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The insolation on vertical surface having different directions in the Kingdom of Bahrain

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Abstract

The daily total global (H_T) and diffuse (H_{DIF}) solar radiation, measured at Bahrain International Airport, Kingdom of Bahrain, (latitude 26° 13″N and longitude 50° 39″E), had been recorded, analyzed, and studied. The mean hourly values of H_T and H_{DIF} on horizontal and vertical surfaces (facing North, South, East and West) have been averaged to daily and monthly radiation. The monthly average global solar radiation on a horizontal, vertical north, vertical east, vertical south and vertical west was 22.5, 4.0, 9.4, 11.9 and 11.3MJ/m^2, respectively. The monthly average of the diffuse (H_{DIF}) and direct (H_{DIR}) insolation was found 6.9 and 15.4MJ/m^2, respectively. The direct radiation represents, on average, 69.4% of the total insolation while the diffuse represents 30.6% of it. In comparing these values with previously measured total direct and diffuse in 1996 at the University of Bahrain, Isa Town campus, Kingdom of Bahrain (latitude 26° 20″N and longitude 50° 5″E), we found that the previous records give less percentage of H_{DIR}/H than the recent ones by 10.7%, while the opposite is true for H_{DIF}/H, as the recent is larger by 24.5%. This might be attributed either to the difference in the accuracy of the sensors or to the reduction in the atmospheric pollution, bearing in mind that the distance between the two places does not exceed 50 km. The total insolation incident on vertical west-facing surface was found to, on average, be larger than east facing by 20.2%, and as much as by 50.8% in January and larger by only 11.9% in July.

Keywords: Total and diffuse solar irradiation; Vertical surfaces; Insolation; Daylight; Sustainable buildings

1. Introduction

Bahrain is located at 26.24°N and 50.8°E. It is in the region of the earth between latitudes of 40°N and 40°S, that region is generally referred to the solar belt, where an abundant supply of solar irradiation falls, with the sunshine duration of about 4450 h, and 70% of this sunshine is a clear sky [1,2].

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Table 1
The results of calibration of the sensors

Line	Sensors	UK calib (mV/W/m^2)	UK calib (mV/W/m^2)	Bah calib (mV/W/m^2)	Drift (%)
Ch 09	G	4.72 e – 03	211.9	217.8	2.8
Ch 10	N	4.64 e – 03	215.5	221.0	2.5
Ch 11	E	4.62 e – 03	216.5	207.8	–4.0
Ch 12	S	4.65 e – 03	215.1	209.0	–2.8
Ch 13	W	4.66 e – 03	214.6	222.5	3.7
Ch 14	D	4.68 e – 03	213.7	219.1	2.5

Bahrain is located in the eastern side of Saudi Arabia, consisting of a semi-desert region—due to its extremely low precipitation rate (80 mm/yr), high temperature (up to 45°C). The region had occasional heavy sandstorms during summer and late springtime [3]. This makes the demand for electricity for air conditioning is extremely high. Recently, the demand reached 1500MW, which was in peak of summer (August). Seventy percent of this demand goes for air conditioning. The incorrect architectural design for buildings in this region augments the demand for electricity for cooling and ventilation. Furthermore, the lack of insolation data on vertical surfaces and the improper sizing of the passive insolation into buildings make situations even worse. In fact, within the Arab Gulf region, diffuse and global irradiations on a horizontal plane are currently recorded in a limited number of locations. However, nearly no single station exists to measure the total solar irradiation on vertical surfaces facing North, West, South and West.

The rising cost of electricity as well as the concern of the global environment change has provided the motive for making best use of daylight. Muneer [4] has shown that savings of 20–40% are attainable for office buildings, which utilize daylight effectively.

The electricity production in the Kingdom of Bahrain during 2000 was nearly 7 billion kWh and the consumption was nearly 6 billion kWh. The benefits associated with daylight design are several folds. Reduction of electrical lighting load due to the increased contribution of daylight will result in lower sensible heat gains. This has the knock-on effect of lowering the cooling requirements of a building's air conditioning. As cooling plants are high consumers of electricity, the costs associated with their operation can be as much as four times greater than those of heating. Also the overall efficiency of a cooling plant is only 5%, owing to the energy conversions associated with refrigeration and losses accumulating from electricity generation, transmission, and final consumption. Thus any reduction in electrical lighting load produces a much larger saving in primary energy consumption [4].

This study presents the measurements and analysis of one full year (2002) of the actual total solar irradiation on a horizontal and four vertical surfaces (North, West, South, and East), as well as the diffuse solar irradiation in the Kingdom of Bahrain.

2. Apparatus and data collection

A Solar Radiation Station (Commission Inter national de L'Eclairage-CIE) was installed on top of the administration building (4 m above ground) at the Directorate of Meteorology, Civil Aviation at Bahrain International Airport in Muharraq Island (latitude 26° 13′N and longitude 50° 39′E). The station consists of six pyranometers with a hemispherical field of view. They measure 5-min. average data on horizontal and vertical surfaces (North, East, South, and West).

A pyranometer with a shadow band or shading disc (radius 31.0 cm, width 5.5 cm) is used to block the direct solar radiation, i.e. measures the solar diffuse radiation. The sensors are made by Kipp and Zonen. A data logger is installed at the site to monitor, calculate, and store the data at 5min. intervals. The stored data in mV unit are converted to W/m^2. Special care was taken for daily adjustment of the shadow band ring. The sensors were calibrated using a reference sensors used by UK meteorological [5] as shown in Table 1.

3. Results and discussions

Fig.1 displays the total solar radiation on a horizontal surface (H_T). The maximum radiation was in June, which is expected as the zenith angle (θ_z) has its lowest value throughout the year in Bahrain ($\theta_z = 4°$ on the 21st of July). The recorded monthly average value for this month was nearly 31 MJ/m^2. The direct solar irradiation (H_{DIR}) recorded for this month was 24.4 MJm^{-2} and the diffuse solar irradiation H_{DIF} was 6.5MJ/m^2. The ratio of H_{DIR} to H_{DIF} is nearly 4–1. In December, H_T was the lowest as it reached only 12.2 MJm^{-2}, whileH_{DIR} was only 6.7MJ/m^2 and H_{DIF} was 5.5 MJ/m^2.This is expected since θ_z on 21st December goes as high as 46° in Bahrain, i.e. very low solar altitude (44°). The ratio of H_{DIR} to H_{DIF} in this month was 4.0–3.3.

Table 2 displays the daily averaged global solar irradiation incident on horizontal and vertical (North, East, South, and West-facing) surfaces, as well as the actually measured diffuse (and hence the direct) solar irradiation on a horizontal surfaces. These results are represented in a series of figures.

The direct solar irradiation, on average, represents 69.4% of the total solar irradiation, while the diffuse represents 30.6%. A previous study [6] showed that in Bahrain H_{DIR} represents 62% of H_T, while H_{DIF} represents 38.1%, while maximum H_T was also in June (582 W/m^2) with sunshine duration of 12.1 hs, i.e. $H_T = 25.4$ MJ/m^2, which is slightly less than the recent one (30.9 MJ/m^2). The separation between the two locations does not exceed more than 50 km. The pyranometers used in the previous study was Rotating Shadow Band Pyranometer (RSP) manufactured by Ascension Technology, Inc., Lincoln Centre, and M.A., USA. Assuming that the precision of the sensors were identical, then the higher H_T and H_{DIR}/H_T values can be attributed to the cleaner sky of Bahrain, i.e. less pollution (by 25%) resulted from more steps towards a cleaner environment made by the government and industrial sector.

Fig. 2 shows the results of total solar radiation measured on North-facing vertical surface ($H_{T,N}$). The minimum monthly recorded $H_{T,N}$ value was 2.1 MJ/m^2 (in January) and the maximum was 7.4 MJ/m^2 (in July). This is expected

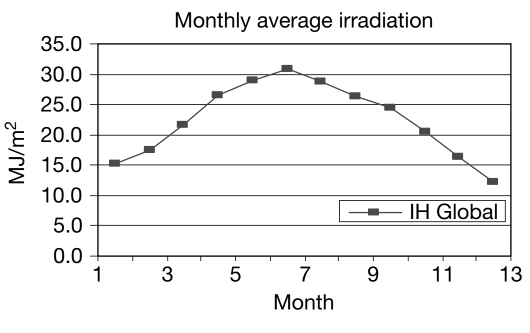

Fig. 1. The actually measured global solar irradiation (H_T) in Bahrain in 2001.

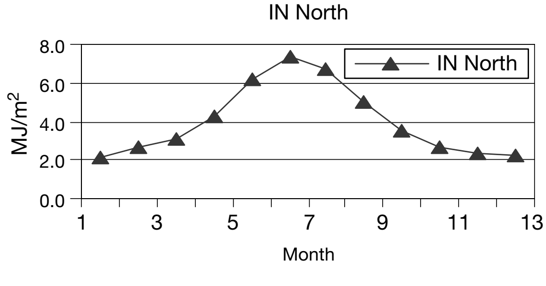

Fig. 2. The actually measured total solar irradiation on a vertical north-facing surface ($H_{T,N}$) in Bahrain in 2001.

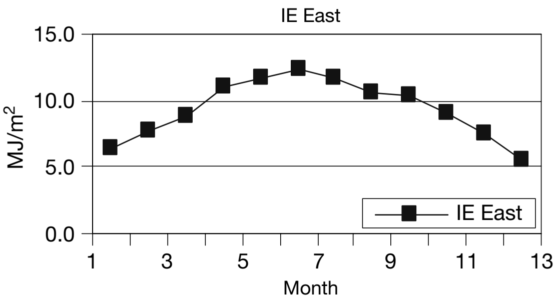

Fig. 3. The actually measured total solar irradiation on vertical East - facing surface ($H_{T,E}$) in Bahrain in 2001.

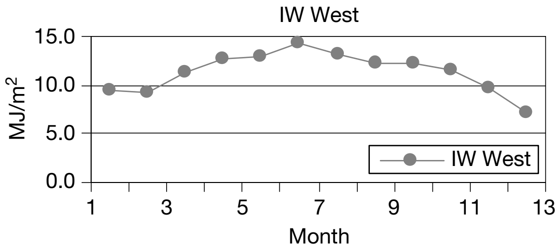

Fig. 4. The actually measured total solar irradiation on a vertical West-facing surface ($H_{T,W}$) in Bahrain in 2001.

as the average measured sunshine duration in January is fluctuating from 8.4 to 10.6 h, while in June it fluctuates from 12.1 to 13.6 h. The solar azimuth at sunrise in Bahrain on 1st January is 116° and at sunset is 224.5° while on the 31st of January; it is at 109° and 251°, respectively. The relatively short daylight period, with less solar intensity due to low value of solar declination (–23°25′), lead us to expect less recorded value of $H_{T,N}$. However, in July, the situation changes substantially. The solar azimuth at sunrise in the 1st of July is 65°9′ and at sunset is 295°, while at 30th of June it is 64° and 296°, respectively. The long daylight period, with high solar intensity, is due to high value of solar declination (+23°25′).

Fig. 3 shows the total insolation on a vertical East-facing surface ($H_{T,E}$). The lowest daily recorded value was 5.6 MJ/m^2 and was in December, while the highest value was 12.4 MJ/m^2 in July, which is expected. Although one expects that similar values should be obtained for the insolation on both vertical West ($H_{T,W}$) and east ($H_{T,E}$) facing surface—because of the expected obvious geometrical symmetry between them [7]—surprisingly, the situation is different herein.

Table 2
The monthly average total solar irradiation (H_T), diffuse (H_{DIF}), direct (H_{DIR}) on a horizontal surface as well as the total solar irradiation on vertical surfaces facing North ($H_{T,N}$), East ($H_{T,E}$), South ($H_{T,S}$) and West ($H_{T,W}$). H_{DIF}% and H_{DIR}% are the percentage of the diffuse and direct solar irradiation to the total solar irradiation (H_T) respectively.

Year	Month	H_T	$H_{T,N}$	$H_{T,E}$	$H_{T,S}$	$H_{T,W}$	H_{DIF}	H_{DIR}	H_{Dif}%	H_{Dir}%
2001	1	15.3	2.1	6.3	17.2	9.5	5.0	10.3	32.7	67.3
2001	2	17.6	2.7	7.7	15.1	9.3	6.4	8.3	32.4	63.6
2001	3	21.6	3.1	8.7	12.5	11.2	7.5	14.1	34.7	65.3
2001	4	26.5	4.2	11.0	9.3	12.7	8.1	18.4	30.6	69.4
2001	5	29.0	6.1	11.7	6.3	13.0	8.8	20.2	30.3	69.7
2001	6	30.9	7.4	12.4	4.7	14.2	6.5	24.4	21.0	79.0
2001	7	28.9	6.7	11.7	5.7	13.1	8.3	20.6	28.7	71.3
2001	8	26.4	5.0	10.7	8.0	12.3	8.8	17.6	33.3	66.7
2001	9	24.4	3.5	10.3	11.7	12.3	7.0	17.4	28.7	71.3
2001	10	20.4	2.6	9.1	16.3	11.5	5.3	15.1	26.0	74.0
2001	11	16.4	2.3	7.4	17.9	9.8	4.7	11.7	28.7	71.3
2001	12	12.2	2.2	5.6	14.3	7.1	5.5	6.7	45.0	55.0
	Average	22.5	4.0	9.4	11.6	11.3	6.83	15.40	31.0	69.0

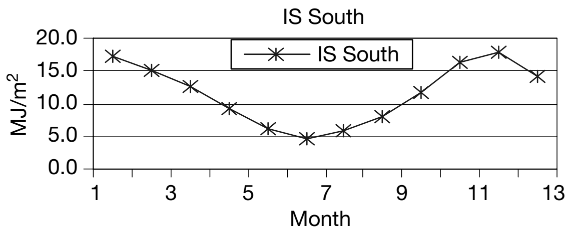

Fig. 5. The actually measured total solar irradiation on a vertical South-facing surface ($H_{T,S}$) in Bahrain in 2001.

Fig. 4 shows that $H_{T,W}$ is different, and larger, than $H_{T,E}$ by nearly 20.2% in average, and as much as by 50.8% in January, and by 11.9% in July. This maybe attributed that insolation is affected by haze, humidity, and aerosols in the early hours of the day in Bahrain, which cause it to reflect back to space and to diffuse.

Fig. 5 shows the total insolation on vertical South facing surface ($H_{T,S}$). It exhibits a classical behavior for regions at the northern hemisphere at middle latitude (23° to 44° N). The maximum insolation was in winter sessions (18 MJ/m^2 > $H_{T,S}$ > 14.3 MJ/m^2) which is expected since the sun is at low altitude, while the least insolation in summer session (8 MJ/m^2 > $H_{T,S}$ > 4.7 MJ/m^2) as

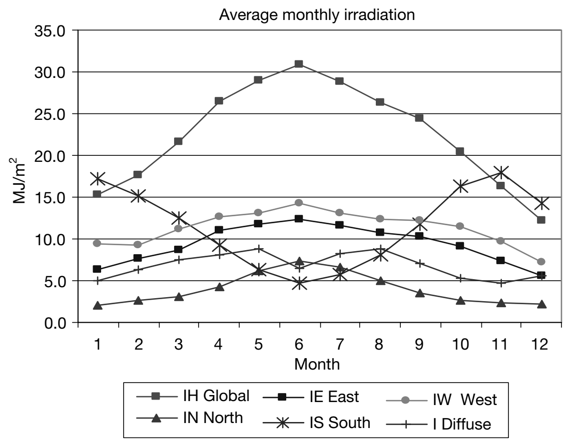

Fig. 6. The monthly variation of H_H, $H_{T,N}$, $H_{T,E}$, $H_{T,S}$, $H_{T,W}$, and H_{DIF} in the Kingdom of Bahrain in 2001.

the sun's altitude is high; although the solar intensity is high during this month. The monthly average insolation on this surface was 11.6 MJ/m^2, which is larger than West (11.3 MJ/m^2), East (9.4 MJ/m^2), and North (4 MJ/m^2), but definitely less than insolation on a horizontal surface (22.5 MJ/m^2). This is clearly illustrated in Fig. 6.

4. Conclusion

The recorded H_T, $H_{T,E}$, $H_{T,W}$, $H_{T,S}$, $H_{T,W}$, H_{DIF} and H_{DIF} show normal pattern. No anomaly is noticed except the slight non-symmetrical shape of $H_{T,W}$ and $H_{T,E}$ (vertical West and East total solar irradiation) where $H_{T,W}$ was found slightly larger than $H_{T,E}$. The data listed in the literature [8] for countries having similar latitude to Bahrain ($\phi = 26°$N, $H = 22.5$ MJ/m^2) such as Karachi, Pakistan ($\phi = 24.8°$N, $H = 19.86$ MJ/m^2), Miami, USA($\phi = 25.8°$N, $H = 16.72$ MJ/m^2) and West Palm Beach, USA, strongly supports our actual measurement—taking into consideration the differences in longitude, elevation from sea level and sky quality.

Further use of this data for modeling the incident solar irradiation on vertical surfaces facing North, East, South, and West in Bahrain and nearby regions, will be published shortly. This will allow architects and engineers to build more environmentally friendly houses and premises (sustainable buildings), i.e. less electricity and energy consumption and environmentally friendly.

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