ARTICLE

일조시간 및 운량을 이용한 태양고도에 따른 수평면 전일사 산출

이관호1† ･ 재프 리버모어2

1울산과학대학교 건축학부, 교수
2맨체스터대학교 MACE, 명예교수

Generation of Horizontal Global Irradiance using the Cloud Cover and Sunshine Duration According to the Solar Altitude

Lee Kwan-Ho1† ･ Geoff J. Levermore2

1Professor, School of Building & Environment Design, Ulsan College

2Emeritus Professor, School of Mechanical Aerospace and civil Engineering, Manchester University, UK

†Corresponding author: ghlee@uc.ac.kr



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Abstract

This study compares cloud radiation model (CRM) and sunshine fraction radiation model (SFRM) according to the solar altitude using hourly sunshine duration (SD) and cloud cover (CC) data. Solar irradiance measurements are not easy for the expensive measuring equipment and .......

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제목, 저자, 소속, 텍스트, 키워드 및 해당 저자를 포함한 정보는 첫 페이지에 입력해야합니다.

for fourteen locations. It may be concluded that the SFRM models of South Korea coefficients generated in this study may be used reasonably well for calculating the hourly horizontal global irradiance (HGI) at any other location of South Korea.

**Keywords:** 일조시간(Sunshine duration, SD), 운량(Cloud Cover, CC), 수평면 전일사(Horizontal Global Irradiance, HGI), 청명지수(Clearness Index), 태양고도(Solar altitude)

Symbols and abbreviations

A, B, C, D : Coefficients for cloud cover model

a, b, c, d : Regression coefficients of sunshine duration

h : Solar altitude (Degree)

H : Monthly average daily global radiation on a horizontal surface, (W/m2)

He : Estimation value of global solar irradiance, (W)

Greek symbols

ρ : density [kg/m3]

Superscripts

\* : Dimensionless parameters

Subscripts

∞ : Inflow refrigerant into the pipe

1. Introduction

Solar energy is a clean renewable energy source that is abundant in South Korea. Therefore, the precise measurement of local solar irradiance and easy-to-use solar irradiance estimation model is requested for renewable energy and building energy saving. The horizontal global irradiance data of fourteen cities (Chuncheon, Gangneung, Seoul, Incheon, Suwon, Cheongju, Daejeon, Andong, Deagu, Jeonju, Jinju, Gwangju, Busan, and Jeju) is used to evaluate sunshine fraction radiation model (SFRM) and cloud radiation model (CRM), one based on the sunshine duration (SD) and the other on the cloud cover (CC). They are compared to a statistical SFRM using SD data and a statistical CRM using CC data. In South Korea, while SD and CC data are measured 79 and 42 weather station locations, respectively, solar irradiance is measured only 22 stations.

Jo et al. (2012)1) estimated solar radiation in Korea using The CC and the SD data to predict the daily horizontal global irradiance (HGI). The hourly HGI required the correlation between the SD and the CC data according to the solar altitude that changes with time. The correlation between the measured and the calculated data is compared according to solar altitude. Lee et al. (2013)2) predicted the hourly HGI using the SD and CC for six cities of South Korea during the period (1986-2005). In this study, the two models to predict hourly HGI are estimated this model allows interpretation through physical parameters. This study evaluated the two models using site fitting and South Korea coefficients for fourteen cities of South Korea during the period (1986-2015) and compared the corelation of the measured and calculated data according to the solar altitude of 10 degrees.

2. Data and Methodology

2.1 Measured Data and Quality Control

All data ffor fourteen cities of South Korea during the period (1986-2015) were measured by the Korea Meteorological Administration (KMA). Currently, there is a central meteorological office, five regional offices, and 73 weather stations, totaling 79 weather stations. Hourly SD and CC data recorded during the daytime over 30 years period (from 1986 to 2015) were gathered for analysis. The 3-hour CC data were linearly interpolated into 1-hour data. The hourly HGI data, which is the value accumulated for 1 hour, was corrected the average value of the current and subsequent hours. Using the site fitting and South Korea coefficients from this process, the fourteen different locations whose different distances can be seen in Fig. 1, Table 1 showed the characteristics of measured data for the fourteen cities.

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| Fig. 1 Location of weather files locations in South Korea (O sunshine measurement, ● sunshine and cloud measurement, ● sunshine, cloud and horizontal global irradiation measurement)  |

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| Table 1 Geographical data and weather database for locations considered in this study |
| LocationStation (No.) | Latitude(∘N) | Longitude(∘E) | Altitude(m) | Period (years) | Solarradiation | Cloudcover | Sunshineduration | QC Error(%) |
| Chuncheon (101) | 37.90 | 127.73 |  77.7 | 1986-2015 (30) | O | O | O | 5.96 |
| Gangneung (105) | 37.75 | 128.90 |  26.0 | 1986-2015 (30) | O | O | O | 5.73 |
| Seoul (108) | 37.57 | 126.97 |  85.5 | 1986-2015 (30) | O | O | O | 5.65 |
| Incheon (112) | 37.47 | 126.63 |  68.9 | 1986-2015 (30) | O | O | O | 7.14 |
| Suwon (119) | 37.27 | 126.98 |  33.6 | 1986-2015 (30) | O | O | O | 6.59 |
| Cheongju (131) | 36.63 | 127.45 |  57.4 | 1986-2015 (30) | O | O | O | 5.37 |
| Andong (136) | 36.57 | 128.72 | 139.4 | 1986-2015 (30) | O | O | O | 5.92 |
| Daejeon (133) | 36.37 | 127.24 |  77.1 | 1986-2015 (30) | O | O | O | 6.14 |
| Daegu (143) | 35.88 | 128.62 |  57.8 | 1986-2015 (30) | O | O | O | 5.89 |
| Jeonju (146) | 35.82 | 127.15 |  53.5 | 1986-2015 (30) | O | O | O | 6.00 |
| Jinju (192) | 35.20 | 128.12 |  20.4 | 1986-2015 (30) | O | O | O | 6.50 |
| Gwangju (156) | 35.17 | 126.90 |  70.9 | 1986-2015 (30) | O | O | O | 6.08 |
| Busan (164) | 35.10 | 129.03 |  69.2 | 1986-2015 (30) | O | O | O | 5.42 |
| Jeju (184) | 33.50 | 126.51 |  30.2 | 1986-2015 (30) | O | O | O | 5.73 |

(1) Sunshine Duration and Cloud Cover Model

The irradiance data has been checked for continuous data sets without gaps and simulation purposes. The missing data had to be filled using quality control of Muneer and Fairooz (2002)3), Younnes et al. (2005)4), and Lee et al. (2013) method. This study used the following criteria of quality control:

∙ missing irradiance data,

∙ global hourly data that are greater than the corresponding extraterrestrial solar irradiance,

∙ hourly data with a solar altitude lower than 5° (low accuracy measurements)

The error percentages of quality control ranged from 5.37% (Cheongju) to 7.14% (Incheon) for fourteen cities as in Table 1.

 (1)

3. Results and Discussion

The method of comparison is used the mean bias error (MBE) and root mean square error (RMSE) for the fourteen cities. The MBE shows the long-term performances and a negative MBE value indicates the amount of underestimation. The RMSE shows the short-term performances and the amount of the errors indicates the scattering of data around the regression.

Table 2 summarizes the error of the two models with site fitting and South Korea coefficients to estimate HGI for fourteen cities listed in Table 1. The CRM has a smaller MBE in all locations and the SFRM has a smaller RMSE in all locations same as Lee et al. (2013). The MBE of site fitting coefficients varied small ranges: -1.61% ~ 2.56% (Seoul) for the CRM and 2.08% ~ 8.95% (Seoul) for the SFRM, but the MBE of South Korea coefficients varied considerable ranges: -20.90% (Seoul) ~ 10.18% (Jinju) for the CRM and –5.69% ~ 11.81% (Jinju) for the SFRM. The RMSE of site fitting coefficients varied small ranges: 26.64% ~ 30.39% for the CRM and 21.19%~26.53% for the SFRM, and the RMSE of South Korea coefficients varied similar ranges of site fitting coefficients: 26.52% ~ 30.98% for the CRM and 22.31% ~ 27.92% for the SFRM. The overall averages RMSE of the site fitting and the South Korea coefficients were 26.61% and 28.83% for the CRM, respectively, and 24.13% and 24.38 for the SFRM, respectively. Comparing the error of two models in Table 6, we can see that the CRM with site fitting coefficients and the SFRM with site fitting and South Korea coefficients are a good method to protect hourly HGI. Compared to the results of this study and six cities of South Korea during 20 years, the MBE and the RMSE improved 6.71% and 5.62% for the CRM, respectively, and 2.94% and 6.28 for the SFRM, respectively. This improvement is due to an increase of 10 years of measurement data and the correction of hourly HGI data.

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| Table 2 Error of two models with site fitting and South Korea coefficients |
| Location | Cloud cover model |  | Sunshine duration model |
| Site fitting coefficients | South Korea coefficients |  | Site fitting coefficients | South Korea coefficients |
| MBE (%) | RMSE (%) | MBE (%) | RMSE (%) |  | MBE (%) | RMSE (%) | MBE (%) | RMSE (%) |
| Chuncheon | 1.17 | 28.11 | 5.62 | 28.64 |  | 4.62 | 23.47 | 7.52 | 23.79 |
| Gangneung | 2.12 | 30.39 | 8.99 | 30.70 |  | 2.75 | 22.66 | 10.52 | 23.80 |
| Seoul | 2.56 | 29.72 | -20.90 | 30.52 |  | 8.95 | 26.53 | -5.69 | 26.24 |
| Incheon | 1.97 | 28.75 | 0.15 | 28.84 |  | 5.36 | 25.05 | 0.99 | 24.76 |
| Suwon | -1.61 | 30.15 | -11.77 | 30.98 |  | 6.81 | 27.68 | -3.42 | 27.92 |
| Cheongju | 0.72 | 28.20 | 1.53 | 28.37 |  | 4.76 | 24.10 | 4.07 | 24.06 |
| Andong | 0.97 | 28.45 | -1.05 | 28.45 |  | 5.27 | 23.32 | 4.95 | 23.54 |
| Daejeon | 0.61 | 28.49 | 7.28 | 28.76 |  | 5.44 | 23.62 | 10.26 | 24.40 |
| Daegu | 0.13 | 26.64 | -0.48 | 26.56 |  | 3.03 | 25.13 | 5.84 | 25.51 |
| Jeonju | 0.72 | 27.92 | -12.19 | 28.21 |  | 6.33 | 23.34 | 4.62 | 23.22 |
| Jinju | 1.80 | 27.41 | 10.18 | 27.93 |  | 6.88 | 21.19 | 11.81 | 22.31 |
| Gwangju | -0.22 | 28.15 | 4.64 | 28.23 |  | 7.09 | 22.83 | 8.60 | 23.05 |
| Busan | 0.90 | 28.37 | 0.96 | 28.54 |  | 2.08 | 24.35 | 2.50 | 24.28 |
| Jeju | 2.26 | 29.77 |  |  |  | 2.96 | 24.51 |  |  |

4. Conclusions

Solar irradiance measurements are not easy for the expensive measuring equipment and precise measuring technology. The hourly HGI was calculated using the SFRM and CRM of SD and CC for the fourteen cities in South Korea. This study compared the hourly HGI and two models according to the solar altitude using hourly SD and CC data. Results of cloud cover and sunshine fraction models have been compared with the measured data on the r2, MBE, and RMSE. The difference in the correlation between the site fitting and South Korea coefficients was very small, similar to previous studies. Comparing the error of two models, we can see that the CRM with site fitting coefficients and the SFRM with site fitting and South Korea coefficients are a good method to protect hourly HGI. Compared to the results of this study and six cities of South Korea during 20 years, the MBE and the RMSE improved 6.71% and 5.62% for the CRM, respectively, and 2.94% and 6.28 for the SFRM, respectively. Therefore, further study is required to increase the measurement period and correct the Hourly HGI.

We analyzed the variation of MBE and RMSE according to the solar altitude of 10° for the CRM and the SFRM. Comparing the MBE of the site fitting coefficients, the average MBE was similar, but the CRM difference of MBE was more than three times for the solar altitude below 25° and about two times above 25°. Comparing the RMSE of the site fitting coefficients between the CRM and the SFRM, the difference was about 5% for all solar altitudes. The RMSE of the South Korea coefficients of the CRM and the SFRM showed a 5% difference as site fitting coefficients. From the variation of the errors of MBE and RMSE, it is found that the SFRM with the site fitting coefficients could be the best method for fourteen locations. The SFRM models of South Korea coefficients generated in this study may be used reasonably well for calculating the hourly horizontal global irradiance (HGI) at any other location of South Korea. Further research is the optimization of South Korea coefficients and the expansion of the research scope to 22 cities.

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