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# Study and Analysis Solar Energy as a Renewable Resource Assessment

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**Keywords**

*Bifurcation Phenomena, Statistica, methodologies, Non-Linearly Coupled Oscillator, Primary Bifurcations, Secondary Bifurcations, Catastrophe Theory.*

**Abstract**

This manuscript contains mainly two parts: 1- the solar energy resource assessment through measurements and comparison of solar irradiance models and analysis of atmospheric turbidity factors; 2- Sensitivity analysis of solar cooling system, monitoring on solar cooling system and pre-design of a solar cooling system test. Firstly, the solar energy resource assessment is based on the measurements of solar beam normal irradiance and solar global horizontal irradiance. Measured data have been compared with clear-sky models and the atmospheric turbidity factors have been calculated and compared with that in 1975-6 to evaluate the airquality variation during the last three decades. Secondly, a series of sensitivity analysis on solar cooling system with various configurations has been undertaken through simulation software Polysun. Field data of solar cooling system. clear-sky model mostly fits the solar beam normal irradiance while it has been found that the solar diffuse radiation factor 'C' (C=Gdh/Gbn) actually not constant but varies all through the day in a typical way; The turbidity factors are lower during winter time due to usage of cleaner fuels and district heating while during summer they increase due to heavier traffic; Solar factor (SF) increases as solar collector area is larger, but its increasing ratio is decreasing and SF decreases as volume size of storage tank is bigger after the demand side is satisfied..

## I. Introduction

This manuscript is focus on solar thermal energy, and it is started from the energy structure. The International Energy Agency (IEA), founded in 1973/4 in response to oil crisis, including 28 member countries, is an autonomous body which works to ensure reliable, affordable and clean energy within the framework of the Organization for Economic Co-operation and Development (OECD). CERT is IEA Committee on Energy Research and Technology. CERT includes four working parties: working party on energy end use technologies, renewable energy technologies, fossil fuels and fusion power co-coordinating committee. Both working parties on energy end use and renewable energy technologies are related to solar thermal energy shown as follows. In the Energy end-use working party, the buildings sector includes District heating and cooling, Energy conservation in buildings and community systems and Energy conservation through energy storage. While in the working party of Renewable energy, there is Solar heating and cooling systems (SHC). SHC is Solar Heating & Cooling Implementing Agreement, which was established in 1976, and its mission is to facilitate an environmentally sustainable future through the greater use of solar design and technologies. In Europe, the status of installed solar driven systems until 2007 is: there are about 100-120 systems, around 8-9 MW cooling capacity. The collector area is approximately 20000 m2. The technologies can be divided as: 60% of absorption, 12% of adsorption, 25% of desiccant solid, and 4% of desiccant liquid. Solar thermal energy (STE) is a technology for harnessing solar energy for thermal energy, namely heat. Classified by the United States Energy Information Administration, Solar thermal collectors are with low-, medium-, or high-temperature. Low-temperature collectors are flat plates generally used to heat swimming pools; medium-temperature collectors are also usually flat plates but are used for heating water or air for residential and commercial use, and high temperature collectors concentrate sunlight using mirrors or lenses and are generally used for electric power production. STE is different from and much more efficient than photovoltaic, which converts solar energy directly into electricity.

### *I.I Solar thermal for air-conditioning*

Around thirty years ago, there was much development of solar energy systems for air conditioning applications particularly in United States and Japan, such as the components and systems. Those activities were terminated mainly because of economic reasons. Nowadays, solar cooling has been prevalent in Europe for many awhile, while it is just become more common in the United States. Research and demonstration projects are carried out in many countries and also in international framework of the SHC-IEA (Solar Heating and Cooling Programme of the International Energy Agency). Particularly the development of the market of high efficient solar thermal collectors, which are nowadays produced on a semi-industrial or industrial level, provides a good starting point for new attempts.) Solar assisted cooling is most promising for large buildings with central air-conditioning systems. However, the growing demand for air-conditioned homes and small office buildings is opening new sectors for this technology. In many regions of the world, air-conditioning represents the dominant share of electricity consumption in buildings, and will only to continue to grow. The current technology, electrically driven chillers, unfortunately do not offer a solution as they create high electricity peak loads even if the system has a relatively high energy efficiency standard. Also, from the environment point of view, solar cooling systems have advantages over conventional air-conditioning ones which use problematic coolants (CFCs), furthermore, less CO2 emissions from solar cooling systems.

## II. Extra-terrestrial solar radiation

The Solar System consists (Selfe 2006) of the Sun and all objects such as the planets and associated satellites, the asteroids, the Kuiper Belt Objects (KBOs) and the comets that orbit the Sun in the far off Oort Cloud. All these objects are gravitationally bound to the Sun. The Solar System was formed approximately five billion

years ago when a cloud of dust and gas was disturbed and coalesced to form the Sun, the planets and a handful of dwarf planets. The light and heat that reach the Earth is essential for the human being's survival and the survival for every creature on the planet.

### *II.I Solar spectra with zero atmosphere*

For calculating the turbidity factor, it is necessary to know the spectral distribution of the extraterrestrial radiation, which is the radiation that would be received without atmosphere. There are several data of solar spectra with zero air mass, and the two main standard ones are 2000 ASTM Standard Extraterrestrial Spectrum Reference E-490-00 (ASTM E-490) and 1985 Wehrli Standard Extraterrestrial Solar Irradiance Spectrum. The ASTM E-490 was developed for use by the aerospace community in 2000 by the American Society for Testing and Materials (ASTM), and the solar spectral irradiance is based on data from satellites, space shuttle missions, high-altitude aircraft, rocket soundings, ground-based solar telescopes, and modeled spectral irradiance. As for the integrated spectral irradiance, it has been made to conform to the solar constant value, 1366.1 W/m 2, which is accepted by the space community. The 1985 Wehrli Standard Extraterrestrial Solar Irradiance Spectrum (also called WMO/WRDC Wehrli Air Mass Zero solar spectral irradiance) was constructed in 1985, and the curve has often been cited for the use of extraterrestrial solar spectral irradiance distribution. To evaluate the two standard spectra, a plot of the two standard spectra was done, and there are slightly small differences between ASTM E490 and Wehrli 1985.

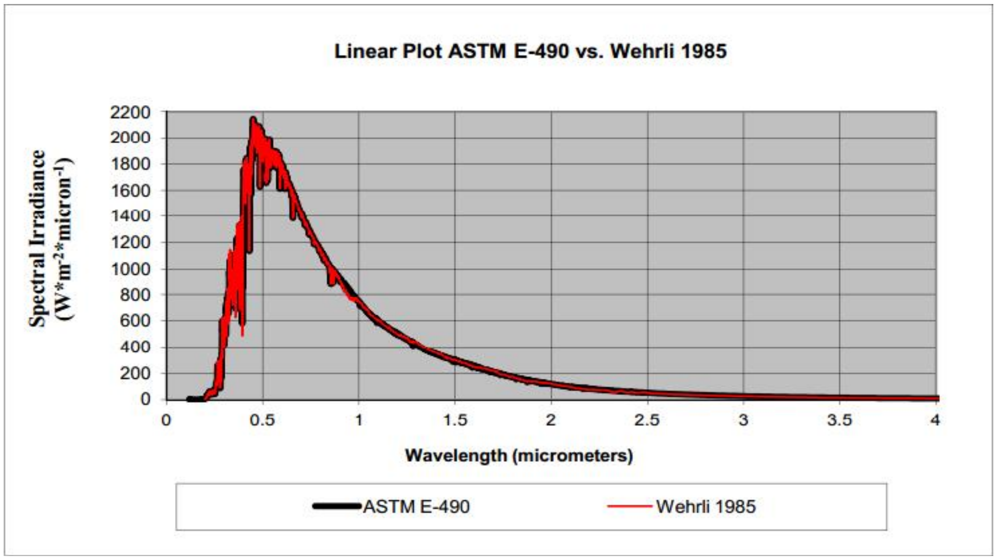


Figure (1) Linear plot of wavelength and spectral distribution for ASTM E490 and Wehrli 1985 on top of the atmosphere for a mean Sun-Earth distance

Solar constant (Gsc) is the energy from the sun per unit time received on a unit area of surface perpendicular to the direction of propagation of the radiation at mean earth-sun distance outside the atmosphere. In the calculation, the ASTM E-490 is used as the solar extra-terrestrial irradiance source, and the solar constant can be found by summing up all products of delta wavelength( Δλ )and spectral irradiance:

$$G_{st} = \sum_{\lambda=0.1195}^{400} \Delta\lambda \times G_{\lambda} = 1367.6\ W/m^2$$

$$\lambda : \mu m$$

$$\Delta\lambda_i = \lambda_{i+1} - \lambda_i \quad i = 1, 2, \cdots, 1696$$

### *II.II The Sun-Earth geometry*

The geometrical relationship between the Sun and Earth affects the solar radiation reaching on the Earth and the Earth's climates.

### A- Variation of Sun-Earth distance

The Sun, with a diameter of 1.39×109 m (about 109 times that of Earth), is around 1.5×1011 m from the Earth. As observed from the Earth, the Sun rotates on its axis about once every four weeks. The Sun does not rotate as a solid body: the equator takes around 27 days, while the Polar Regions take around 30 days.

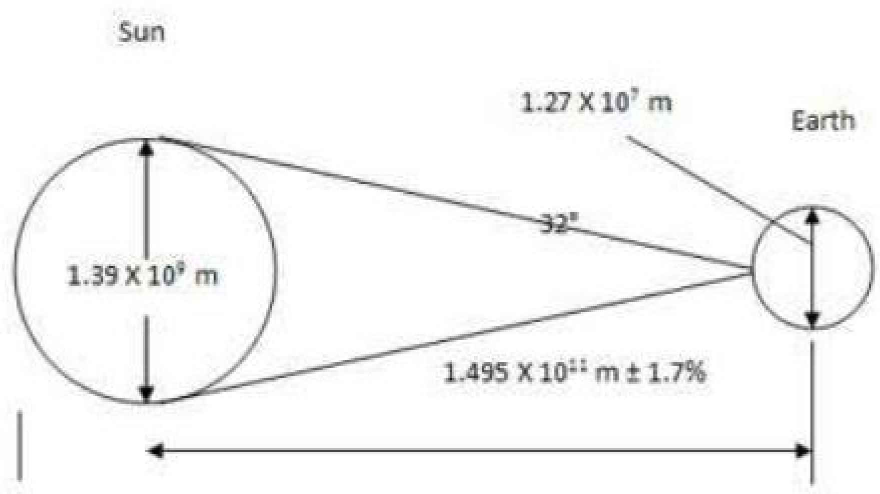


Figure (2) The Sun-Earth geometry relationship

**a. Celestial sphere:** The celestial sphere is a very practical tool for positional astronomy. It is an imaginary sphere of arbitrarily large radius, concentric with the Earth and rotating upon the same axis. Projected upward from the Earth's equator and poles are the celestial equator and the celestial poles (Wiki:Celestial sphere s.d.).

**b. Ecliptic:** The ecliptic is the plane of the Earth's orbit around the Sun. More accurately speaking, it is the intersection of the celestial sphere with the ecliptic plane, which is the geometric plane containing the mean orbit of the Earth around the Sun. The name ecliptic arises because eclipses occur when the full or new Moon is very close to this path of the Sun (Wiki: Ecliptic s.d.).

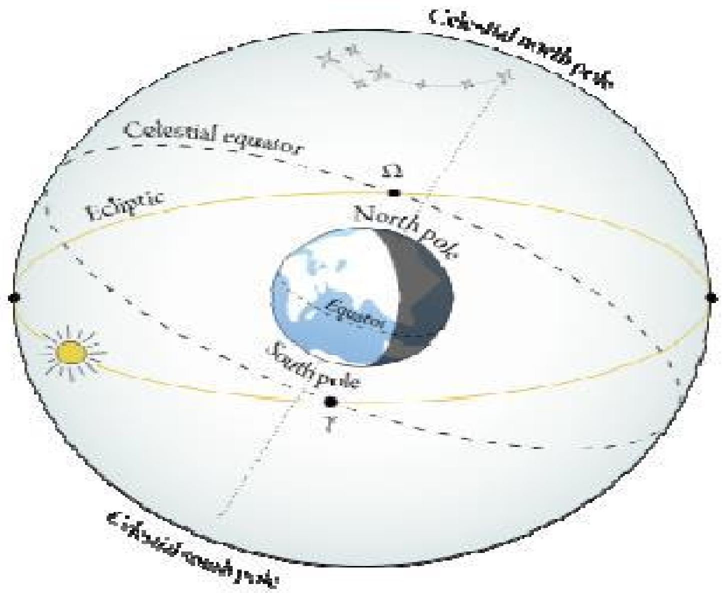


Figure (3) Ecliptic

The term ecliptic describes the centre-line of Zodiac, which extends some eight degrees above and below the ecliptic. In other words, the Zodiac is a belt 160 wide centre on the ecliptic (Ennis s.d.).

### c. Perihelion and Aphelion

The Earth's orbit around the Sun is almost- circular elliptic and the Sun is at the focal point of this ellipse. The Earth moves closer towards and further away from the Sun as it orbits since the Sun is not at the center of the elliptical orbit. The closest point to the Sun in the Earth's orbit is called perihelion which occurs in early January (on January 3rd), while the furthest point is called aphelion which occurs in early July (on July 4th). The terms 'perihelion' and aphelion' came from Greek, as 'helios' mean Sun, 'peri' means near, and 'apo' means away from. The distance from Earth to the Sun is about 147 million km when Earth is at perihelion, 152 million km at aphelion, and the average distance of the Earth from the Sun over a one year period is 150 million km (Perihelion and Aphelion s.d.). The variation of Sun-Earth distance does influence the amount of the extraterrestrial solar radiation intercepted by the Earth, approximately an increase of 6.9% of at perihelion as related to aphelion. Nevertheless, the seasons are not caused by the variation of distance between Sun and Earth. The truth is that the Earth moves fastest at perihelion and slowest at aphelion, and for example, in January the Earth's reaches perihelion when it is winter.

## *B- Earth Revolution*

The two principle movements of the Earth are revolution and rotation. Earth rotates on its axis as it revolves around the Sun. Revolution is the movement of the Earth in an elliptical orbit around the Sun whose average distance is 150 million km away. The elliptical orbit causes the Earth's distance from the Sun to vary at different times of the year. The Earth revolves around the Sun every 365 days and 6 hours which define the astronomical year and also the calendar year. During this time there are 365.25 rotations of the Earth. Due to that extra one quarter day that it takes for the Earth to complete its journey, the calendar of 365 days is corrected once every four years with an additional day to February when the so-called Leap Year arrives.

### *1. Inclination of the Earth's axis*

The Earth's polar axis is not perpendicular to the plane of the ecliptic, but inclined at a fixed angle of about 23.5° from the perpendicular to the ecliptic. As the Earth revolves about the Sun, the angle of inclination of the earth's axis in relation to the plane of the ecliptic is constant, and this is known as the parallelism of the axis (currently toward Polaris, the North Star). However, the relative position of the Earth's axis to the Sun (The direction of solar irradiance and the direction the Earth's axis leaning towards) does change during this cycle which causes seasons and day lengths of day due to the change of the height of Sun above the horizon annually. The Earth's axis is tilted relative to the perpendiculars to the ecliptic plane by an angle of 23.5°, which causes the circle of the ecliptic to be tilted relative to the celestial equator again by the same angle, which as a result is called the obliquity of the ecliptic. In fact, the tilt of the Earth changes slightly, with a dominant cycle every 41,000 years (Movements of the Earth s.d.). The change in angle of inclination is only 1 degree from the present tilt, from 23.5° to 24.5°. However, Earth's tilt is a critical factor in climate resulting in very large differences in solar radiation. Changes in Earth's angle with respect to the Sun often go by the name 'obliquity'.

### *2. Seasons, Solstice and Equinox*

The circumstance of tilt angle of the Earth's axis also causes seasons by controlling the intensity and duration of sunlight the local position receives on the Earth. Without the inclination of the Earth there would be no seasons. Seasonal time (solstice and equinox) is based on the geometry of the Earth in relation to the Sun during its yearly revolution. Solstice refers to the date when the Sun stands directly overhead of the N-S migration of the location in question, 23.5°N on June 21 or 22 (the summer solstice) and 23.5°S on December 21 or 22 (the winter solstice), while equinox, refers to the date of equal night and day period and this occurs when the Sun at noon is directly overhead at the equator on March 21 (vernal equinox in the northern hemisphere) or on September 23 (autumnal equinox in the northern hemisphere).

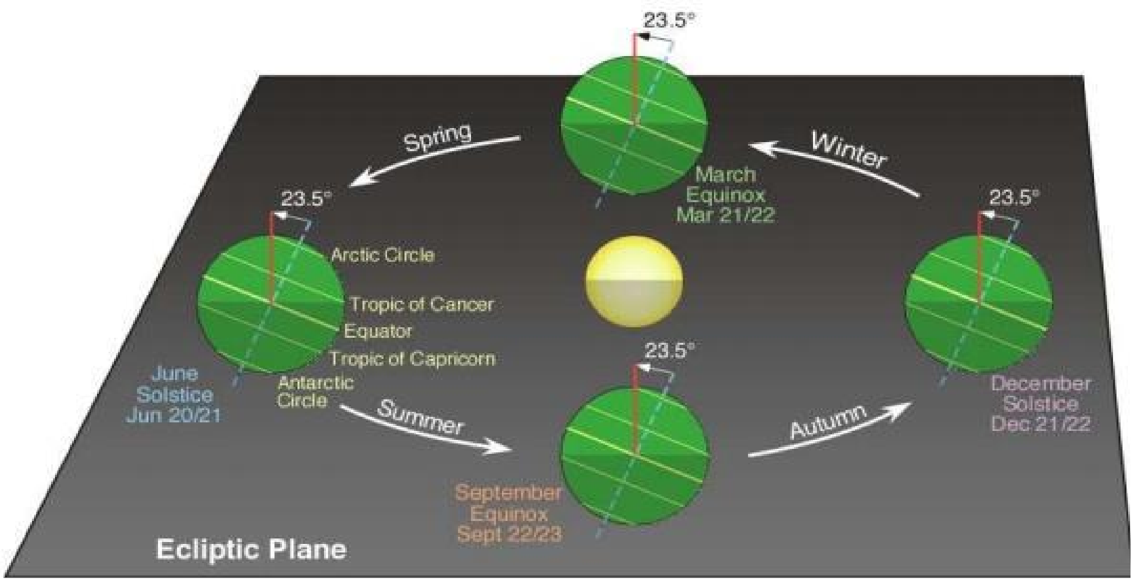


Figure (4) The tilt angle of Earth's axis remains unchanged as season changes

At the times of the solstices, the circle of illumination cuts all parallels except the equator unequally, so that days and nights are unequal in length except at latitude 0. For example, during summer solstice in the northern hemisphere, all locations North of the equator have day lengths greater than twelve hours, while all locations South of the equator have day lengths less than twelve hours. At the times of the two equinoxes, the Sun's noon rays are vertical at the equator, the circle of illumination cuts all parallels in half, so that days and nights are equal (12 hours) over the whole Earth.

### *(3) Earth Rotation*

The Earth Rotation refers to the spinning movement of the Earth on its imaginary axis (North and South Pole). One rotation takes 24 hours, which is called a mean (average) solar day and this is why there is a day and night in each 24 hours (Earth-Sun Geometry s.d.). The direction of Earth rotation is counterclockwise when viewed from above the North Pole, namely, Earth rotates from West to East which explains that the Sun rises in the East and sets in the West apparently. The rotation produces night and day, and due to the tilt angle of Earth, the lengths of day and night change all through the year. The height of the Sun throughout the year changes. During winter, the Sun has lower height at its highest point, while in summer, the Sun reaches its highest point at the sky for the Northern Hemisphere Apparently, the Sun rises in the East and sets in the West, and for a whole year, the Sun rises in the northeast horizon for half of the year, and Southeast for the remainder. This is because the Earth's rotation and the increasing deviation from the eastern horizon with latitude. In a word, the geometry of Sun-Earth (Revolution, Parallelism, tilt angle of Earth, Earth Rotation, oblate spherical shape of Earth, ect.) produces an unequal distribution of solar energy over the Earth and responsible for lengths of night and day, and changes of seasons.

## III. Extra-terrestrial solar radiation reaching on Earth

The solar radiation at normal incidence received at the surface of the atmosphere of the Earth changes due to the variation of extra terrestrial radiation which is inflected by variation in the radiation emitted by the Sun and the one of the Sun-Earth distance. For engineering purposes, the energy emitted by the Sun can be considered to be fixed in a view of the uncertainties and variability of atmospheric transmission, while the variation of the Sun-Earth distance leads to the variation of extra terrestrial radiation flux in the range of ±3.3%. Gon is the extra-terrestrial radiation incident on the plane normal to the radiation on the nth day of the year. There are two main equations for calculating Gon: A simple equation (John A. Duffie s.d.) with accuracy adequate for most engineering calculations is given as:

$$G_{on} = G_{sc}(1 + 0.033\cos\frac{360n}{365})$$

And a more accurate equation (±0.01%) is given by Spencer (1971) and cited by Iqbal (1983) as:

$$G_{on} = G_{sc}(1.000110 + 0.034221\cos B + 0.001280\sin B + 0.000719\cos 2B + 0.000077\sin 2B)$$

Where B is the fractional year in radians (Declination s.d.), and given by

$$B = \frac{2\pi}{365}(n-1)$$

Or

$$B = (n-1)\frac{360}{365}$$

And n is the nth day of the whole year.

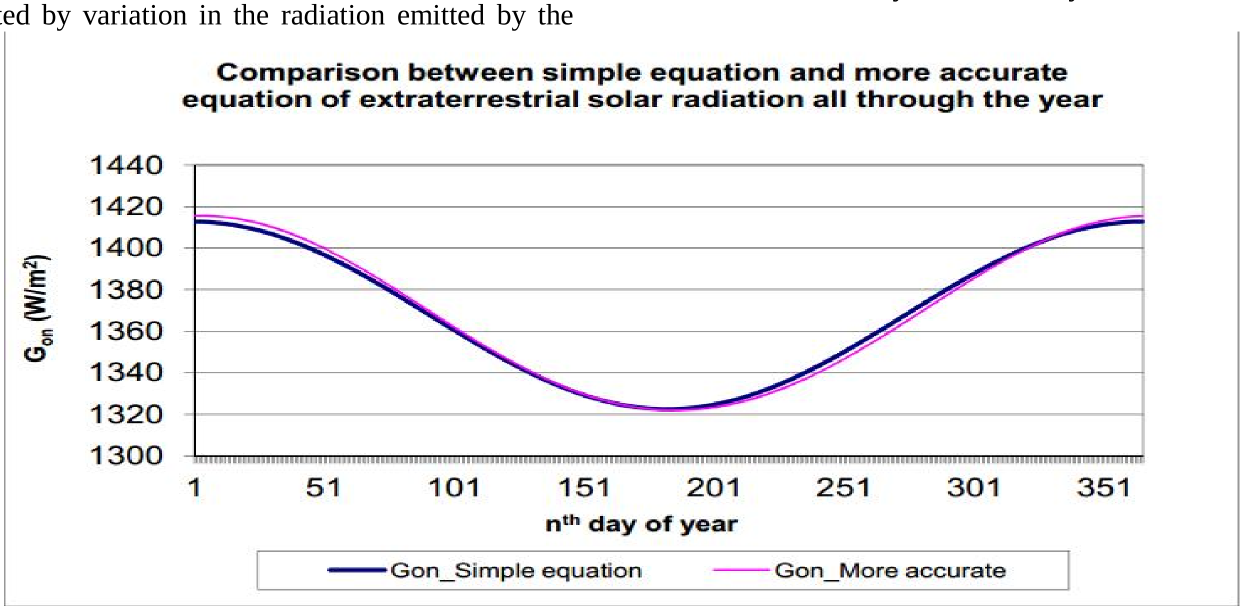


Figure (5) Variation of extraterrestrial solar radiation all through the year

## IV. Solar Time and Angles

In all of the Sun-angle relationships, solar time is used. Solar time is the time based on the apparent angular motion of the Sun across the sky, with solar noon which is the time when the Sun crosses the meridian of the observer. Solar time does not coincide with local clock time, so it is necessary to convert local standard time to solar time by applying two corrections. Firstly, there is a constant correction for the difference in longitude between the observer's meridian (longitude) and the meridian on which the local standard time is based. Apparently the Sun takes around 24 hours to rotate around the Earth, namely, the Sun takes 4 minutes to transverse 1° of longitude. Secondly, there is a correction from the equation of time due to the perturbations in the Earth's rate of rotation which affect the time when the Sun crosses the observer's meridian. The difference in minutes between solar time and standard time is:

$$\text{Solar time} - \text{standard time} = 4\,(L_{st} - L_{loc}) + E$$

where Lst is the standard meridian for the local time zone, Lloc is the longitude of the location in question, and longitudes are in degree west, that is, 0° < L <360°. The parameter E is the equation of time (in minutes) given by Spencer (1971), as cited by Iqbal (1983):

$$E = 229.2 \times (0.000075 + 0.001868\cos B - 0.032077\sin B - 0.014615\cos 2B - 0.04089\sin 2B)$$

It is necessary to note that the equation of time and displacement from the standard meridian are both in minutes. Moreover, there is a 60-min difference between daylight saving time (DST) and local standard time. Time is usually specified in hours and minutes. Air mass (m) is the ratio of the mass of atmosphere through which beam radiation passes to the one it would pass through if the sun were at the zenith. It is a measure of how far the light travels through the earth's atmosphere. One air mass or AM1 is the thickness of the earth's atmosphere. Air mass zero (AM0) describes the solar irradiance in space which is unaffected by the atmosphere. The solar irradiance of AM1.5 is around 1000 W/m 2, while the one of AM0 is considered to be the solar constant Gsc.

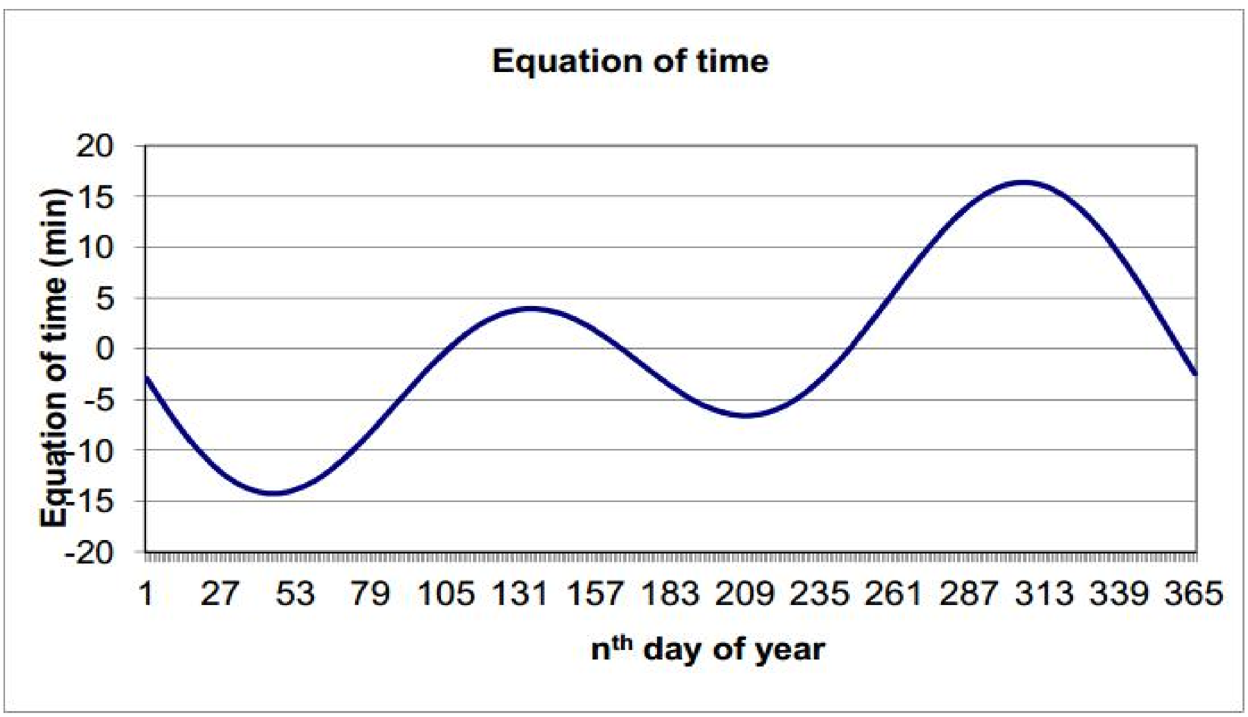


Figure (6) Equation of time varies through a year

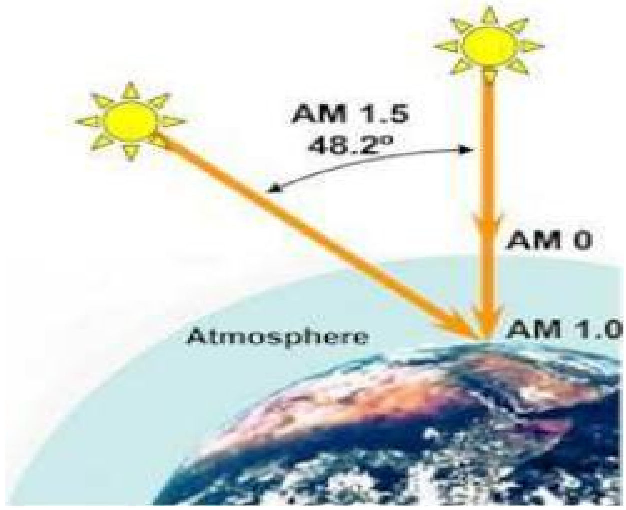


Figure (7) Air mass

For zenith angle DE from 0° to 70° at sea level, to a close approximation:

$$m = \frac{1}{cos\theta_z}$$

An empirical relationship from Kasten and Young (1989) for air mass that works for zenith angles approaching 90° is:

$$m = \frac{e^{(-0.0001184h)}}{cos\theta_z + 0.5057 \times (96.080 - \theta_z)^{-1.634}}$$

Where h is the site altitude in unit of m. The geometric relationships between a plane of any particular orientation relative to the Earth at any time (whether that plane is fixed or moving relative to the Earth) and the incoming beam solar radiation, that is, the position of the Sun relative to that plane, can be described in terms of several angles (Benford and Bock, 1939). Some of the angles are indicated. The angles and a set of consistent sign conventions are as follows:

*Ø* Latitude, the angular location north or south of the equator, north positive; -90̊ ≥ *Ø*90̊ .

¢ Declination, the angular position of the Sun at solar noon (i.e., when the Sun is on the local meridian) with respect to the plane of the equator, north positive, -23.5̊ ≥ ¢ 23.5̊

*ω* Hour angle (°), the angular displacement of the Sun east or west of the local meridian due to rotation of the Earth on its axis at 15° per hour; morning negative, afternoon positive.

$$\omega = \frac{360°}{24hrs} \times (ST - 12) = 15 \times (ST - 12)$$

ST: Standard Time.

Surface azimuth angle, the deviation of the projection on a horizontal plane of the normal to the surface from the local meridian, with zero due south, east negative, and west positive -180≥ γ ≥180.

*θ* Angle of incidence, the angle between the beam radiation on a surface and the normal to that surface. Additional angles are defined that describe the position of the Sun in the sky:

$\theta_z$ Zenith angle, the angle between the vertical and the line to the Sun, that is, the angle of incidence of beam radiation on a horizontal surface.

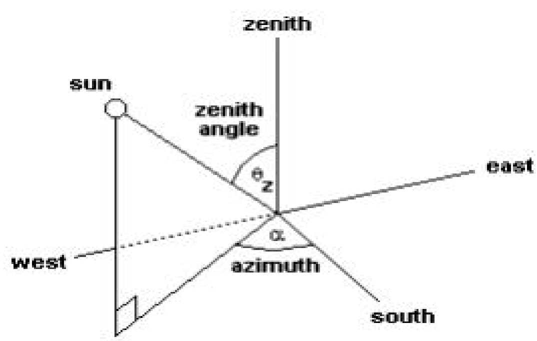


Figure (8) Zenith Angle and Azimuth Angle

Declination angle δ which may be calculated, for engineering purposes, from the approximate equation of Cooper (1969):

$$\delta = 23.45 \times \sin\left(360 \times \frac{284 + n}{365}\right)$$

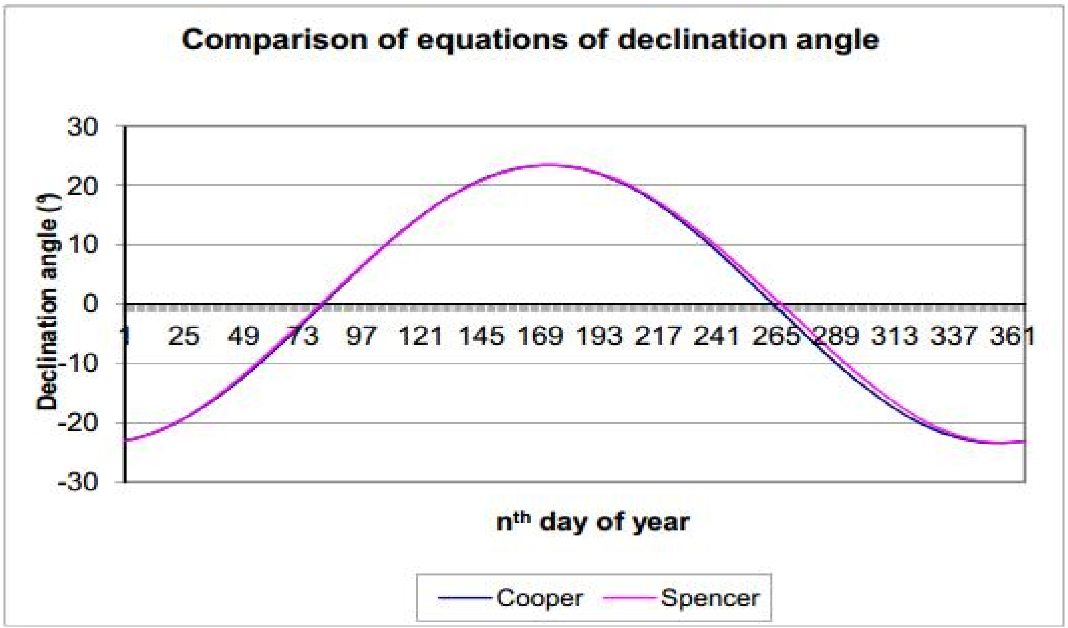


Figure (9) Comparison of equations of declination angle

As the variation in Sun-Earth distance, the equation of time E, and declination are all continuously varying functions of time of year, it is customary to express the time of year in terms of n, the day of the year, and thus as an integer between 1 and 365, for many computational purposes. Note that the maximum rate of change of declination is about 0.4° per day. The use of integer values of n (nth day of the year) is adequate for most engineering calculations. There is a set of useful relationships among these angles. Equations relating the angle of incidence of beam radiation on a surface, θ, to the other angles are:

$$\cos\theta = \sin\delta\sin\phi\cos\beta - \sin\delta\cos\phi\sin\beta\cos\gamma + \cos\delta\sin\phi\sin\beta\cos\gamma\cos\omega + \cos\delta\cos\phi\cos\beta\cos\omega + \cos\delta\sin\beta\sin\gamma\sin\omega$$

And

$$\cos\theta = \cos\theta_z\cos\beta + \sin\theta_z\sin\beta\cos(\gamma_s - \gamma)$$

When the Sun is behind the surface, the angle θ may exceed 90°. Also, when using the first equation, it is necessary to ensure that the Earth is not blocking the Sun (i.e., that the hour angle is between sunrise and sunset). There are several commonly occurring cases for which the first equation is simplified. For horizontal surfaces, the angle of incidence is the zenith angle of the Sun,θz. Its value must be between 0 and 90 when the sun is above the horizon. For this situation, β = 0, and the first equation becomes:

$$\cos\theta_z = \cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta$$

The equation above can be solved for the sunset hour angle $\omega_z$, when $\theta z = 90°$.

$$\cos\omega_s = -\frac{\sin\phi\sin\delta}{\cos\phi\cos\delta}$$

The sunrise hour angle is the negative of the sunset hour angle. It also follows that the number of daylight hours is given by

$$N = \frac{2}{15}\cos^{-1}(-\tan\phi\tan\delta)$$

A convenient nomogram for determining day length has been devised by Whillier (1965). Information on latitude and declination for either hemisphere leads directly to times of sunrise and sunset and day length.

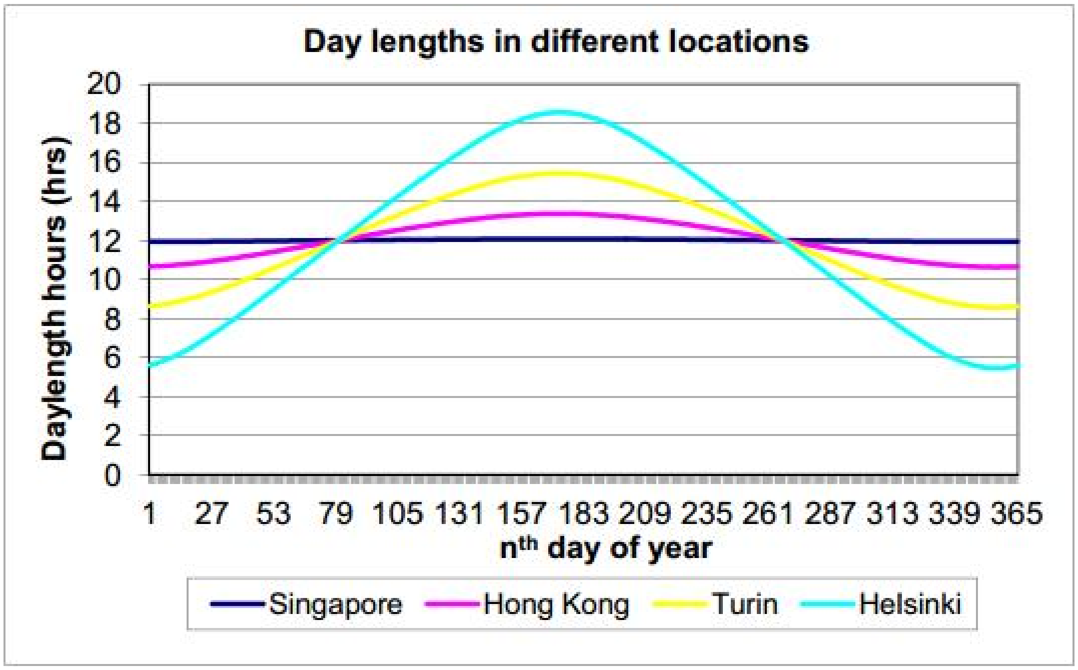


Figure (10) Day lengths all through the year in locations with different latitudes

The Figure above shows how the sunlight hours profile changes depending on several cities latitude. Helsinki is just South of the Arctic, while Singapore is just North of the Equator.

Hemisphere tilts toward the Sun has longer daylight and beam sunlight, while the other hemisphere which tilts away has shorter ones.

## V. Conclusion

From the comparison between measured solar beam normal irradiance and solar global horizontal irradiance, the results shown that the ASHRAE clear-sky model mostly fits the solar beam normal irradiance while the experimental C and C' values are in the average well above the C predicted by the ASHRAE model. The most interesting finding is however that a daily regular oscillation of experimental C values, symmetrical to noon time, occurs, with very high values at the extremities of the day and at noon. These findings may be explained by the limits of the isotropy assumption implicit in the ASHRAE model: as the sun rises, circumsolar sky radiation increases in altitude, and therefore its vertical component tends to become more relevant. On the other hand, for very low altitude angles the vertical component of $G_{bn}$ in equation $Gdh = Gth – Gbn \cos\theta_z$ tend to decrease faster than producing an asymptotical increase of C ratio up to an infinite value for $\theta_z$=90̊ . The regular symmetrical trend is visible in all clear sky days, and further sets of data could lead to a new "clear sky diffuse irradiance" model.

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## AUTHOR PROFILES

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