

## **METEONORM 7.0-Aided Generation of Synthetic Metrological Year used in Energy Simulation, for Climatic Regions of Saudi Arabia**

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**Abstract:** Energy simulation and modeling in buildings require annual hourly weather data. The accuracy and completeness of the data is vital to assess the annual energy performance of building and to evaluate alternative building design strategies. Weather stations in Saudi Arabia conduct and archive weather data measurements for major cities and Airbases. However, these data are summaries or incomplete and in varying formats. To overcome these shortcomings, weather generation models have been developed in the US and Europe and can be utilized for Saudi Arabian climates. These models use available weather statistical summaries to synthetically generate year-long hourly data as required by energy simulation models format. Some models generate weather data for remote locations from weather stations by interpolation techniques. Saudi Arabia can be classified into five climatic regions, representing Central, Upland, Northern, Western, and Eastern regions, and the present work was aimed at synthetically generating weather data for these regions by using METEONORM 7.0 (MN7). The data generated by MN7 was compared with those obtained from the national Presidency of Meteorology and Environment (PME), and found in acceptable agreement with each other. It was also observed that, in many cases the MN7 data need proper scrutiny and rectification in order to be consistent with the long-term PME data.

**Keywords:** Energy simulation; Weather data; Synthetic yetrological year; METEONORM 7.0, Air temperature; Relative humidity; Wind speed; Solar radiation.

### **1. Introduction**

Accurate and complete annual hourly weather data is crucial in evaluating the energy performance of buildings. Reliable simulation and modeling of building energy consumption and economic evaluation of renewable-energy systems utilization depend on reliable year-long hourly weather data for the duration of the simulation. Also, the estimation of heating and cooling degree days and maximum and minimum ambient temperatures for sizing Heating Ventilation and Air Conditioning (HVAC) equipment are performed based on year-long hourly weather data. In addition, Synthetic Metrological Year (SMY) hourly weather data can be utilized to evaluate passive heating and cooling strategies.

Long-term data records are either not necessarily available or incomplete. This limits the preparation of typical year-long weather data files in any format. Thus, as a feasible alternative, the weather data files required for energy simulation are synthetically generated from long-term available weather data obtained by using standard procedure, and from statistical weather summaries. Several procedures to generate such weather files have been developed over the years. These files are articulated in different formats and parameters to meet varying research requirements. The most common weather file formats include Typical Metrological Year (TMY) of evolved versions, Test Reference Year (TRY), Weather Year for Energy Calculation (WYEC), and Design Reference Year (DRY). If any of these formats is not available

for the building site, the practical substitute is generating SMY. The synthesized hourly data should possess statistical properties of TMYs or long-term hourly data. In some cases, this can be difficult, but minor differences are acceptable. Most of the synthesized yearly weather data follow the sequences of actual daily, monthly, and seasonal data fluctuations. A comprehensive review of these weather files was provided by Almoftaz et al. (2012).

Procedures and techniques to generate different weather files and parameters, sources, and periods of hourly data are well documented in literature. Degelman (1991) proposed an hourly weather simulation model which contained both deterministic and probabilistic portions to perform sun angle calculations, sky opacity, dry-bulb temperatures, dew-point temperatures, wind speed, and barometric pressures. The model was useful for creating synthetic hourly weather data files in TRY or TMY formats. A methodology to generate one-year weather data which would yield the same simulation result as obtained from long-term data was proposed by Knight et al. (1991). This approach could reduce the computational effort needed to assess the long-term data. A model based on vector auto-regressive (VAR) time series was presented by Hong and Jiang (1995). The accuracy of this model was found to be sufficient for the simulation and stochastic analysis of building HVAC systems. In an attempt to account for cross-correlations between ambient temperature and solar radiation, Heinemann et al. (1996) proposed a procedure for the synthesis of hourly temperature data, suitable for a wide range of sites and climatic conditions. Their study was based on a large number of temperature and radiation data sets measured at locations in the US, Europe and Indonesia. Bouhaddou et al. (1997) presented auto regressive moving average (ARMA) models of the weather parameters such as ambient temperature, humidity and clearness index at or near Marakech, based on higher order statistics. The use of Lisbon software for the simulation of a mid-latitude temperate climate was reported by Aguiar et al. (1999). Thermal performance was evaluated by using long term observed time series, long-term stochastic data, and TMY obtained by classic and by stochastic methods. Adelard et al. (2000) used RENEOLE software program for providing weather data in building applications with a method adapted to all kind of climates. The proposed model was tested for thermal comfort study of a residential building

in Reunion Island. A method for determining typical one-year weather data from a multi-year record was proposed by Gazela and Mathioulakis (2000) for evaluating solar energy systems. It was made up of a concatenation of 12 months individually selected from a multi-year database. Van Paassen and Luo (2002) proposed a weather generator model that could take into account the climatic changes. This model was then modified to be "location independent" while being adaptable to a local climate change. The proposed model was able to generate hourly weather data that could be used as input for all kinds of simulation programs to study the effect of climate change on the design and energy consumption of HVAC systems.

The development of TMYs using Sandia method for seven different locations in Oman based on meteorological data covering 7 to 17 years was reported by Sawaqed et al. (2005). It was shown that Sandia method was highly affected by solar flux, while the weights of other parameters such as temperature, wind, and relative humidity had less impact on the selection of TMY. Skeiker and Ghani (2009) reported the use of software tool 'Delphi 6.0' which utilizes the Finkelstein-Schafer statistical method for the creation of TMY for any site of concern. A TMY was generated for Damascus, capital of Syria, with the meteorological data over a period of 10 years.

Saudi Arabia can be classified into five climatic regions, representing Central, Upland, Northern, Western, and Eastern regions (Numan et al., 2008). Summaries of weather variables statistics in Saudi Arabia can be obtained for most weather stations for over the last 30 years (National Meteorology & Environment Center, 2009). These records could be effectively utilized for the purpose of synthetic generation of weather files. As far as the author is aware, no productive attempts have been reported so far from Saudi Arabia, on the synthetic generation of weather files suitable for energy simulation requirements. Accordingly, this study was aimed at generating SMY for the five aforementioned climatic regions of Saudi Arabia, using state-of-the-art model METEONORM 7.0 (MN7) and to validate the generated SMY with the PME long-term means.

## 2. Methodology

Long-term weather data for the study zones were obtained from the respective weather stations. The data were smoothed and filtered from abnormal readings, and subsequently stored in a Microsoft Excel TM workbook file for further

analysis. MN7 was utilized to generate SMY (Meteotest, 2009; Pierre, 2006) files which are available in Energy-Plus Weather (EPW) format. However, MN7 is designed to generate hourly weather file in several formats. Some files were created from means of weather stations such as Dhahran, Riyadh, and Jeddah, and the files for Tabuk and Khamis Mushait (Khamis) were generated based on long-term records of basic weather parameters data from Air Force Bases. The synthetically generated files were converted to design day files and statistical summaries using E-Plus weather convertor. The summary files contained average hourly readings of means and maxima. The parameters such as Air Temperature (Ta), Global Horizontal Radiation (Gh) Relative Humidity (RH), and Wind Speed (FF) were compared with long-term weather means data from the Presidency of Meteorology and Environment (PME) records. The PME statistical summaries are limited

to means of 27 years of maximum and minimum temperatures in each month. On daily basis, the hourly SMY data can be used to evaluate passive heating and cooling strategies. The monthly means of these parameters were plotted against the corresponding long-term measured means from the nearest weather station. MN7 uses different techniques to generate EPW files. It applies a testing criterion which checks if the station is in the World Meteorological Organization (WMO) database, in order to use the available data from stations. The parameters usually measured are: air temperature (Ta), mean global irradiance (Gh), relative humidity (RH), wind speed (FF), wind direction (DD), precipitation (RR) and/or dew point temperature (Td). Most files contained at least three measured parameters and the rest were interpolated from 1-3 nearby stations and calculated weather parameters (Table 1).

**Table 1. Techniques used to synthetically generate weather files by MN7**

Climatic Regions	Riyadh	Jeddah	Dhahran	Khamis	Tabuk
Altitude (m)	612	4	17	2066	770
Latitude (deg.)	24.65	21.683	26.267	18.3	28.36
Longitude (deg.)	46.77	39.15	50.167	42.8	36.63
Temperature period	1996-2005	1961-1990	1961-1990	1967-1990	1996-2005
Radiation period	1981-2000	1998-2002	1981-1990	1981-1990	1998-2002
Relative humidity (RH) %	Interpolation	Measured	Calculated	Interpolation	Calculated
Wind speed (FF) m/s	Measured	Measured	Measured	Interpolation	Measured
Rainy days (RD)	Interpolation	Interpolation	Interpolation	Interpolation	Interpolation
Global irradiance (Gh) (kWh/m <sup>2</sup> month)	Measured	Measured	Interpolation	Calculated	Measured
Air temperature (Ta) °C	Measured	Measured	Measured	Measured	Measured
Wind direction (DD) deg	Calculated	Measured	Measured	Interpolation	Interpolation
Dew point temp. (Td) °C	Measured	Measured	Measured	Interpolation	Measured
Sunshine duration (SD) (days)	Interpolation	Interpolation	Interpolation	Interpolation	Calculated
Precipitation (RR) mm	Interpolation	Interpolation	Measured	Measured	Interpolation

Table 2 summarizes the year-to-year variations of various weather parameters for the climatic regions studied. The difference between synthetically generated and PME data means are acceptable if the difference in monthly means are within the year-to-year variations of four consecutive years, which have to be established based on long-term measured data. The long-term (15 years or more) data means of annual temperature and wind speed were obtained from Tutiempo.<sup>1</sup> Solar

radiation data were obtained from NREL;<sup>2</sup> the month whose daily means were closest to those of annual means was chosen for establishing the year-to-year variation. A similar procedure was adopted for relative humidity data which was obtained from Weather Underground, Inc.<sup>3</sup>

1. [http://www.tutiempo.net/en/Climate/Saudi\\_Arabia/SA.html](http://www.tutiempo.net/en/Climate/Saudi_Arabia/SA.html)
2. [http://redc.nrel.gov/solar/new\\_data/Saudi\\_Arabia/](http://redc.nrel.gov/solar/new_data/Saudi_Arabia/)
3. <http://www.wunderground.com/>

**Table 2. Actual year-to-year variation of weather variables**

Weather Parameter	Climatic Zones					Remarks
	Tabuk	Khamis	Jeddah	Riyadh	Dhahran*	
Global Solar Radiation Wh/ m <sup>2</sup> /day	208	366	628	379	705	Based on representative months of years from 1999 to 2002
Temp Deg. C	2.4	1.9	1.5	1.8	0.7	Based on representative months of years from 2009 to 2013
Wind Speed m/s	0.7	1.5	1.1	0.6	0.9	Based on representative months of years from 2009 to 2013
Humidity %	7.4	4.7	11.5	10	3.9	Based on representative months of years from 1999 to 2002

\*Solar data based on Al-Ahsa data which is about 150 km from Dhahran.

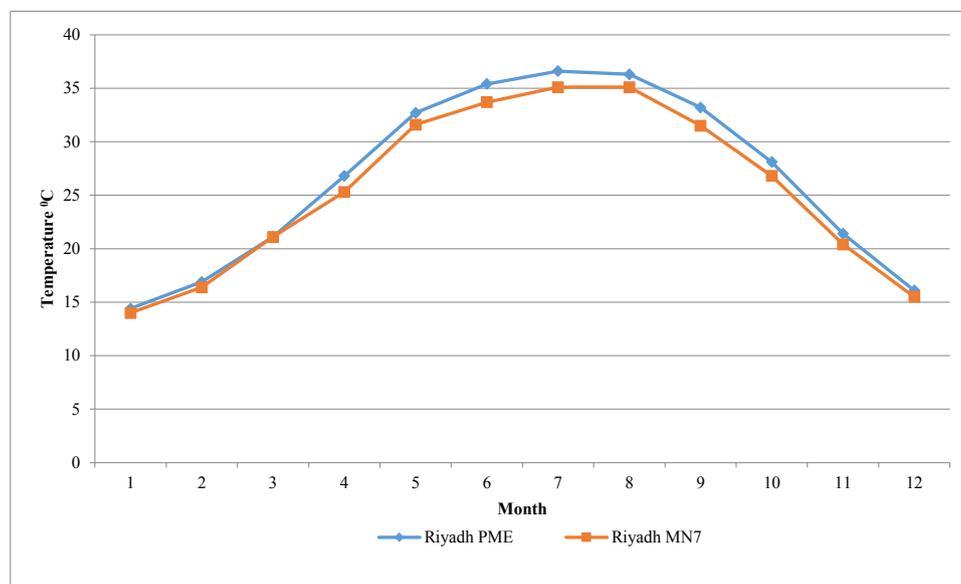
### 3. Results and Discussion

In all SMY files, weather parameter data were generated by interpolation from three stations, measured or calculated using data for at least 10 years statistical summaries from Table 1. The synthetically generated weather files were converted to statistical EPW files.

#### 3.1. Air temperature (Ta)

Figures 1 to 5 illustrate comparison for Ta monthly means from observed PME data and MN7 generated data for the climate zones of Saudi Arabia, such as Riyadh, Jeddah, Dhahran, Tabuk and Khamis respectively. Dhahran and Jeddah show very good agreement between monthly MN7 and PME norms. Riyadh and Khamis show systematic error; MN7

underestimates Ta in Riyadh and overestimates in Khamis. This discrepancy is attributed to the difference in the data source, i.e. MN7 and PME probably have taken data from two different weather stations. There are two weather stations in Riyadh, one at the airport which is far from the city center and another one near the city center; it is obvious that the air temperature recorded by the airport station would be lesser compared to the other station which is significantly affected by the 'Heat Island'. In the case of Khamis, one station is in Abha airport which is very close to Khamis, and the other is at the Khamis military airbase; there is a likelihood of variations in the recorded temperature due to the difference in the altitudes of the two locations. Tabuk shows reasonable agreement between MN7 and PME norms, and single weather source is believed to be the reason.



**Figure 1. Comparison of PME and MN7 generated Ta data for Riyadh.**

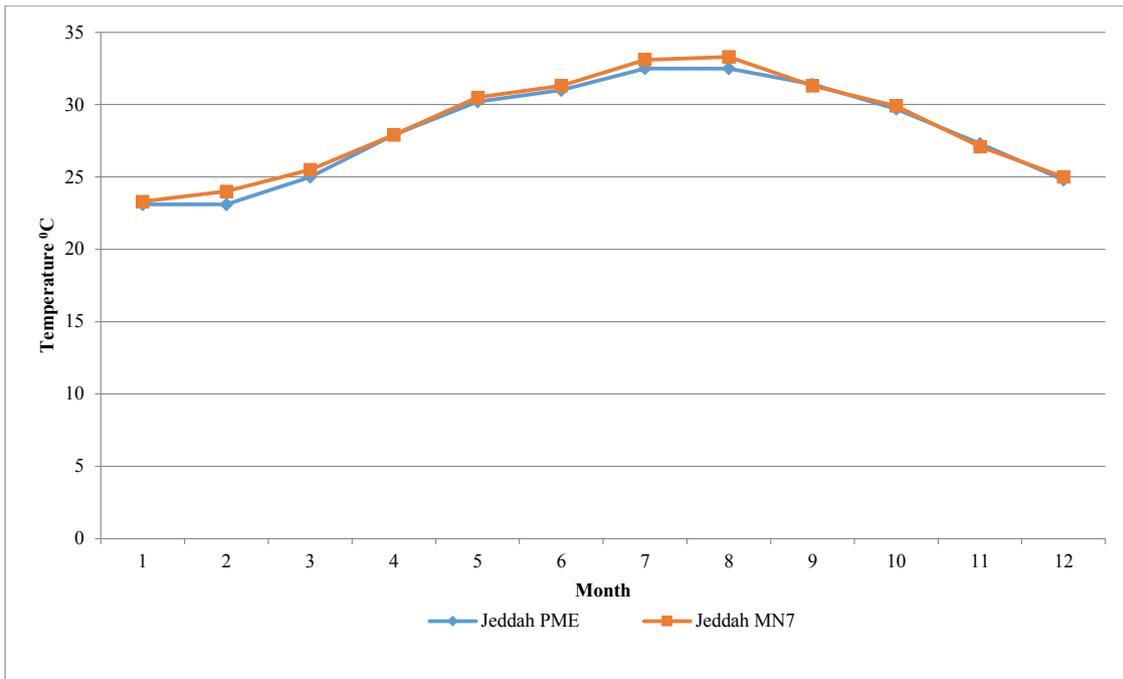


Figure 2. Comparison of PME and MN7 generated Ta data for Jeddah.

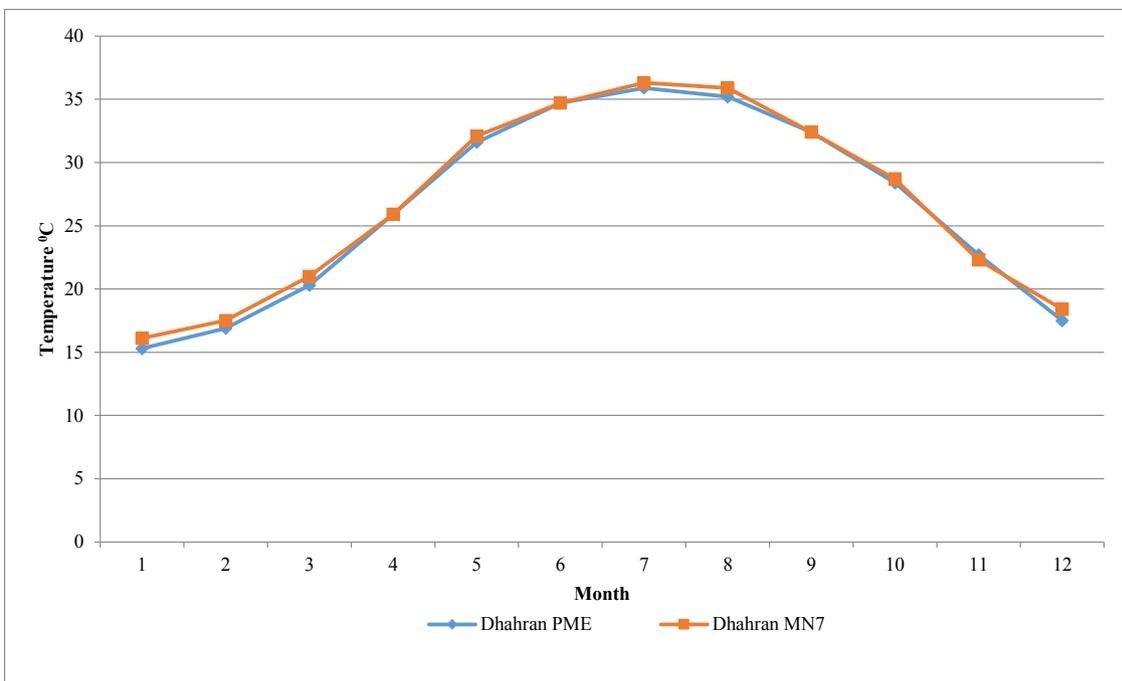


Figure 3. Comparison of PME and MN7 generated Ta data for Dhahran.

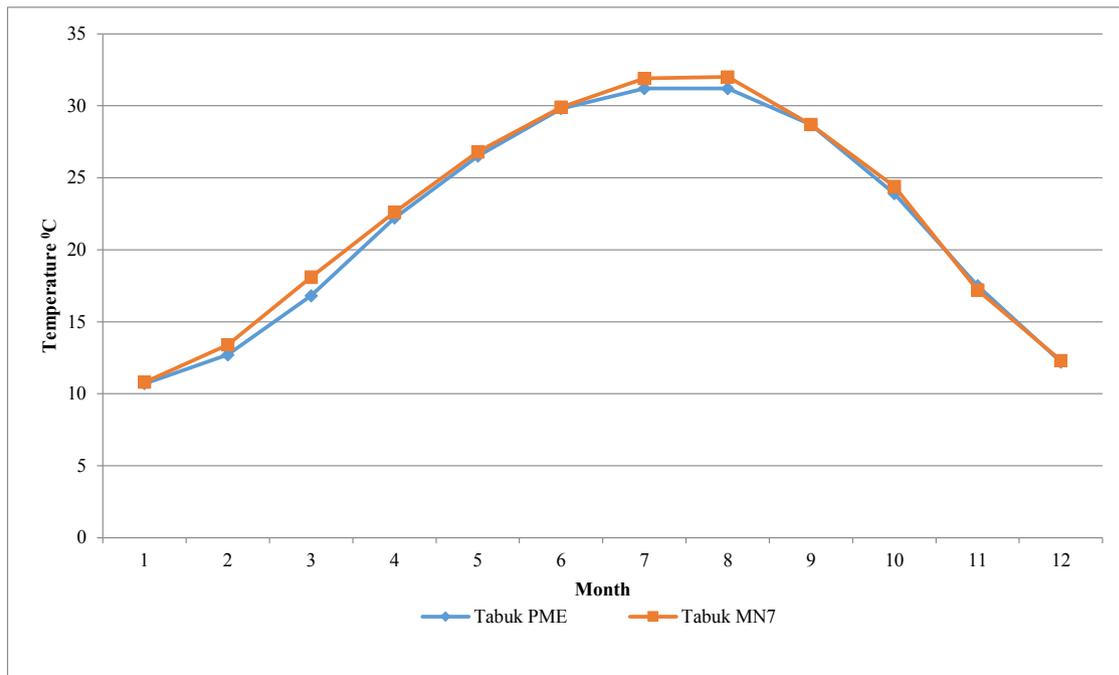


Figure 4. Comparison of PME and MN7 generated Ta data for Tabuk.

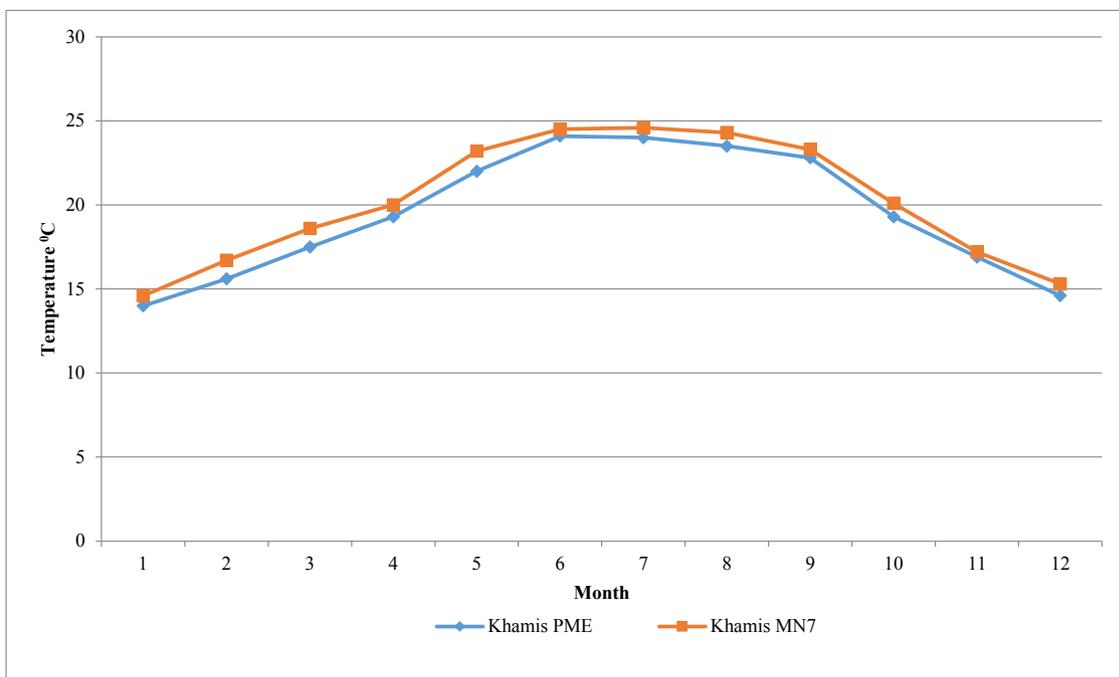


Figure 5. Comparison of PME and MN7 generated Ta data for Khamis.

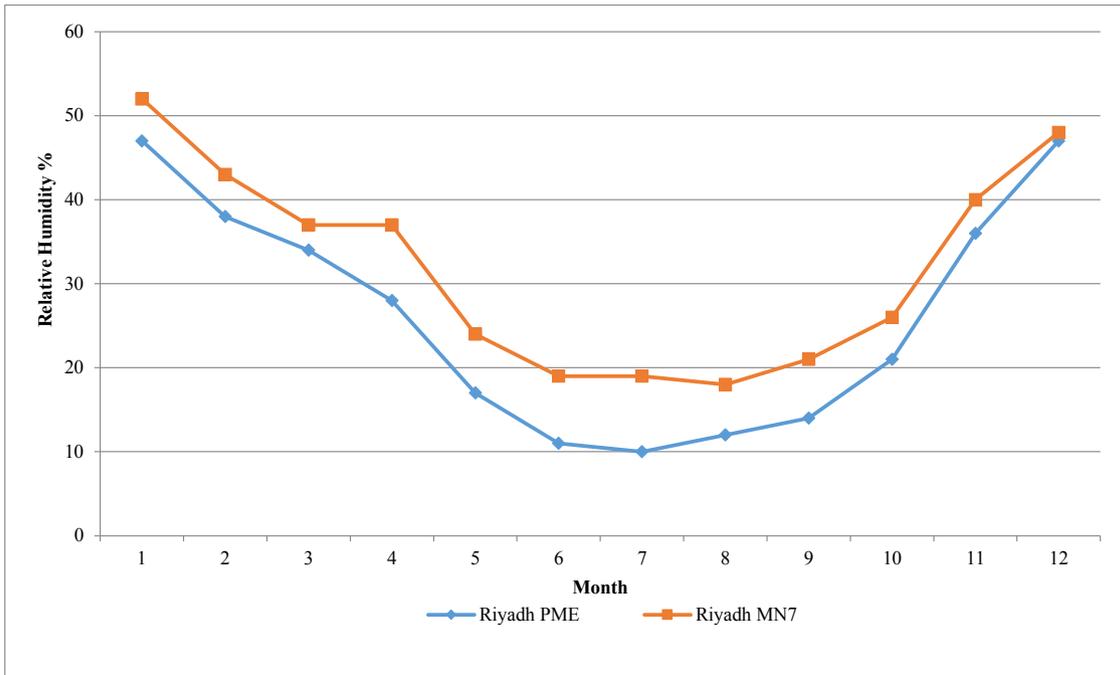


Figure 6. Comparison of PME and MN7 generated RH data for Riyadh.

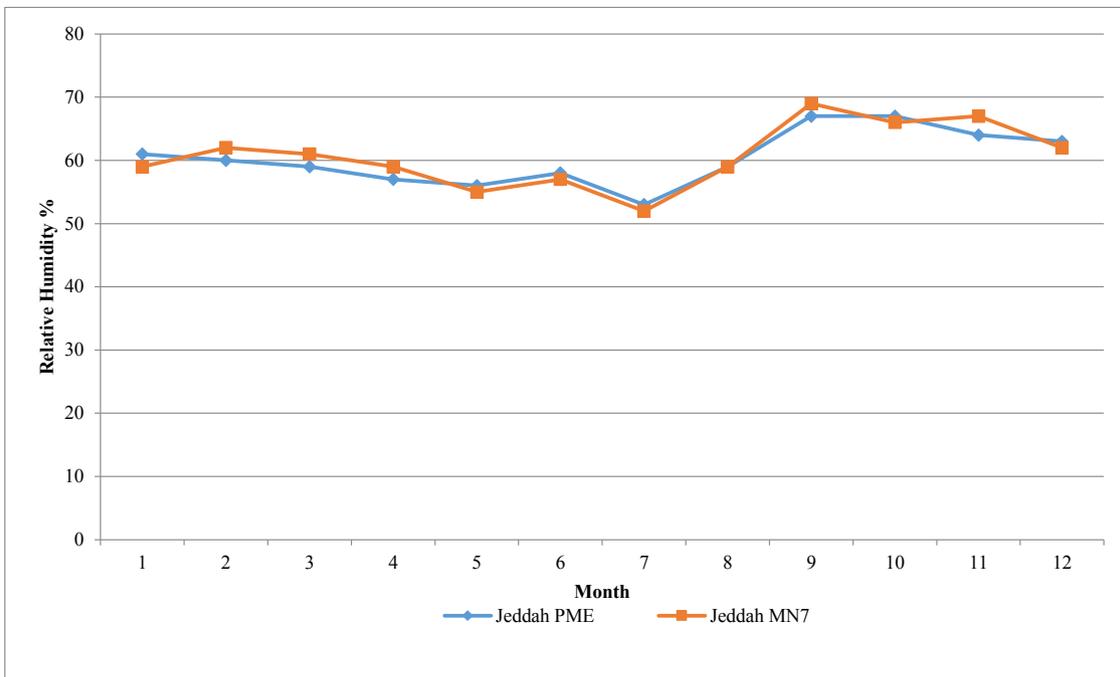


Figure 7. Comparison of PME and MN7 generated RH data for Jeddah.

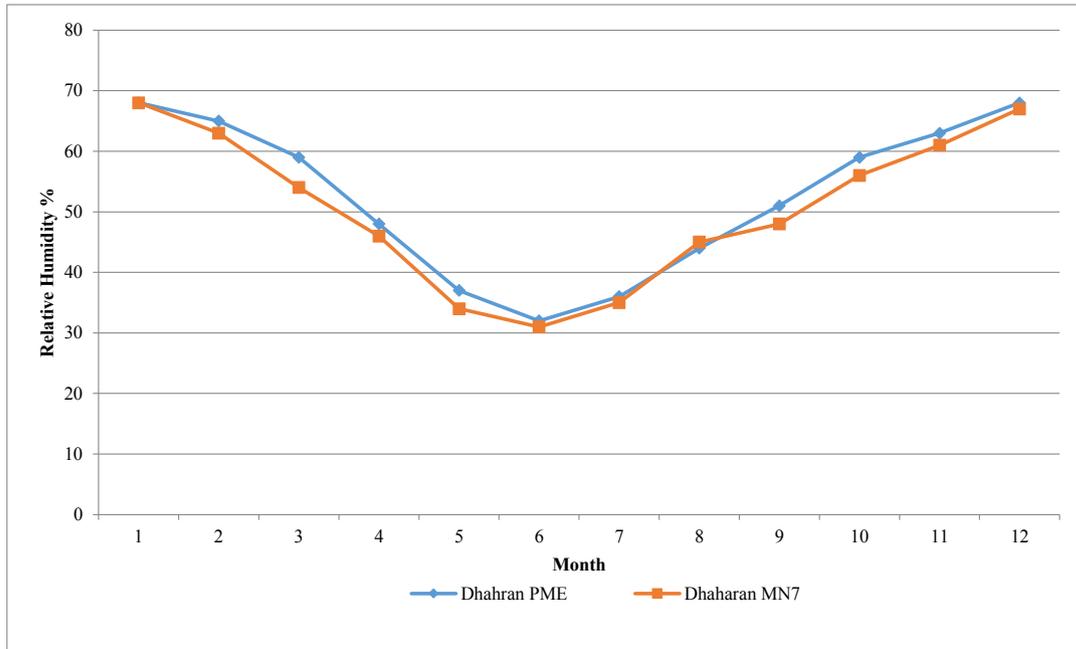


Figure 8. Comparison of PME and MN7 generated RH data for Dhahran.

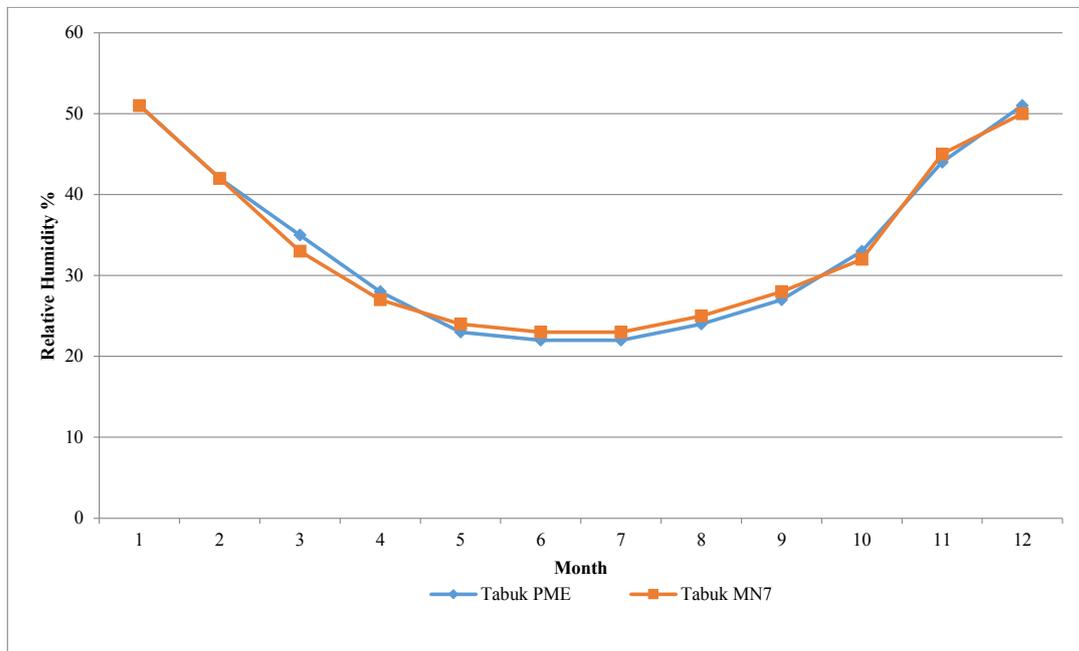


Figure 9. Comparison of PME and MN7 generated RH data for Tabuk.



Figure 10. Comparison of PME and MN7 generated RH data for Khamis.

### 3.2. Wind Speed (FF)

Figures 11 to 15 illustrate comparison of monthly means of Wind Speed (FF) from observed PME and

MN7 generated data for Riyadh, Jeddah, Dhahran, Tabuk and Khamis respectively. All cities show slight discrepancies which are acceptable since the variations do not exceed the year-to-year variations.

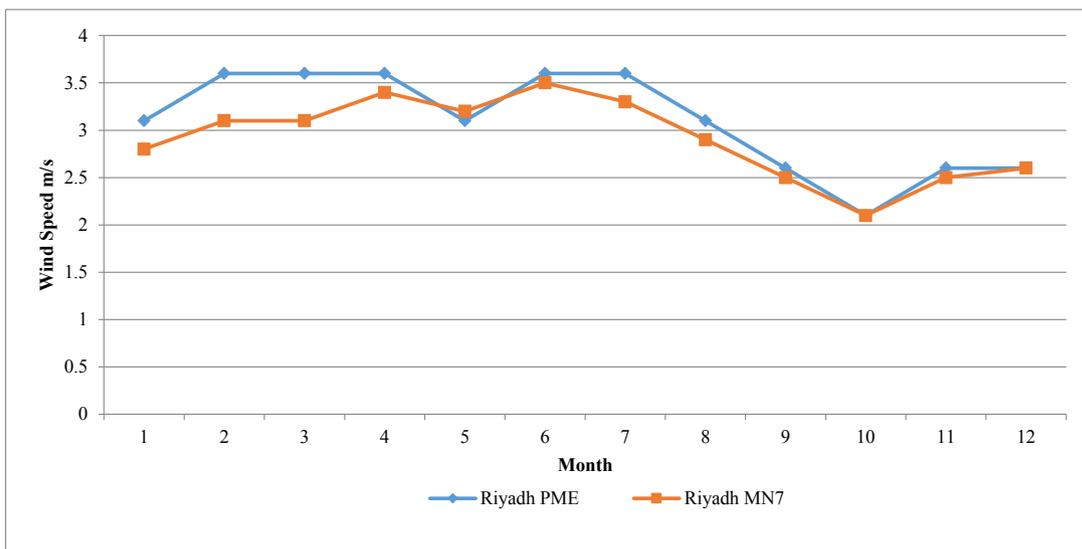


Figure 11. Comparison of PME and MN7 generated FF data for Riyadh.

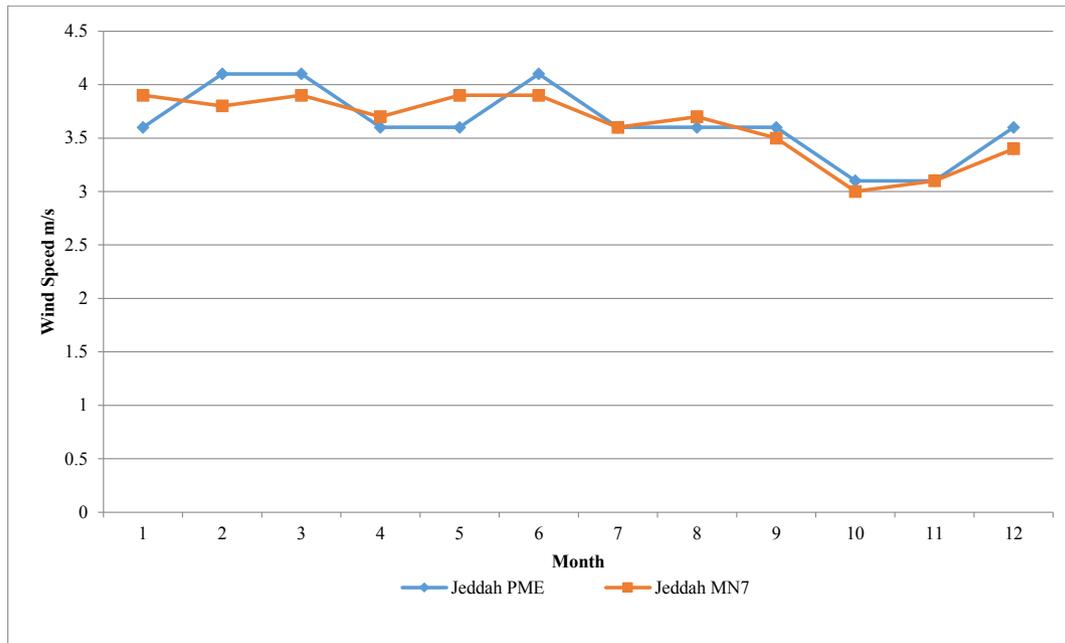


Figure 12. Comparison of PME and MN7 generated FF data for Jeddah.

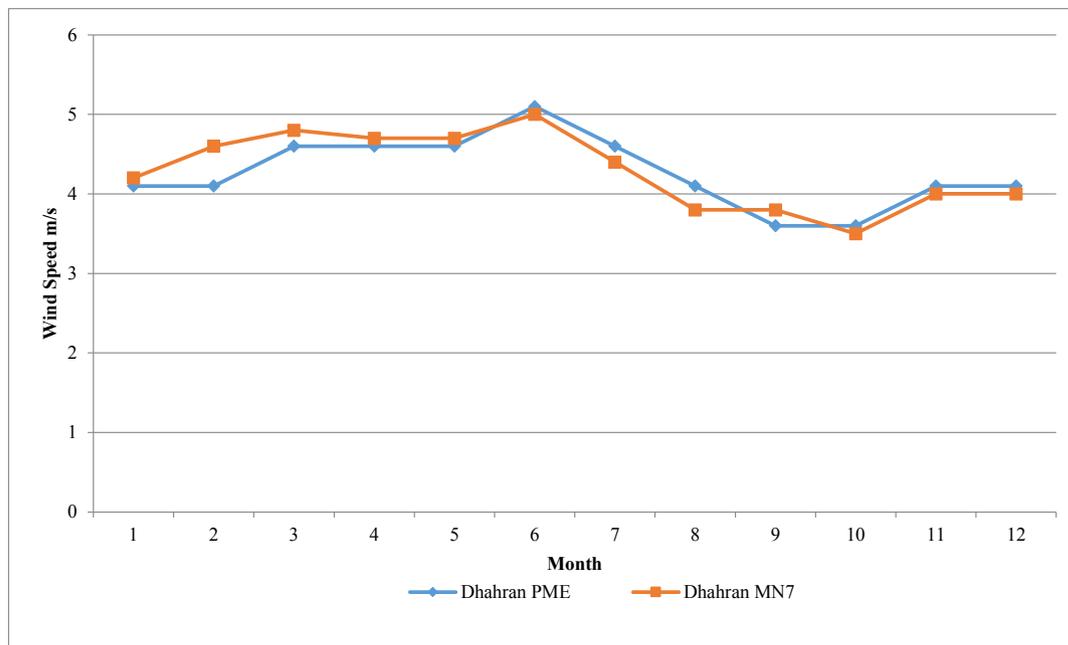


Figure 13. Comparison of PME and MN7 generated FF data for Dhahran.

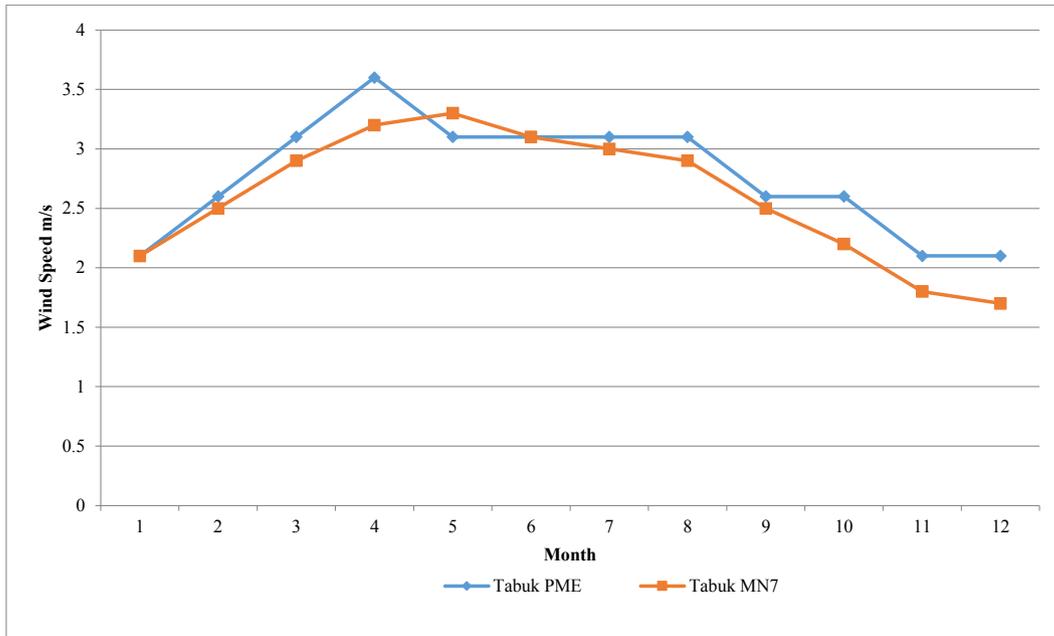


Figure 14. Comparison of PME and MN7 generated FF data for Tabuk.

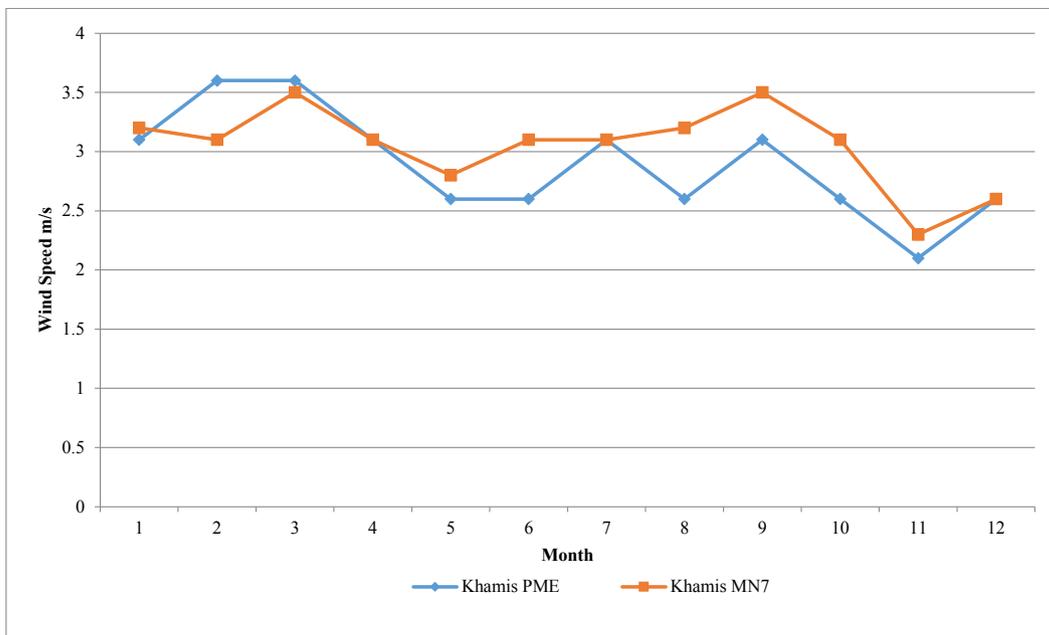


Figure 15. Comparison of PME and MN7 generated FF data for Khamis.

### 3.3. Global mean radiation (Gh)

Figures 16 to 20 illustrate the comparison of the PME observed and MN7 generated monthly means of radiation data for Riyadh, Jeddah, Dhahran, Tabuk and Khams respectively. Dhahran exhibits reasonable agreement while Riyadh, Jeddah and

Khams show some level of deviations. The deviations are attributed to the fact that MN7 solar calculation methods partially rely on sky clearance index which strongly varies in four seasons. The systematic error observed for Tabuk is due to the overestimation of solar radiation by MN7 calculation model.

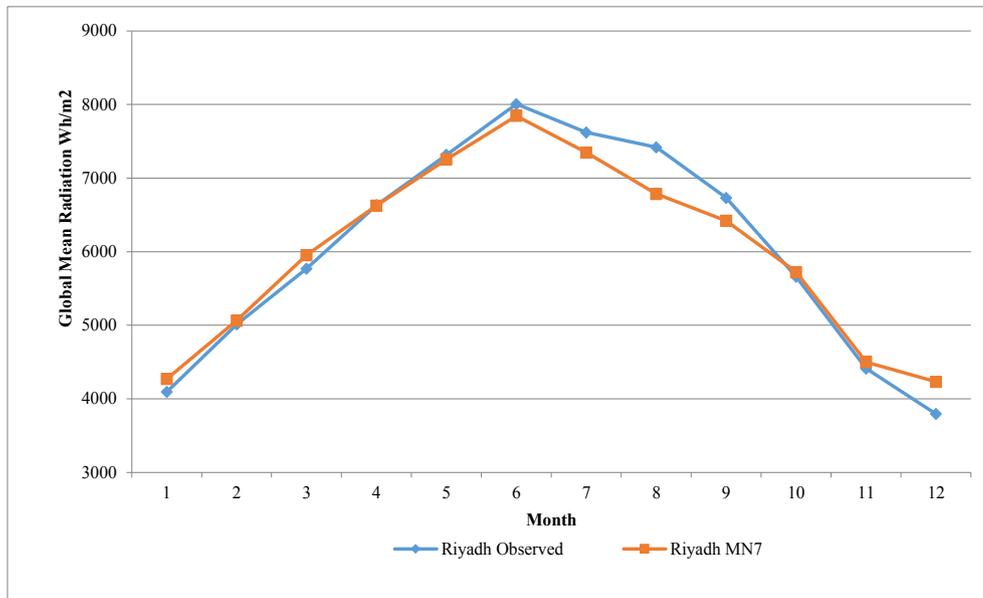


Figure 16. Comparison of observed and MN7 generated Gh data for Riyadh.

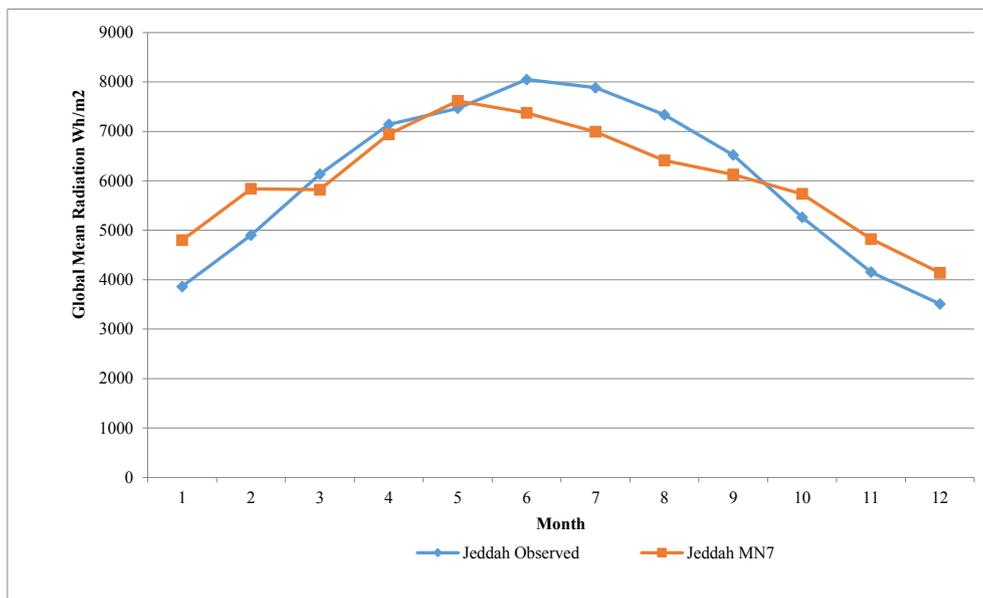


Figure 17. Comparison of observed and MN7 generated Gh data for Jeddah.

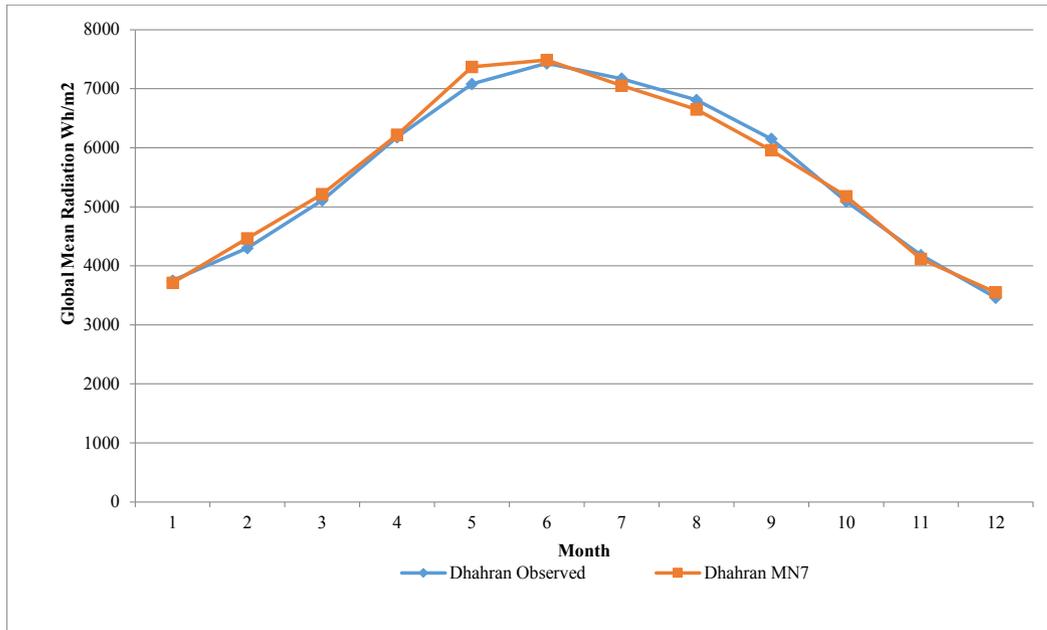


Figure 18. Comparison of observed and MN7 generated Gh data for Dhahran.

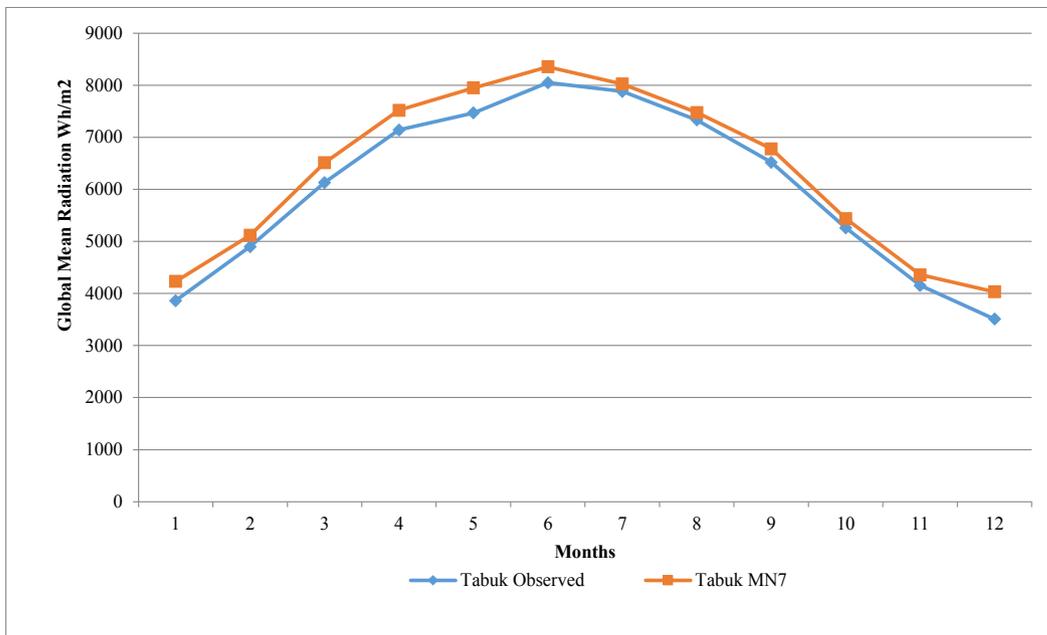


Figure 19. Comparison of observed and MN7 generated Gh data for Tabuk.

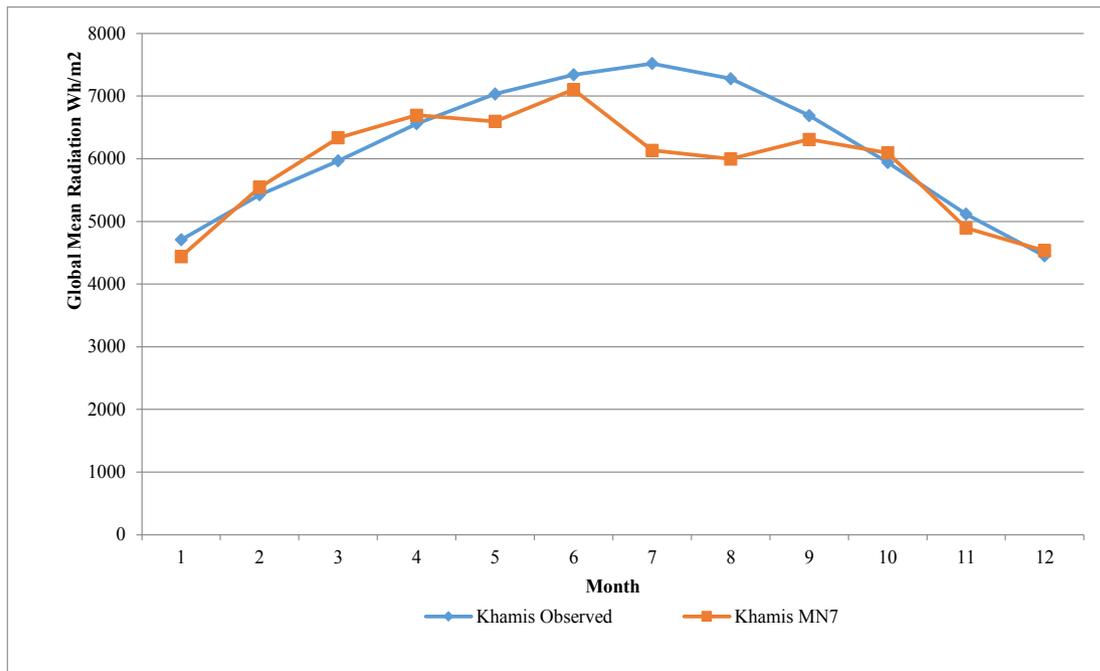


Figure 20. Comparison of observed and MN7 generated Gh data for Khamis.

#### 4. Conclusion

An attempt has been made to synthetically generate weather data for energy simulation application, for five cities representing the typical climatic zones of Saudi Arabia, such as Riyadh, Jeddah, Dhahran, Tabuk, and Khamis. Long-term weather data of the study zones were collected from the respective weather stations, smoothed, filtered and subsequently processed in Microsoft Excel™ workbook. The Meteonorm™ software - version 7 (MN7) was used to generate SMY files. The MN7 generated SMY data for four main weather parameters, such as dry-bulb temperature, relative humidity, global horizontal solar radiation, and wind speed were compared with the corresponding PME norms. The results show acceptable agreements with each other in most of the regions; however some discrepancies were noticed as in the case of radiation data for Riyadh, Jeddah, Tabuk and Khamis, which need to be addressed. Thus, the following remarks are worth noting from this study:

1. MN7 software is a promising tool for generating SMY files when TMY is not available for the concerned location.
2. The MN7 generated SMY files should be inspected for irregular values before being used in building or renewable energy simulation.
3. The MN7 SMY files of the key weather parameters should be compared to the corresponding PME data to get an idea of the magnitude of error in simulation results.
4. Fine tuning of SMY files (in order to be consistent with the PME data) is important, which would be performed in the author's future work.

#### 5. Acknowledgement

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## انتاج بيانات اصطناعيا لسنة مناخية لمناطق المملكة العربية السعودية بواسطة برنامج ميتينورم ٧ لاستخدامها في برامج محاكاة الطاقة

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قدم للنشر في ١٨ / ١٢ / ١٤٣٤ هـ؛ وقبل للنشر في ١٢ / ٧ / ١٤٣٥ هـ

ملخص البحث. تتطلب محاكاة ونمذجة الطاقة في المباني بيانات مناخية سنوية لكل ساعة. دقة البيانات واكتمالها حيوي لتقدير استهلاك الطاقة السنوي ولتقييم البدائل التصميمية للمباني. محطات رصد الطقس في المملكة العربية السعودية تجمع وتحفظ بالبيانات المناخية المسجلة للمدن الرئيسة والقواعد العسكرية. الا ان هذه البيانات عبارة عن ملخصات او غير مكتملة وبنيات مختلفة. وللتغلب على هذا القصور، يمكن توظيف نماذج حاسوبية تم تطويرها في الولايات المتحدة واوربا لانتاج البيانات المناخية اصطناعيا لمناطق المملكة المناخية. هذه النماذج الحاسوبية تستخدم ملخصات احصائية لبيانات الطقس لانتاج بيانات مناخية اصطناعيا سنوية لكل ساعة حسب متطلبات برامج محاكاة ونمذجة الطاقة. بعض النماذج الحاسوبية تنتج بيانات مناخية لمناطق بعيدة ليس فيها محطات مراقبة للطقس بتقنية الاستيفاء (الاستقراء الداخلي). يمكن تقسيم المملكة العربية السعودية الى خمس مناطق مناخية تمثل المنطقة الوسطى، المرتفعات الجنوبية، المناطق الشمالية، المنطقة الغربية والمنطقة الشرقية، ويهدف هذا البحث الى انتاج بيانات مناخية للمناطق المختلفة باستخدام برنامج ميتينورم ٧ (MN7). ملخصات البيانات التي تم انتاجها اصطناعيا قورنت بملخصات البيانات الي سجلتها الرئاسة العامة للارصاد والبيئة حيث الفروقات مقبولة. الا ان بعضها تحتاج تمحيص وتصحيح حتى تتوافق مع البيانات التي سجلتها الرئاسة العامة للارصاد والبيئة.

الكلمات المفتاحية: محاكاة الطاقة، بيانات الطقس، سنة مناخية اصطناعية، ميتينورم ٧، درجة حرارة الهواء، الرطوبة النسبية، سرعة الرياح، الاشعة الشمسية.