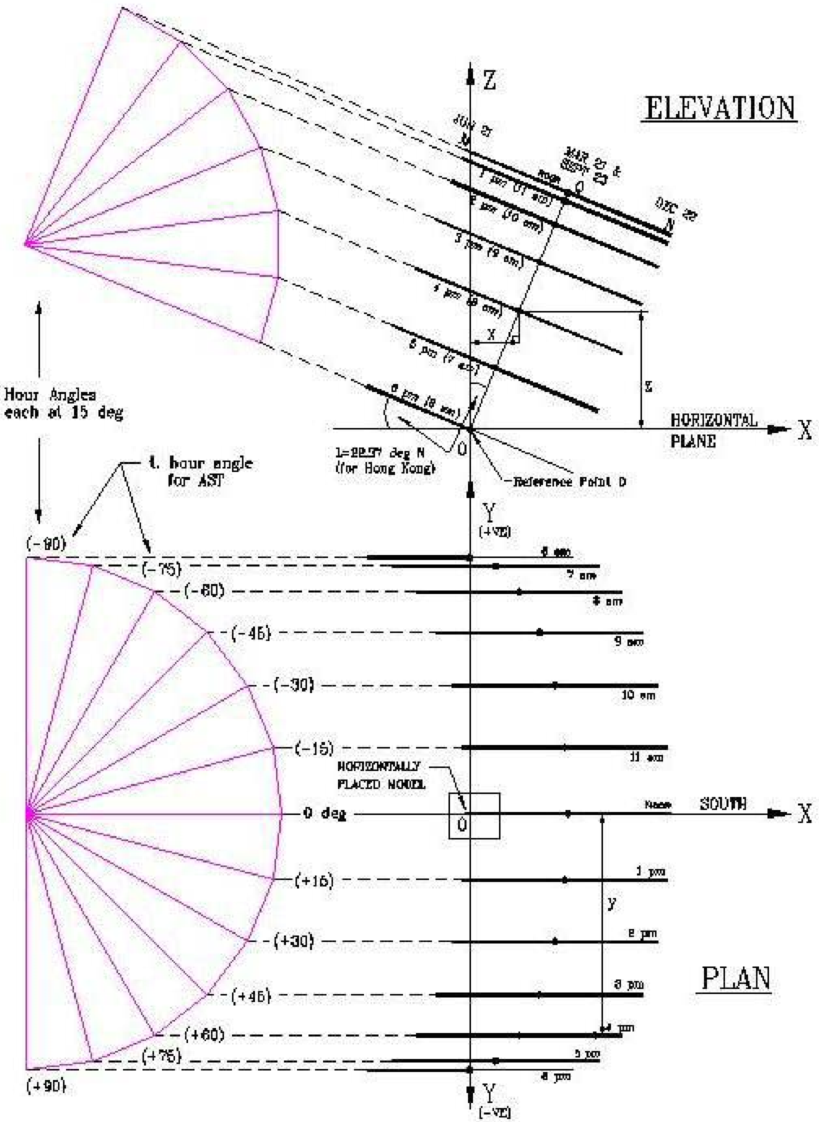


Fig. 2: Selected AST moments of the simulated sun for the latitude of Hong Kong at 22.37 deg N [Adapted form 13]

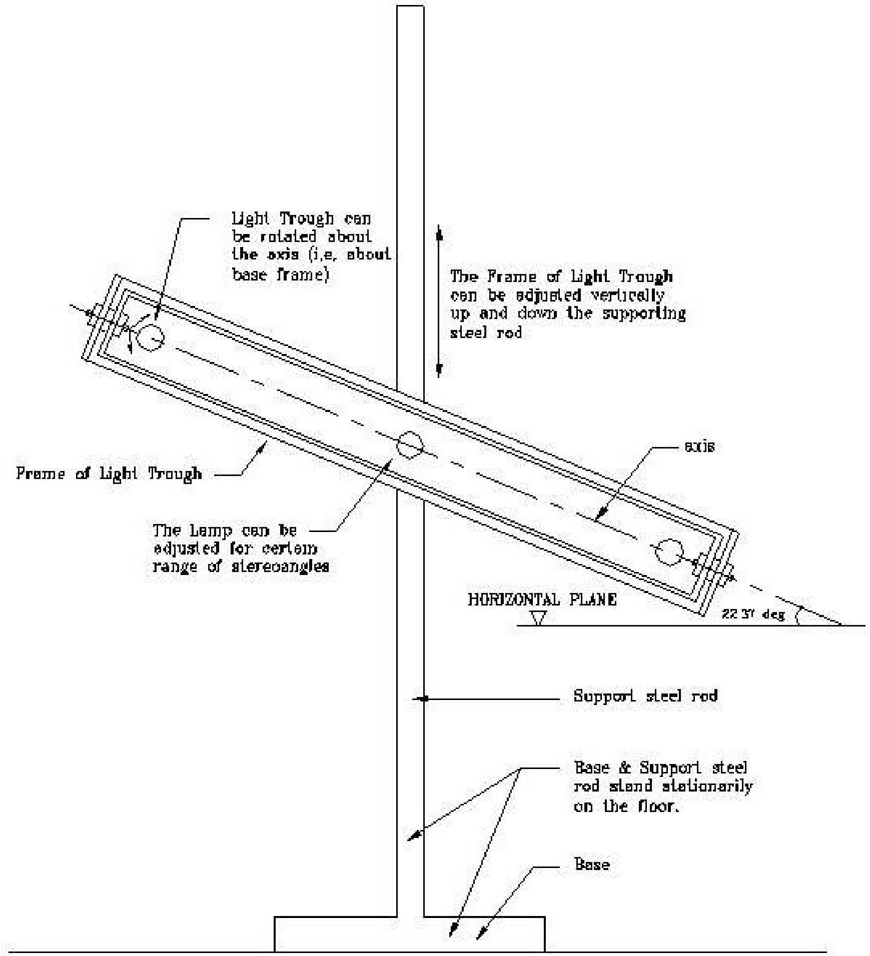


Fig. 3: Conceptual diagram of light trough for setting dichromatic lamps for d, h, A for Hong Kong (22.37 deg N) [Adapted from 8]

3. SIMULATING THE "SUNS" IN THE HELIODON – THE THREE NEW LAMP HOLDING RODS WITH 69 QUARTZ LAMPS

Based on the same concept of an imaginary cylindrical sky vault (Fig. 2) used to develop the 2 straight light troughs of the heliodon with dichromatic lamps [8], three separate lamp holding rods have been designed and manufactured. Each rod contains 23 quartz lamps each of 50 W. Two of these rods are mounted on the two existing metal light troughs (Fig. 4) which are set at fixed locations, such that the light emitting elements of the quartz lamps in the two newly mounted rods represent the selected positions of the sun at 9 am AST and 4 p m AST. In addition there is one more rod, containing 23 quartz lamps each of 50 W, mounted at the ceiling of the laboratory in between the two existing light troughs, to present the selected positions of the sun at noon AST. (Fig. 5) The three lamp holding rods (Fig. 6) are set to slant at 22.5 degree to the horizon, in the North-South orientation. 22.5 degree is a practically adjustable value for the heliodon , for the latitude of Hong Kong which is situated at 22.37 degree North.

Fig. 4: The pair of handed Keliodon fitted with dichromatic lamps [from Ref. 8]

Notes:

- The far side one is for simulating the am sun and the near side one for the pm sun.
- The helidon is set for the latitude of Hong Kong at 22.37 degree N.

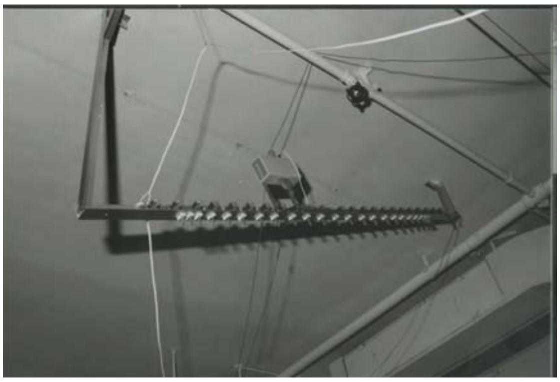


Fig. 5: The lamp holding rod containing 23 quartz lamps for simulating the "suns" at noon AST

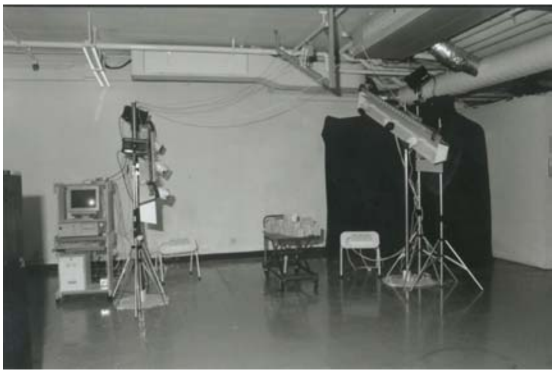


Fig. 6: A computer controlled multi-lamp heliodon consisting of 3 lamp holding rods, each having 23 quartz lamps; and 6 dichromatic lamps

Notes:

- When operating with quartz lamps, the right rod, middle rod and the left rod are respectively set for 9am (right), noon (middle), 4pm (left) AST, for Hong Kong. The top lamps are for Summer solstice. All the lamps, i.e. 69 lamps for 3 rods, are controlled by the computer.
- The space envelope containing the helidon and the computer measures 4.2 m wide x 2.44 m deep x 3.15 m high.
- When operating with dichromatic lamps, each light trough is fitted with a red lamp (top) for summer solstice, green lamp (middle) for solstice days, and blue lamp (bottom) for Winter Solstice. These lamps have simple separate on-off electrical controls.

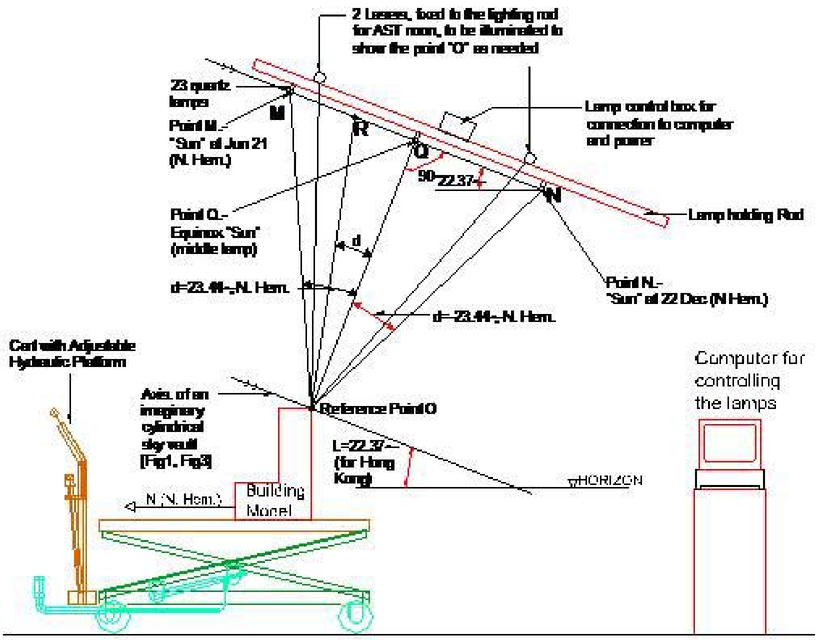
The three new lamp holding rods of quartz lamps are now parallel. Since the quartz lamps are inserted into sockets provided in the standard electronic modules proprietarily made, the light emitting elements of the three rods join into three practically parallel lines in space, conforming to the parallelity of the 3 lines representing the positions of the "sun" at 9 am, noon, and 4 p m AST (Fig. 2).

Because the heliodon is primarily designed for testing buildings in Hong Kong which is in Southern China region, the 11 lamps on each rod are located to represent the starting days of the Chinese twenty-four fortnightly periods (Table 1) [13-15]. Furthermore, because physically there is space in between the 11 lamps in each lamp holding rod, other than the two lamps at the extremities of the rods, 10 lamps are added in between these 11 lamps on each rod. Totally, therefore there are 23 lamps (Table 1, Fig. 5) on each rod, with one lamp representing a difference of, on average, about 8.1 days from the adjacent lamp (i.e. 8.1 days = 365 days ÷ (23+22)), because 45 days are represented by 23 lamps on each rod (Table 1).

In Northern Hemisphere the top lamp of the slanting rod represents the sun at Summer Solstice, the middle one the Equinox days, and the lowest one Winter Solstice. The lamps are controlled by the computer so that only one lamp is operating at any moment (Table 2). There are various options of controlling the lamps. For instance, the lamps can be scheduled to light up one after the other at intervals of 3 seconds for demonstration of the solar path.

The physical building model is located on a hydraulic cart which can allow about 600 mm vertical adjustment of the building model relative to the lamps. Of course horizontal planar movement of the model can be adjusted by moving the cart which travels on its wheels, or by adjusting the building model on the surface of the elevated platform of the cart. This vertical and horizontal adjustments are needed, because the lamps (i.e. in fact their light emitting elements) are actually positioned with respect to the reference point O in space (Fig. 2 & 7). In the heliodon, this reference point in space is the meeting point of 2 laser beams calibrated and fixed on the lamp holding rod for noon AST (Fig. 7).

The line joining each lamp to this reference point simulates accurately the sun light direction for the hour and day represented by that lamp. Therefore, for example, if the top corner of the meeting edge of two walls of the building model is placed at this reference point, the shadow of the top corner cast by the light from the lamp onto the other parts of the model will give a practically accurate shadow. If however this top corner is moved to other locations, error will occur to the shadow of this corner cast. Also although this top corner is adjusted at the reference point, other portions of the model receiving the testing light are of course not at the reference point. This is an inherent situation for errors in heliodons using artificial lighting source. For teaching purpose in architectural schools, this inherent error is immaterial.



Notes:

- Point O (Table 1) is the reference point for calculating the solar angles before the lamps are positioned
- The locus of the light emitting elements of the quartz lamps form the locus of the simulated "suns" (Table 1, Fig. 2)
- The helidon is set at 22.37 deg, the latitude of Hong Kong (L=22.37 deg N)
- See Table 1 for the days represented by the lamps
- R is the simulated sun at solar declination angle d =11 deg 39 min (Appendix C)

Fig. 7: The schematic diagram for relating the 23 lamps of the lighting rod for AST noon to the testing model

Table 1: Days simulated by the light emitting elements of the lamps for heliodon operation in Northern Hemisphere and Southern Hemisphere respectively [from Ref. 14]

For China -- Chhi - The starting days of the 24 fortnight periods of the Chinese Agricultural Calendar [13-15] (Table 4) (Note 1)	For Northern Hemisphere - Corresponding days of Chhi simulated	Solar declination angle selected deg.	min	Theoretical Distance of light emitting element from centre element, mm (Note 2)	For Southern Hemisphere - Days simulated by the Lamps (See Note 3)
10 夏至	21 Jun	+23	26.4	775.7	22 Dec
9 芒種, 11 小暑	6 Jun, 7 Jul	+ 22	38	745.9	7 Dec, 5 Jan
8A, 11A	29 May, 15 Jul	+21	35	707.7	30 Nov, 13 Jan
8 小滿, 12 大暑	21 May, 23 Jul	+20	08	655.9	22 Nov, 20 Jan
7A, 12A	13 May, 31 Jul	+18	20	592.8	15 Nov, 28 Jan
7 立夏, 13 立秋	5 May, 8 Aug	+16	12	519.8	7 Nov, 4 Feb
6A, 13A	28 Apr, 15 Aug	+14	06	449.4	31 Oct, 11 Feb
6 穀雨, 14 處暑	21 Apr, 23 Aug	+11	39	368.9	24 Oct, 18 Feb
5A, 14A	14 Apr, 31 Aug	+08	39	272.2	16 Oct, 26 Feb
5 清明, 15 白露	5 Apr, 7 Sept	+ 06	04	190.1	9 Oct, 5 Mar
4A, 15A	28 Mar, 16 Sept	+02	49	88	30 Sept, 14 Mar
4 春分, 16 秋分	21 Mar, 23 Sept	+ 00 00	04 00	2.6 0 (centre element)	23 Sept, 21 Mar
3A, 16A	13 Mar, 1 Oct	- 03	03	95.3	15 Sept, 29 Mar
3 驚蟄, 17 寒露	6 Mar, 8 Oct	- 05	46	180.7	8 Sept, 4 Apr
2A, 17A	27 Feb, 15 Oct	- 08	26	265.2	1 Sept, 12 Apr
2 雨水, 18 霜降	19 Feb, 23 Oct	- 11	21	359.1	24 Aug, 20 Apr
1A, 18A	12 Feb, 30 Oct	- 13	45	437.8	16 Aug, 27 Apr
1 立春, 19 立冬	4 Feb, 7 Nov	- 16	15	521.4	8 Aug, 5 May
24A, 19A	28 Jan, 14 Nov	- 18	13	588.8	31 July, 13 May
24 大寒, 20 小雪	20 Jan, 22 Nov	- 20	08	655.9	23 July, 21 May
23A, 20A	12 Jan, 30 Nov	- 21	39	710.1	15 July, 29 May
23 小寒, 21 大雪	5 Jan, 7 Dec	- 22	37	745.3	7 July, 6 Jun
22 冬至	22 Dec	- 23	26.4	775.7	21 Jun

Notes:

1. Chhi in Chinese are shown.
2. See Appendix for calculations of distance of light emitting element of lamp from the centre lamp. In actual fixing work, this distance is rounded up to the nearest mm.
3. For simulating the days by the lamps in Southern Hemisphere, the signs (i.e. +ve, -ve signs) for solar declination angles are reversed. For example in Southern Hemisphere, the simulated days of 22 Nov, 20 Jan correspond to the solar declination angle of -20 deg 08 min. (Table 4).

Table 2: Operating the lamps for testing models in Northern Hemisphere, especially in northern, central and southern regions in China

For China -- Chhi - The starting days of The 24 fortnight periods of the Chinese Agricultural Calendar [13-15] (Table 1)	For Northern Hemisphere - Corresponding days of Chhi simulated	Computer entry for switching on the lamps for 3 different moment of Apparent Solar Time		
		4 p.m.	noon	9 a.m.
10 夏至	21 Jun	A0222	A0122	A0022
9 芒種, 11 小暑	6 Jun, 7 Jul	A0221	A0121	A0021
8A, 11A	29 May, 15 Jul	A0220	A0120	A0020
8 小滿, 12 大暑	21 May, 23 Jul	A0219	A0119	A0019
7A, 12A	13 May, 31 Jul	A0218	A0118	A0018
7 立夏, 13 立秋	5 May, 8 Aug	A0217	A0117	A0017
6A, 13A	28 Apr, 15 Aug	A0216	A0116	A0016
6 穀雨, 14 處暑	21 Apr, 23 Aug	A0215	A0115	A0015
5A, 14A	14 Apr, 31 Aug	A0214	A0114	A0014
5 清明, 15 白露	5 Apr, 7 Sept	A0213	A0113	A0013
4A, 15A	28 Mar, 16 Sept	A0212	A0112	A0012
4 春分, 16 秋分	21 Mar, 23 Sept	A0211	A0111	A0011
3A, 16A	13 Mar, 1 Oct	A0210	A0110	A0010
3 驚蟄, 17 寒露	6 Mar, 8 Oct	A0209	A0109	A0009
2A, 17A	27 Feb, 15 Oct	A0208	A0108	A0008
2 雨水, 18 霜降	19 Feb, 23 Oct	A0207	A0107	A0007
1A, 18A	12 Feb, 30 Oct	A0206	A0106	A0006
1 立春, 19 立冬	4 Feb, 7 Nov	A0205	A0105	A0005
24A, 19A	28 Jan, 14 Nov	A0204	A0104	A0004
24 大寒, 20 小雪	20 Jan, 22 Nov	A0203	A0103	A0003
23A, 20A	12 Jan, 30 Nov	A0202	A0102	A0002
23 小寒, 21 大雪	5 Jan, 7 Dec	A0201	A0101	A0001
22 冬至	22 Dec	A0200	A0100	A0000

Note:

A0222, etc. are codes to be entered on the keyboard for switching on the specific lamp. For example, keying in A0100 will switch on the lamp representing noon AST at 22 Dec. Of course, one lamp is to be switched on at one time to present the position of the sun at that moment.

4. THE THREE NEW LAMP HOLDING RODS – OPERATION SPEED AND TEACHING OF SOLAR GEOMETRY FOR 3 SELECTED HOURS OF APPARENT SOLAR TIME

Since the lamps are controlled by the computer, and the model can be easily adjusted relative to the lamps, building models can be quickly tested. The speed of operation will suit architectural schools which have a large number of students.

Furthermore, as the lamps along a rod can be programmed to light up in different sequences, the set up can be used to demonstrate the relative position of the sun at the various selected days for 9 am, noon, 4 pm AST (Table 1 & 2) around a place at the latitude for which the three rods are set. If the lamps set for the solstice days and equinox days are repeatedly switched on, the students will obtain a strong physical sense of the relative position of the sun in the morning, noon, and afternoon, for these important seasonal demarcation days. This strong physical sense will be very useful when they design buildings.

5. SIMULATING THE "SUNS" IN THE HELIODON USING DICHROMATIC LAMPS – REFITTING THE TWO EXISTING LIGHT TROUGHS WITH DICHROMATIC LAMPS

Now two new lamp holding rods have been added on two existing light troughs which are to be fixed, contrasted to the previously reported heliodon [8] (Fig. 4) which allowed the trough to move in the horizontal plane and vertically with the building model placed horizontally and stationary.

In order to maintain the capability of testing the building models using dichromatic lamps, [7,8] the building model is placed on the hydraulic cart which allows the model to be set relatively to the two light troughs (i.e. the red, green, blue lamps fitted to the light troughs).

Like the previous version [8] (Fig. 4), three dichromatic lamps can be located at suitable locations on the trough, with the red lamp at Summer Solstice, green at Spring/Autumn equinox, blue at Winter Solstice (Fig. 6).

The x, y, z co-ordinates for the simulated sun at Spring/Autumn Equinox (i.e. d = 0 deg) for a particular location of latitude L at different AST moments (Fig. 2, Table 3) can be set by moving and adjusting the building model relative to the fixed light trough, (i.e. adjusting for $\underline{x}$, $\underline{y}$, $\underline{z}$) always with the light emitting element of the lamp at Equinox position (i.e. $\underline{x}$, $\underline{y}$, $\underline{z}$) set relative to reference point 0 which now travels with the building model.
Besides using lighting fittings which have an angle adjusting capability, the light trough can be rotated about its base frame for emitting the simulated sunlight towards the travelling reference point 0 at various moments of AST (Fig. 3 & 4).

In order to avoid the light trough stand to cast a shadow on the model, and for the convenience of use and demonstration, the two existing troughs from the previous one [8] are used, one for morning use, and one for afternoon use [3] (Fig. 4). Note that the light trough and stand for afternoon use is physically symmetrically constructed to the one for morning use.

Alternately, 3 dichromatic lamps can also be selectively located at three different strategic days. The building has to be white, such that the white areas on the model with the 3 dichromatic lamps operating will indicate areas receiving sunlight at all the 3 days represented by the lamps, and the dark areas on the model will indicate areas not receiving sunlight at those 3 days.

Of course, one other option of using the heliodon is to locate a lamp along the light trough at any solar declination angle for the required day, with optional fitting of a "sunlight filter" for projecting a light source more like the solar spectrum onto the building model.

6. THE THREE NEW LAMP HOLDING RODS – OPERATION IN OTHER MOMENTS OF APPARENT SOLAR TIME

Normally for student design projects, the prime hours of 9 am, noon, 4 pm AST are sufficient.

However adjustment can be made for operating in other moments of AST. This topic is discussed here because it follows the concept for the relative setting of dimensions x, y, z stated earlier for the arrangement of dichromatic lamps relative to the building model (Table 3).

For operating the three new lamp holding rods at other moments of Apparent Solar Time, the quartz lamps are set relative to the building model using the same adjustment as shown earlier [8] (Table 3), noting however that $\underline{OQ}$ = 1.789 m instead, by adjusting the hydraulic cart, and hence the building model which is supported on it.

Table 3: The position of the light emitting element of the lamps of the heliodon relative to the reference point of the model for Hong Kong (Fig. 2 & 6)

Apparent Solar Time hour	t deg	x mm	y mm	z mm	Apparent Solar Time Hour	t deg	x mm	y mm	z mm
06:00	-90.0	0	1800	0	12:00	0.0	689	0	1663
06:10	-87.5	30	1798	73	12:10	2.5	688	-79	1661
06:20	-85.0	60	1793	145	12:20	5.0	686	-157	1657
06:30	-82.5	90	1785	217	12:30	7.5	683	-235	1649
06:40	-80.0	120	1773	289	12:40	10.0	678	-313	1638
06:50	-77.5	149	1757	360	12:50	12.5	673	-390	1624
07:00	-75.0	178	1739	430	13:00	15.0	665	-466	1606
07:10	-72.5	207	1717	500	13:10	17.5	657	-541	1586
07:20	-70.0	236	1691	569	13:20	20.0	647	-616	1563
07:30	-67.5	264	1663	636	13:30	22.5	636	-689	1536
07:40	-65.0	291	1631	703	13:40	25.0	624	-761	1507
07:50	-62.5	318	1597	768	13:50	27.5	611	-831	1475
08:00	-60.0	344	1559	831	14:00	30.0	597	-900	1440
08:10	-57.5	370	1518	894	14:10	32.5	581	-967	1403
08:20	-55.0	395	1474	954	14:20	35.0	564	-1032	1362
08:30	-52.5	419	1428	1012	14:30	37.5	546	-1096	1319
08:40	-50.0	443	1379	1069	14:40	40.0	528	-1157	1274
08:50	-47.5	465	1327	1123	14:50	42.5	508	-1216	1226
09:00	-45.0	487	1273	1176	15:00	45.0	487	-1273	1176
09:10	-42.5	508	1216	1226	15:10	47.5	465	-1327	1123
09:20	-40.0	528	1157	1274	15:20	50.0	443	-1379	1069
09:30	-37.5	546	1096	1319	15:30	52.5	419	-1428	1012
09:40	-35.0	564	1032	1362	15:40	55.0	395	-1474	954
09:50	-32.5	581	967	1403	15:50	57.5	370	-1518	894
10:00	-30.0	597	900	1440	16:00	60.0	344	-1559	831
10:10	-27.5	611	831	1475	16:10	62.5	318	-1597	768
10:20	-25.0	624	761	1507	16:20	65.0	291	-1631	703
10:30	-22.5	636	689	1536	16:30	67.5	264	-1663	636
10:40	-20.0	647	616	1563	16:40	70.0	236	-1691	569
10:50	-17.5	657	541	1586	16:50	72.5	207	-1717	500
11:00	-15.0	665	466	1606	17:00	75.0	178	-1739	430
11:10	-12.5	673	390	1624	17:10	77.5	149	-1757	360
11:20	-10.0	678	313	1638	17:20	80.0	120	-1773	289
11:30	-7.5	683	235	1649	17:30	82.5	90	-1785	217
11:40	-5.0	686	157	1657	17:40	85.0	60	-1793	145
11:50	-2.5	688	79	1661	17:50	87.5	30	-1798	73
12:00	0.0	689	0	1663	18:00	90.0	0	-1800	0

Notes:

1. L=22.37 deg North for Hong Kong and d = 0 deg 5 min, averaged over 21 March and 23 September.
2. For operating with dichromatic lamps, OQ = 1.8m, based on which this table is computed.
3. For operating with quartz lamps, OQ = 1.789m, a multiplier is to be applied to this table.

Note that OQ is 1.8m (Fig. 2 & 7, Table 1, 2 & 3) for operating with dichromatic lamps and 1.789 m for operating with quartz lamps.

Note also that the reference point 0 for using the quartz lamps, is the intersecting point of the two laser beams (Fig. 7), and that for using the dichromatic lamps, an earlier method [8] (Table 3) should be followed.

7. ADAPTATION OF THE HELIODON FOR OPERATING IN OTHER LATITUDES AND OTHER MOMENTS OF TIME – A BRIEF DISCUSSION ONLY

The heliodon described has endeavoured to maintain the building model to be placed horizontally for a given latitude.

For still keeping the building model horizontal, the slanting angle of the lamp holding rods and the light troughs can be set to the latitude of the building, with adjustable devices fitted. This has not been done, but should not be difficult.

If the building model is allowed to be tilted, then devices such as a turntable, an adjustable angle plate used in the manufacturing industry, can be fitted on the hydraulic cart to enable:

- the building model to be turned about the axis (Fig. 1), with respect to the lamps at noon AST, i.e. lamps along line MQN (Fig. 1), with every 15 degree turn for 1 hour difference. (Note: this can be effected by using a turntable, which has not been installed.)
- Furthermore, put the turntable on to an adjustable angle plate to fix the desirable latitude with respect to the noon AST lamps (i.e. line MQN – Fig. 1), without adjusting the slanting angle of the lamp hold rods. (Note: This assembly has not been carried out yet.)
- For adjustment to local standard time, an earlier established method can be used [14].

The hydraulic cart can be moved to adjust the building model for choosing the reference point of the heliodon, as indicated by the intersecting point of the 2 laser beams.

8. CONCLUSION

With the "suns" quickly switched on and off by computer control, the relative position of the sun to the earth for the latitude set for the 3 lamp holding rods at various seasonally significant days, in the morning, noon and the afternoon, can be clearly demonstrated to the users. Furthermore quick testing of the building models is possible for 9 am, noon 4 pm AST. This will suffice teaching purpose for leaning solar geometry and testing of building models in student design projects.

Since the building model is kept horizontal, options of quick working models loosely fitted together can be tested. This allows quick comparison of options.

Furthermore using the same space for these 3-rod 69-lamp heliodon, a 6-lamp heliodon with dichromatic lamps have been refitted, using the 2 existing light troughs of a previous version [8]. The building model is to be moved in this newly refitted version. This use of the same space for another heliodon gains merits of space efficiency which is always a problem in architectural schools. The space containing the heliodon and the computer controls measures 4.27m wide x 2.44m deep x 3.15m high.

The overall heliodon is therefore a multi-lamp heliodon which is set for the latitude of 22.5 degree in Northern Hemisphere. If tilting of physical models are allowed, it can be used to test models at other latitudes, with minor adaptation to the model support platform.

The heliodon described above is for testing building models in Northern Hemisphere. However the same principle can be applied for testing building models in Southern Hemisphere using the same heliodon, provided the following three points are noted:

- The lamp holding rods and light troughs are slanting towards South.
- The lamps have reversed designation (Table 1).
- The 9am AST, and 4 pm AST lamps for Northern Hemisphere will respectively become 3 pm AST, and 8 am AST lamps for Southern Hemisphere.

NOMENCLATURE

A Solar Azimuth angle, A = 0 deg for south direction, A is positive if the sun is due West and negative if the sun is due East

AST Apparent Solar Time, or true solar time

d declination angle of the sun with respect to the centre of the earth, d = +23.44 deg at Summer Solstice and d = -23.44 deg at Winter Solstice. Different declination angles correspond to the different days of the year (Table 4)

Table 4: Mean value of the solar declination (for l99l, noon UT (GMT), abstracted from The Nautical Almanac l99l, HMSO, UK [from Ref. 13]

DAY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1	-23 01	-17 10	-07 40	+04 27	+15 01	+22 02	+23 08	+18 04	+08 22	-03 06	-14 22	-21 46
2	-22 56	-16 53	-07 17	+04 50	+15 19	+22 10	+23 03	+17 49	+08 00	-03 29	-14 41	-21 55
3	-22 51	-16 35	-06 54	+05 14	+15 37	+22 17	+22 59	+17 34	+07 38	-03 53	-15 00	-22 04
4	-22 45	-16 17	-06 31	+05 36	+15 54	+22 24	+22 54	+17 18	+07 16	-04 16	-15 18	-22 13
5	-22 38	-15 59	-06 08	+05 59	+16 11	+22 31	+22 49	+17 02	+06 54	-04 39	-15 37	-22 20
6	-22 31	-15 41	-05 45	+06 22	+16 28	+22 38	+22 43	+16 46	+06 32	-05 02	-15 55	-22 28
7	-22 24	-15 23	-05 22	+06 45	+16 45	+22 44	+22 37	+16 29	+06 09	-05 25	-16 13	-22 35
8	-22 16	-15 04	-04 59	+07 07	+17 02	+22 50	+22 30	+16 12	+05 47	-05 48	-16 30	-22 42
9	-22 08	-14 45	-04 35	+07 30	+17 18	+22 55	+22 23	+15 55	+05 24	-06 11	-16 48	-22 48
10	-21 59	-14 25	-04 12	+07 52	+17 34	+23 00	+22 16	+15 38	+05 01	-06 34	-17 05	-22 54
11	-21 50	-14 06	-03 48	+08 14	+17 49	+23 04	+22 08	+15 20	+04 39	-06 56	-17 22	-22 59
12	-21 41	-13 46	-03 25	+08 36	+18 05	+23 08	+22 00	+15 02	+04 16	-07 19	-17 38	-23 04
13	-21 31	-13 26	-03 01	+08 58	+18 20	+23 12	+21 52	+14 44	+03 53	-07 41	-17 54	-23 08
14	-21 21	-13 06	-02 37	+09 20	+18 35	+23 15	+21 43	+14 26	+03 30	-08 04	-18 10	-23 12
15	-21 10	-12 45	-02 14	+09 41	+18 49	+23 18	+21 34	+14 07	+03 07	-08 26	-18 26	-23 15
16	-20 59	-12 25	-01 50	+10 03	+19 03	+23 21	+21 24	+13 48	+02 44	-08 48	-18 41	-23 18
17	-20 47	-12 04	-01 26	+10 24	+19 17	+23 23	+21 14	+13 29	+02 21	-09 10	-18 56	-23 21
18	-20 35	-11 43	-01 02	+10 45	+19 30	+23 24	+21 04	+13 10	+01 57	-09 32	-19 10	-23 23
19	-20 23	-11 21	-00 39	+11 06	+19 43	+23 25	+20 53	+12 51	+01 34	-09 54	-19 25	-23 25
20	-20 10	-11 00	-00 15	+11 27	+19 56	+23 26	+20 42	+12 31	+01 11	-10 16	-19 38	-23 26
21	-19 57	-10 38	+00 09	+11 47	+20 08	+23 26.4	+20 31	+12 11	+00 47	-10 37	-19 52	-23 26.3
22	-19 44	-10 17	+00 33	+12 07	+20 21	+23 26	+20 19	+11 51	+00 24	-10 58	-20 05	-23 26.4
23	-19 30	-09 55	+00 56	+12 28	+20 32	+23 26	+20 07	+11 31	+00 01	-11 20	-20 18	-23 26.1
24	-19 16	-09 33	+01 20	+12 47	+20 44	+23 25	+19 55	+11 11	-00 23	-11 41	-20 30	-23 25
25	-19 01	-09 10	+01 44	+13 07	+20 55	+23 24	+19 42	+10 50	-00 46	-11 01	-20 42	-23 24
26	-18 46	-08 48	+02 07	+13 27	+21 05	+23 22	+19 29	+10 29	-01 09	-12 22	-20 54	-23 22
27	-18 31	-08 26	+02 31	+13 46	+21 16	+23 20	+19 16	+10 09	-01 33	-12 42	-21 05	-23 20
28	-18 15	-08 03	+02 54	+14 05	+21 26	+23 18	+19 02	+09 47	-01 56	-13 03	-21 16	-23 18
29	-17 59		+03 18	+14 24	+21 35	+23 15	+18 48	+09 26	-02 19	-13 23	-21 26	-23 15
30	-17 43		+03 41	+14 42	+21 44	+23 11	+18 34	+09 05	-02 43	-13 43	-21 36	-23 11
31	-17 27		+04 04		+21 53		+18 19	+08 43		-14 02		-23 07

Note: Declination to north of the Equator is positive, to south is negative; thus for 11 Jan l99l, solar declination angle was 21 deg 50 min south of the Equator.

h solar altitude angle

L geographical latitude of a place at Northern Hemisphere

OQ, OM etc. alphabets with a line underneath mean a line joining the points denoted by the alphabets

t hour angle, t = 0 deg for solar noon (i.e. AST l2:00 noon), for one hour, the hour angle elapsed is l5 deg, t is positive for AST p.m. and negative for AST a.m.

x,y,z co-ordinates of the simulated sun at Equinox in the Cartesian X, Y, Z co-ordinate system of this paper

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APPENDICES

Appendix A - Calculations for Fig. 1

MQ = QN = OQ tan(d)

= OQ tan(23.44 deg)

Therefore MN = 2 MQ = 2 QN

Appendix B - Calculations for Fig. 2

x, y, z represent the co-ordinates of the light emitting element (i.e. point Q, Fig. 2, Table 3) of the lamp at Spring/Autumn equinox, with the lamp fitted to the straight light trough.

x = OQ cos t sin L

y = -OQ sin t

z = OQ cos t cos L

Note: - sign is introduced to suit the convention of the Cartesian X, Y, Z co-ordinate system.

Appendix C - Calculations for Fig. 7 and Table 1, on the relationship among the locations of the lamps, the reference centre of the equipment, and solar declination angle

See Appendix A for the relations among MQ, QN, OQ, MN, QN.

For a lamp locating at point R simulating the sun at a day having solar declination angle d, RQ = OQ tan(d)

Note: For the heliodon (Fig. 7), OQ = 1789mm (Table 1), i.e. the light emitting element of the lamp simulating Equinox day is 1789mm from the reference centre O of Fig. 7.

Example:
For d = 11 deg 39 min, (Fig. 7)
RQ = OQ tan(d)
= 1789 mm tan(11.65 deg) = 368.9mm
(Table 1)