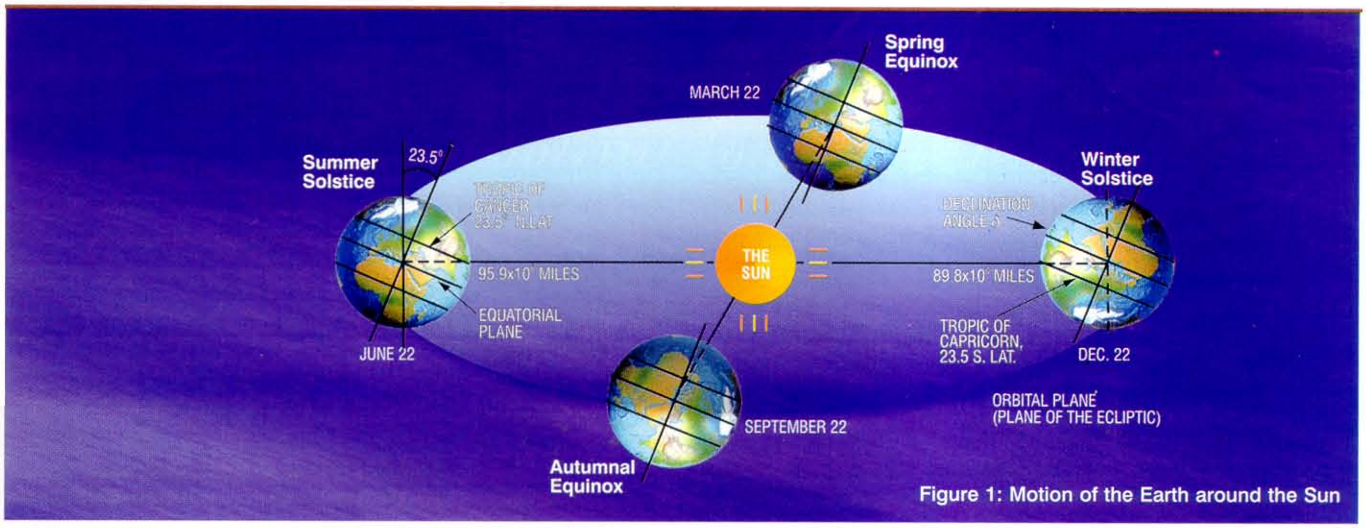

Figure 1: Motion of the Earth around the Sun

Where is the Sun? How does it impact your building?

By R. V. Simha
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Solar gain through glazing is a conspicuous item in all heat gain calculations due to solar gain for buildings. The geographical location, the orientation and the distribution of glazing on the envelope of the building are some of the parameters that play an important role in these calculations. This article discusses all these aspects in relation to the positions and the movements of the Sun. Views showing several elevations of the Sun, have been employed to help enhance visualization of the phenomenon. The concepts are illustrated by citing examples of Delhi and Bangalore. The importance of looking critically and analytically at these aspects of solar gain in relation to the prevailing scenario of ever increasing emphasis on conservation of energy is stressed. It is also pointed out that HVAC engineers are in the best position to help project the aspects discussed to architects, owners and others involved in building design and construction.

Background

It is common knowledge that contemporary architecture favours glass and chrome buildings. *Curtain walls* with structural glazing are the order of the day. These features, which emphasize the contemporary trends in buildings, have been driven mainly by aesthetics. While chrome and glass produce eye-catching and glittering buildings, they also compel, at the same time, considerations of the consequences on the quality of the built-in environment - which includes temperature, glare-free day lighting and energy costs. Notwithstanding these concerns, we are all aware that, aesthetics is compelling. As engineers, power and energy considerations are equally compelling for us. The challenges before the architects and engineers are therefore to produce buildings, which satisfy the architect and the owners' goal of producing attractive buildings, while, at the same time, ensuring optimum owning costs.

Some four to five decades ago, buildings used to have a lot of masonry in them. Power and energy costs were not occupying center place in the scheme of things. But the 70's changed all that. Power and energy became everybody's concern. The term *Energy Efficient Buildings* was coined. At about the same time, buildings with *curtain walls* came into vogue. In some cases, it has been found that as much as 25 percent of the building cooling load turns out to be due to the radiation

About the Author

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heat gain through the glazing. Engineers were driven to design plants and systems not just to achieve and maintain stipulated conditions, but also to achieve that goal with minimum power and energy penalties.

The Elements Of Solar Gains

The radiation gains are due to the incidence of the Sun's rays on the surface of the glazing. This is impacted by -

- Position of the Sun.
- The geographical location of the building.
- The orientation of the building.
- The distribution of glazing on the envelope of the building.
- The thermal characteristics of the glazing employed.

Of the five points noted above, obviously, our concern will be with the first four only.

So, Where Is The Sun?

Everybody knows that the Sun rises in the east and sets in the west everyday. However, while this is true, it is a simplistic perception. The fact is that sunrise does not occur in the east at the same position each day nor is the sunset (in the west) at the same position everyday. This position keeps shifting from the north of the *Equatorial Plane* to the south of the *Equatorial Plane* and then again back to the north across the equator over a period of one year.

The axis of the Earth (the line through the center of the Earth joining the two poles) is tilted by an angle of 23½ ° from the perpendicular to the *plane of the ecliptic*. This is the same thing as saying that the Earth's *Equatorial Plane* is tilted by 23½ ° to the plane of the Earth's orbit. The solar declination (i.e., the angle between the Earth-Sun line and the *Equatorial Plane*) varies through out the year. It is this variation of solar declination that causes the north-south and the south-north movement of the Sun. It is primarily responsible for the changing seasons.

The Sun moves from a latitude of 23½ ° north (Tropic of Cancer) to a latitude of 23½ ° south (Tropic of Capricorn) and back to 23½ ° north during the course of a year.

Longest day of year tomorrow

Times of India June 21, '06

New Delhi : Tomorrow (June 22) will be the longest day of the year in the northern hemisphere. The phenomenon is called summer solstice. On the day of the summer solstice, the sun rays are perpendicular on the Tropic of Cancer.

In India, Ujjain, Ranchi, Durgapur and Bardwan are close to the Tropic of Cancer and on the day of 'solar solstice' there will be no shadow of any object under the Sun in these locations.

There will be one latitude on Earth where sunrays are perpendicular on any day of the year. On two special days, the equinoxes, the sunrays are perpendicular on the equator.

At the peak of summer, in the northern hemisphere, the Sun is vertically overhead at the Tropic of Cancer; this is called the *summer solstice (June 22)*. Likewise, the Sun is vertically overhead at the Tropic of Capricorn (23½ ° south) on December 22. This represents the *winter solstice*. December 22 is the peak of winter for the northern hemisphere, while it is the peak of summer in the southern hemisphere. From December 22 to June 22, the Sun is going back from the south to the north.

During the southward movement from the Tropic of Cancer, the Sun passes over the Equator (0° latitude) on September 22. This is called the *autumnal equinox*. Likewise - again - it passes over the Equator on its northward journey - on March 22. This is called the *spring equinox*.

On the day of the *summer solstice*, the northern hemisphere has the maximum number of daylight hours and minimum number of hours of darkness. On the day of the *winter solstice* the number of daylight hours will be minimum and number of hours of darkness will be maximum (in the northern hemisphere). The reverse applies to the southern hemisphere.

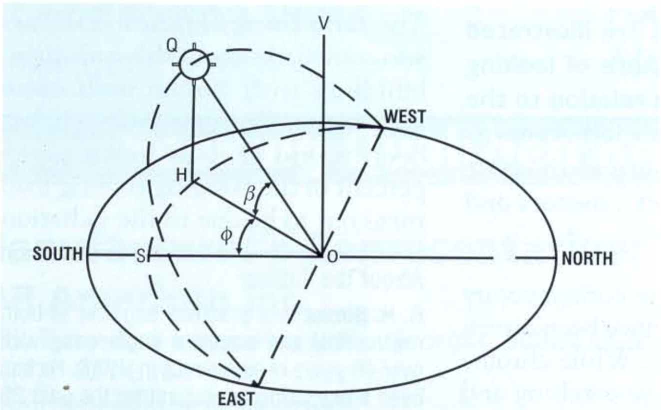

Figure 2 : Apparent daily path of the Sun showing Solar Altitude (β) and Solar Azimuth (ϕ).

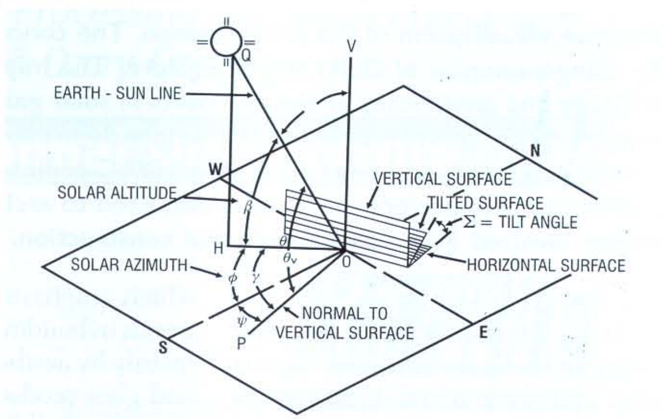

Figure 3 : Solar Angles for vertical and horizontal surfaces.

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Glossary

Curtain walls: The external facade or "skin" of a building, made of light-weight construction, generally glass, instead of brick masonry. It is a very common feature in modern day office buildings.

Equatorial plane: An imaginary plane passing through the Earth's equator dividing the Earth's surface into the northern and southern hemisphere. It is at right angle to the Earth's axis and is equidistant from the poles. *(See figures 1, 2 and 3)*

North light: Glass panes provided on the north-facing drops of roof trusses to allow diffused (instead of direct) sun light into the space. Commonly used in industrial buildings.

Earth's orbit or Ecliptic plane: The plane of the Earth's annual path or orbit around the Sun, as seen from the Sun. *(See figures 1, 2 and 3)*

Solar altitude angle (β): The angle in the plane of the Earth-Sun line between the Earth-Sun line and the horizontal surface. *(See figures 1, 2 and 3).*

Solar azimuth angle (ϕ): The angle between the north-south line and the vertical plane passing through the Earth-Sun line intersecting the horizontal surface. *(See figures 1, 2 and 3)*

On the day of the spring and autumnal equinoxes, the number of hours of daylight and darkness are equal everywhere on earth.

(Please refer *Figures 1, 2* and *3* and the Glossary for a better understanding of the relevant planes and angles in the Sun-Earth scenario.)

Living in India, we are mainly concerned about what happens in the northern hemisphere and it is therefore worthwhile focusing on it more sharply. For cities north of the Tropic of Cancer, the Sun is never vertically overhead at any time. A typical case is Delhi, which has a latitude of 29°N. The Sun will never be closer to the vertical than 5.5° - which occurs on June 22.

In cities between the Tropic of Cancer and the Tropic of Capricorn, the Sun passes vertically overhead twice a year. Consider Bangalore (latitude 13°N), for example. The Sun passes vertically overhead during end April and will be north of the east-west line thereafter - and on June 22, it will be 10½ ° to the north of the vertical. Again, as the Sun travels southwards following the *summer solstice*, it is vertically overhead in the middle of August.

Thereafter, when the Sun reaches the Tropic of Capricorn in December, it will be south of the vertical by 36½ °. This represents the winter-peak situation.

In Delhi, the corresponding angle between the Sun's position and the vertical will be 58° - again, south of the vertical.

Viewing The Sun Paths

The Sun's positions can be shown on solar charts in terms of the *Azimuth* (ϕ) and the *Altitude* (β); but they may be regarded only as plan views of movement of the Sun. Such a chart can be constructed for any city (once the latitude is known). To meet our specific requirements, it is however, necessary to visualize the building of interest, with respect to this chart. We need to know how the Sun's position, affects the solar gains on our building - on its various exposures and at different hours of the day and different parts of the year.

Figures 4 and 5 depict the effect of seasonal movement and daily movement of the Sun on various exposures, but with particular reference to summer and winter and the north and south exposures. The cities chosen are Delhi and Bangalore. *Figure* 6 in particular, furnishes (in the same figure) comparative positions of the Sun at these two stations in peak winter.

It is the selection of specific cities (Delhi and Bangalore) and providing additional views that enhances the scope of visualization of the Sun's positions (with respect to the building). Given a table of *Altitude* and *Azimuth (Table-1)*, solar charts can be constructed for any station. Likewise, additional views can be worked out.

The process of plotting the Sun's path or the solar chart is explained step-by-step separately in this article. *See box - Process of Plotting the Solar Chart on page 48.*

Delhi and Bangalore Compared

Certain features emerge from a study of the sketches furnished in *Figures* 4, 5 and 6.

At latitudes higher than 23½ ° north (Delhi - 29°N), the north wall is essentially in shade in the summer; it is not illuminated between about 9.00 a.m. and 4.00 p.m. In other words, this wall is shaded during the hottest parts of the 24 hour day. Beyond these hours viz., in the mornings upto 9.00 a.m. and in the evening beyond 4.00 p.m., the north exposure is in fact illuminated; but there are three mitigating features:

- The angle of incidence (on the vertical surface) is low.
- If required, vertical breakers can be provided to keep the Sun away. These breakers will be of moderate dimensions.
- Even in peak summer the Sun does not quite go overhead, as the altitude is only 82°. (The margin by which the Sun fails to make it overhead is about 5.5°).

Compare this, on the other hand, with the situation at Bangalore.

It will be seen that between end April and mid-August, the Sun passes overhead twice. In mid April, the Sun is directly overhead; between end April and June 22, it is moving northwards to the Tropic of Cancer. And from June 22, it passes directly overhead again, in mid

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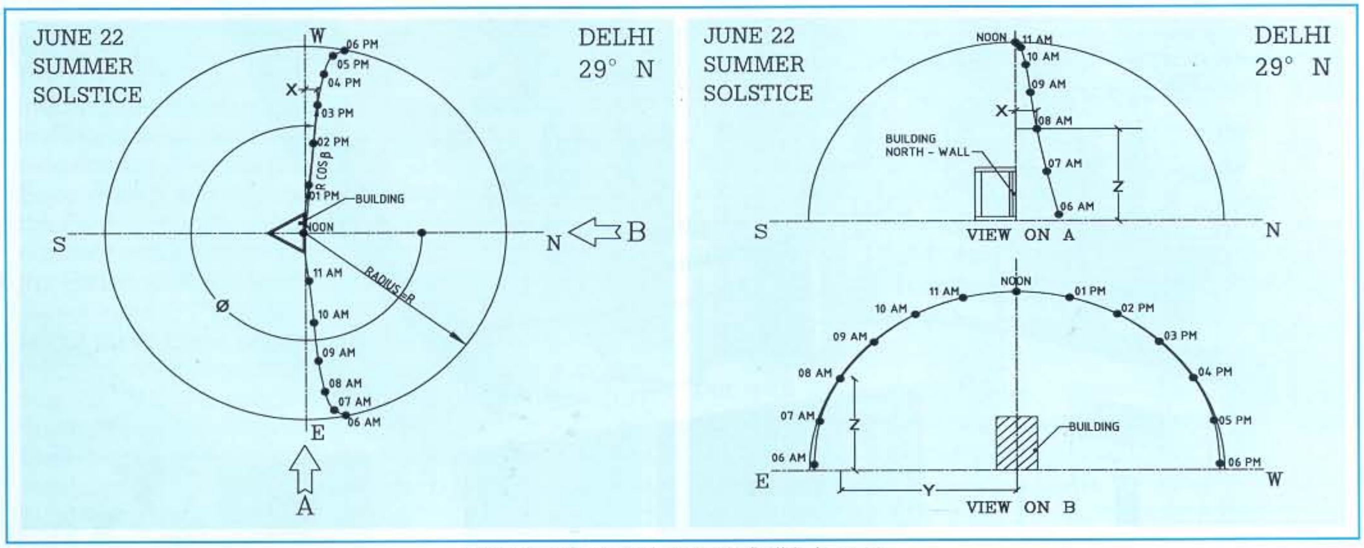

Figure 4 : Summer Solstice in Delhi, June 22

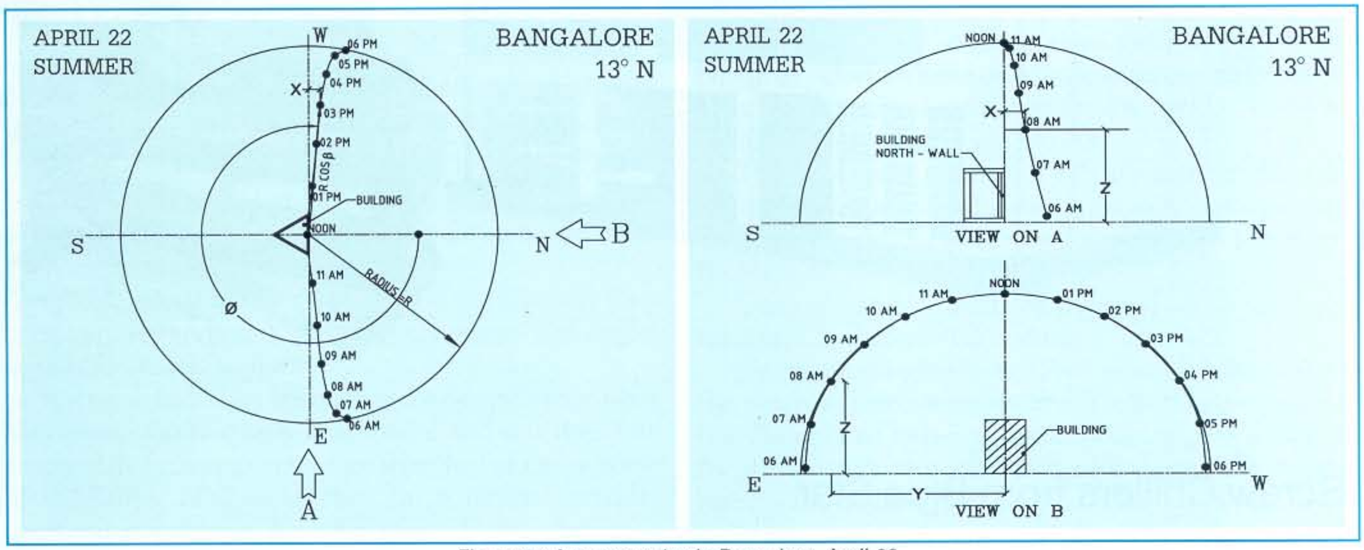

Figure 5 : A summer day in Bangalore, April 22

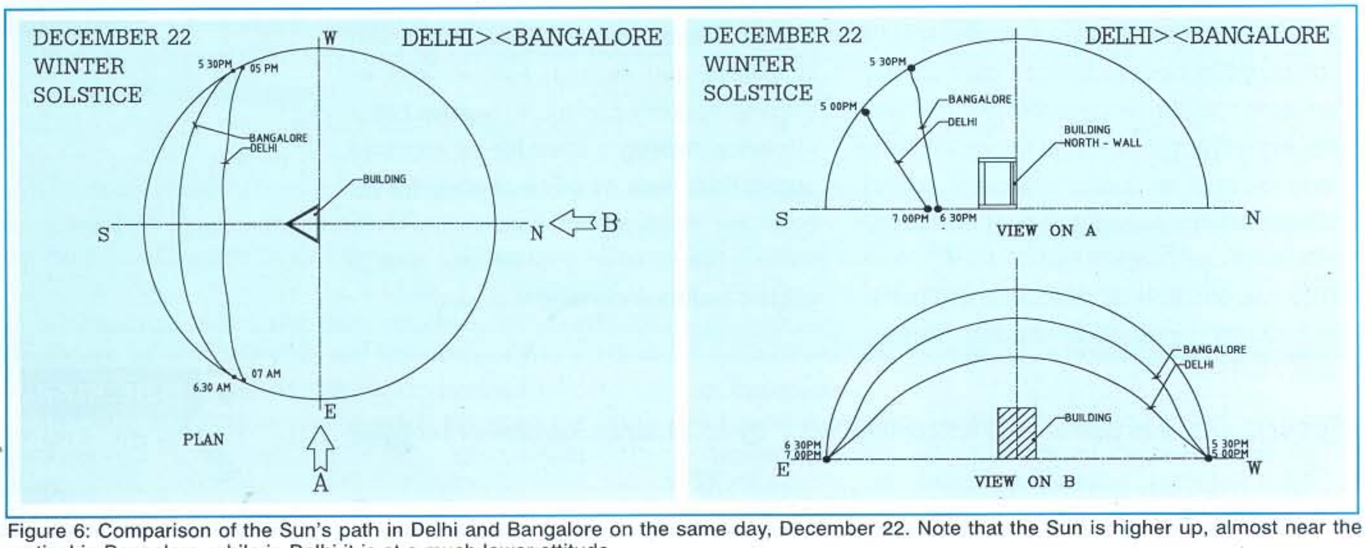

Figure 6: Comparison of the Sun's path in Delhi and Bangalore on the same day, December 22. Note that the Sun is higher up, almost near the vertical in Bangalore, while in Delhi it is at a much lower attitude.

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Process of Plotting the Solar Chart

Following are the steps involved in plotting the Sun's path with respect to a building:

Example: To plot the Sun's path with respect to a building located in Delhi.

Step 1: Note down the latitude of the place where the building is located from the world Atlas. In this example, Delhi is at 29° N.

Step 2: Refer the solar altitude (β) and azimuth (ϕ) angles given in Table 1. This table is available in several technical manuals including the *Carrier Handbook of Air conditioning System Design* - 1965. (Part I, Chapter 4-Solar Gain Through Glass, Table 18).

Step 3: Decide on the time and day of the year at which you want to plot the Sun's position. Let us start with plotting the Sun's position at 11 am on June 21.

Step 4: Note the solar altitude (β) and azimuth (ϕ) angles from the Table (step 2). In case the data for the exact latitude is not available, then choose the data for the closest latitude. Since data for 29° N is unavailable, we choose 30° N. Hence for 11 am, June 21 and 30° N, β =75° and ϕ =112°

Step 5: Draw a circle of any convenient radius, say 10 cm as shown in *Figure 7*. Draw the N-S line passing through the centre O. Plot the angle ϕ of 112° measuring from the north side of the N-S line. *(See Figure 7)*

Step 6: Project a section parallel to the ϕ line around the point O. You thus get a semi-circle as shown in the figure. Plot the angle β = 75° on this section with O as the vertex of the angle. The angle intersects the semi-circle at a point B, which is in fact the Sun's position in space.

Step 7: Extend perpendicular BC to meet the ϕ line on the plan at the point C. Point C is the position of the Sun in a plan view. Different views can be plotted similarly, for further study.

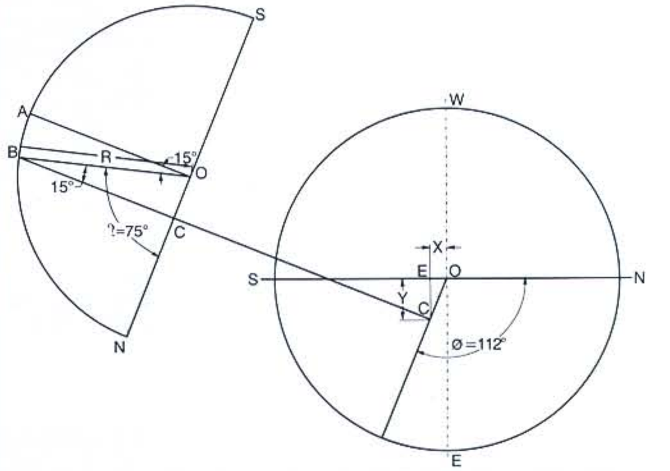

Figure 7 : Illustration for plotting the Sun's position.

Step 8: Repeat steps 4 through 7 for different times of the day, from 5 am to 7 pm. This gives you a locus of points, which when joined together denotes the Sun's path from sunrise to sunset on the particular day, June 21 in this case. In this example, we would get a figure similar to *Figure 4*.

Step 9: Repeat steps 3 through 8 for different days of the year. The resulting diagram would give you the solar chart for all places falling on that latitude. Such solar charts can be extensively used to design buildings that take into account the effect of the Sun.

August on its southward journey. In the interim period - end April and mid August - the north exposure is illuminated. In other words, the north exposure is not in shade. During this period - and thereafter, till end April again, it is the south that is in shade.

Consider now the situation in winter *(Refer Figure 6)*. The Sun is always to the south of the vertical and accordingly, the south wall is illuminated. The altitude during peak winter at Delhi is only about 58°. Because of the low altitude, the Sun is mellow. The shivering Delhites are sure to welcome the Sun - though, to be sure, this occurs only whenever the clouds and smog do not blot the Sun out. The question of the heat gain is, of course, not relevant at this time of the year.

The minimum winter altitude of the Sun is, no doubt, higher at Bangalore (36.5), but still, by and large, the winter Sun is welcome.

Architectural Considerations

The relevance of north light roof trusses

Another interesting point that emerges is that in a location like Bangalore, the north exposure is illuminated about 4 to 5 months in a year (May to September). This occurs during summer.

In an industrial building, *north light roof* trusses are employed mainly, to ensure that the daylight reaching the factory floor is diffused light, and is glare-free; but the fact that the Sun is to the north of the east-west line, means that direct light will enter the building, through the north light glazing. In other words, illumination received is not diffused light, but it is direct light. The purpose of providing the north light roof truss is therefore not achieved.

The above remarks apply to all cities at the same latitude (as Bangalore i.e. 13°). They apply with greater force to cities at lower latitudes as well, that we come across as we approach the tip of the south-India coast - Kerala and Tamilnadu. In other words, in such locations, the application of north light roof trusses is misconceived.

Structural shading and dipsosition of glazing

It is sometimes required to figure-out exposures for which structural shading and internal shading need to be provided.

In a rectangular building, whose walls are parallel to

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NORTH* LATITUDE	SUN TIME	Jan. 21 Alt	Jan. 21 Az	Feb. 20 Alt	Feb. 20 Az	Mar. 22 Alt	Mar. 22 Az	Apr. 20 Alt	Apr. 20 Az	May 21 Alt	May 21 Az	June 21 Alt	June 21 Az	July 23 Alt	July 23 Az	Aug. 24 Alt	Aug. 24 Az	Sept. 22 Alt	Sept. 22 Az	Oct. 23 Alt	Oct. 23 Az	Nov. 21 Alt	Nov. 21 Az	Dec. 22 Alt	Dec. 22 Az	SUN TIME
	6 AM																									6 AM
	7	14	111	15	102	15	90	15	78	14	69	14	66	14	69	15	78	15	90	15	102	14	111	14	114	7
	8	28	113	30	103	30	89	30	77	28	67	27	63	28	67	30	77	30	89	30	103	28	113	27	117	8
	9	42	117	44	106	45	89	44	74	42	63	41	58	42	63	44	74	45	89	44	106	42	117	41	122	9
	10	54	126	58	112	60	89	58	68	54	54	53	49	54	54	58	68	60	89	58	112	54	126	53	131	10
	11	65	144	71	127	75	88	71	53	65	36	62	32	65	36	71	53	75	88	71	127	65	144	62	148	11
LAT	12 N	70	180	79	180	90	0	79	0	70	0	67	0	70	0	79	0	90	0	79	180	70	180	67	180	12 N
0°	1 PM	65	216	71	233	75	272	71	307	65	324	62	328	65	324	71	307	75	272	71	233	65	216	62	212	1 PM
	2	54	234	58	248	60	271	58	292	54	306	53	311	54	306	58	292	60	271	58	248	54	234	53	229	2
	3	42	243	44	254	45	271	44	286	42	297	41	302	42	297	44	286	45	271	44	254	42	243	41	238	3
	4	28	247	30	257	30	271	30	283	28	293	27	297	28	293	30	283	30	271	30	257	28	247	27	243	4
	5	14	249	15	258	15	270	15	282	14	291	14	294	14	291	15	282	15	270	15	258	14	249	14	246	5
	6																									6
	6 AM					1	90	2	78	3	70	4	67	3	70	2	78	1	90							6 AM
	7	10	113	12	103	15	92	16	81	17	72	18	68	17	72	16	81	15	92	12	103	10	113	9	116	7
	8	24	117	27	108	30	95	31	83	32	72	32	68	32	72	31	83	30	95	27	108	24	117	23	121	8
	9	37	124	41	115	44	99	46	84	46	72	45	67	46	72	46	84	44	99	41	115	37	124	35	128	9
	10	48	136	54	125	59	106	61	84	60	67	58	61	60	67	61	84	59	106	54	125	48	136	46	139	10
	11	57	155	64	144	72	122	75	84	73	53	70	44	73	53	75	84	72	122	64	144	57	155	53	156	11
LAT	12 N	60	180	69	180	80	180	89	0	80	0	77	0	80	0	89	0	80	180	69	180	60	180	57	180	12 N
10°	1 PM	57	205	64	216	72	238	75	276	73	307	70	316	73	307	75	276	72	238	64	216	57	205	53	204	1 PM
	2	48	224	54	235	59	254	61	276	60	293	58	299	60	293	61	276	59	254	54	235	48	224	46	221	2
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	4	24	243	27	252	30	265	31	277	32	288	32	292	32	288	31	277	30	265	27	252	24	243	23	239	4
	5	10	247	12	257	15	268	16	279	17	288	18	292	17	288	16	279	15	268	12	257	10	247	9	244	5
	6					1	270	2	282	3	290	4	293	3	290	2	282	1	270							6
	6 AM							4	79	7	71	8	68	7	71	4	79									6 AM
	7	6	114	10	106	14	95	18	84	20	75	21	72	20	75	18	84	14	95	10	106	6	114	5	117	7
	8	19	121	23	112	28	101	32	89	34	79	35	75	34	79	32	89	28	101	23	112	19	121	17	124	8
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	11	47	158	55	152	66	143	72	117	75	88	76	74	75	88	72	117	66	143	55	152	47	158	44	163	11
LAT	12 N	50	180	59	180	70	180	81	180	90	0	87	0	90	0	81	180	70	180	59	180	50	180	47	180	12 N
20°	1 PM	47	202	55	208	66	217	72	243	75	272	76	286	75	272	72	243	66	217	55	208	47	202	44	197	1 PM
	2	40	218	47	227	55	240	59	258	62	275	62	283	62	275	59	258	55	240	47	227	40	218	38	215	2
	3	30	230	36	239	42	252	46	266	48	278	48	283	48	278	46	266	42	252	36	239	30	230	28	227	3
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	5	6	246	10	254	14	265	18	276	20	285	21	288	20	285	18	276	14	265	10	254	6	246	5	243	5
	6							4	281	7	289	8	292	7	289	4	281									6
	6 AM							6	80	10	72	11	69	10	72	6	80									6 AM
	7	2	115	7	107	13	97	19	87	23	79	24	76	23	79	19	87	13	97	7	107	2	115			7
	8	14	124	19	116	26	106	31	95	35	86	37	82	35	86	31	95	26	106	19	116	14	124	11	126	8
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LAT	12 N	40	180	49	180	60	180	71	180	80	180	83	180	80	180	71	180	60	180	49	180	40	180	37	180	12 N
30°	1 PM	38	198	46	201	57	209	67	220	73	238	75	248	73	238	67	220	57	209	46	201	38	198	35	196	1 PM
	2	32	214	40	219	49	230	56	243	61	257	62	264	61	257	56	243	49	230	40	219	32	214	29	211	2
	3	24	226	30	233	38	244	44	256	48	267	49	272	48	267	44	256	38	244	30	233	24	226	21	224	3
	4	14	236	19	244	26	254	31	265	35	274	37	278	35	274	31	265	26	254	19	244	14	236	11	234	4
	5	2	245	7	253	13	263	19	273	23	281	24	284	23	281	19	273	13	263	7	253	2	245			5
	6							6	280	10	288	11	291	10	288	6	280									6
	6 AM							7	81	13	74	15	72	13	74	7	81									6 AM
	7			5	110	12	99	19	91	24	83	26	80	24	83	19	91	12	99	5	110					7
	8	8	125	15	119	23	110	30	102	35	93	37	89	35	93	30	102	23	110	15	119	8	125	5	127	8
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	11	28	164	37	162	48	157	58	151	66	143	69	138	66	143	58	151	48	157	37	162	28	164	25	165	11
LAT	12 N	30	180	39	180	50	180	61	180	70	180	73	180	70	180	61	180	50	180	39	180	30	180	27	180	12 N
40°	1 PM	28	196	37	198	48	203	58	209	66	217	69	222	66	217	58	209	48	203	37	198	28	196	25	195	1 PM
	2	24	211	32	215	42	222	51	231	57	242	60	246	57	242	51	231	42	222	32	215	24	211	21	209	2
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	5			5	250	12	261	19	269	24	277	26	280	24	277	19	269	12	261	5	250					5
	6							7	279	13	286	15	288	13	286	7	279									6
	6 AM							9	83	15	77	18	74	15	77	9	83									6 AM
	7					10	101	18	94	25	88	27	85	25	88	18	94	10	101							7
	8	3	125	10	121	19	114	28	106	34	100	37	97	34	100	28	106	19	114	10	121	3	125			8
	9	10	138	17	134	27	127	37	120	44	114	46	110	44	114	37	120	27	127	17	134	10	138	6	139	9
	10	15	151	23	148	34	143	44	137	52	131	55	128	52	131	44	137	34	143	23	148	15	151	12	152	10
	11	19	165	27	164	39	160	49	157	58	152	61	151	58	152	49	157	39	160	27	164	19	165	15	166	11
LAT	12 N	20	180	29	180	40	180	51	180	60	180	63	180	60	180	51	180	40	180	29	180	20	180	17	180	12 N
50°	1 PM	19	195	27	196	39	200	49	203	58	208	61	209	58	208	49	203	39	200	27	196	19	195	15	194	1 PM
	2	15	209	23	212	34	217	44	223	52	229	55	232	52	229	44	223	34	217	23	212	15	209	12	208	2
	3	10	222	17	226	27	233	37	240	44	246	46	250	44	246	37	240	27	233	17	226	10	222	6	221	3
	4	3	235	10	239	19	246	28	254	34	260	37	263	34	260	28	254	19	246	10	239	3	235			4
	5					10	259	18	266	25	272	27	275	25	272	18	266	10	259							5
	6							9	277	15	283	18	286	15	283	9	277									6
SOUTH* LATITUDE	SUN TIME	July 23		Aug. 24		Sept. 22		Oct. 23		Nov. 21		Dec. 22		Jan. 21		Feb. 20		Mar. 22		Apr. 20		May 21		June 21		SUN TIME

Table 1 : Solar Altitude (β) and Azimuth (φ) angles. (Reproduced from the *Carrier Handbook of Airconditioning System Design - 1965. Part I, Chapter 4 - Solar Gain through Glass.*)

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east-west or north-south axis, difficulties encountered are not appreciable. On the other hand, when the building is not of simple rectangular shape and / or when the orientation differs from east-west and north-south axes, visualization poses greater difficulties. Sketches such as shown in this paper should help in visualization of the problem.

Summary

The approach shown in this paper helps architects to visualize and determine in advance, the various ways in which adequate glazing could be provided at optimum cost - both first cost and operating cost. These necessarily include the quality, the quantum and disposition of glazing.

It will also help engineers to identify and visualize the various exposed surfaces through which heat gain can occur hour-to-hour and also, during the different parts of the year; this visualization will improve his understanding and approach to making energy consumption calculations thereafter.

Till a few decades ago, the architect used to complete his design and forward the drawings to the HVAC engineer to design a suitable air conditioning plant. Decisions on questions like how to orient the building, what material of construction should be used - particularly, glazing, how much of glazing should be used, what kind of shading (structural and internal) should be applied, were arrived at without factoring the impact (of the decisions made) on environmental conditions, power requirements and energy consumption. Today however, architects and owners demand *Energy Efficient Buildings*, without at the same time compromising on aesthetics. This can be achieved if all the factors involved (solar gain is no doubt, one amongst several factors) are factored in the design right from day one. Producing an *Energy Efficient Building* is not the sole responsibility of only the service disciplines - nor for that matter, is it to be thrust on the architects. It should be shared by all members of the design team. And such a design team will include experts from all relevant disciplines and systems like HVAC, electrical, plumbing, structural engineering, civil engineering, interior design, production engineering (in case of industrial projects), etc. It is basically and essentially a team effort.

Energy Efficient Buildings are achieved only by the relentless and dedicated efforts of all fields of expertise involved in producing them, applying latest technologies, innovative design methods and techniques and state-of-art equipment.

Conclusion

Handling solar gains so as to achieve glare-free day lighting without entailing excessive power and energy demands, forms one of the important strategies in producing *Energy Efficient Buildings* of today. A knowledge of the building exposures, which will receive solar radiation during the several hours of the day and the different seasons of the year, enhances the capabilities of the design team to arrive at optimal solutions. This in turn, is facilitated by knowledge of the movement of the Sun, in relation to the building. Architects need to visualize and conceptualize this phenomenon to optimize their design. The HVAC engineer is in the best position to help them in this task.

References

1. *Climatological And Solar Data for India (to design buildings for Thermal Comfort)* - by Central Building Research Institute, Roorkee, - Second Revised Edition 1969 - Published by Sarita Prakashan, Meerut.

2. ASHRAE *Hand Book 1999 - HVAC Applications* - Chapter 32 - Solar Energy Use.

3. ASHRAE *Hand Book 2005 - Fundamentals* - Chapter 31 - Fenestration.

4. *Hand Book of Air Conditioning System Design* - 1965- by Carrier Air Conditioning Company - Part I - Chapter 4 - Solar Gain through Glass - Table 18 - Solar Altitude and Azimuth Angles. ❖