Journal of Tekirdag Agricultural Faculty
Tekirdağ Ziraat Fakültesi Dergisi

Aralık/December 2021, 18(4)
Başvuru/Received: 22/02/21
Kabul/Accepted: 17/03/21
DOI: 10.33462/jotaf.884717

http://dergipark.gov.tr/jotaf
http://jotaf.nku.edu.tr/

ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Creating a Solar Radiation Measuring System (SRMS) Operated by a Programmable Logic Controller (PLC)

Programlanabilir Lojik Kontrolör (PLC) Tarafından İşletilen Bir Solar Radyasyon Ölçme Sisteminin Oluşturulması (SRMS)

Selçuk USTA[1*], Cafer GENÇOĞLAN[2], Serpil GENÇOĞLAN[3]

Abstract

In this study, it is aimed to create a PLC controlled SRMS to be used in rural areas. Firstly a SRMS hardware was prepared consisting of power supply, PLC, analogue module and pyranometer units. Then, a SRMS software was written using CODESYS programming language to measure and record data and to control the hardware by PLC. SRMS software firstly collected the solar radiation in cumulatively by measuring every 30 minutes during the one-day period, and determined the daily total solar radiation. Then it calculated the daily average solar radiation by dividing the daily total solar radiation by the number of measurements. It recorded the daily total and average solar radiation amounts on the SD card. SRMS was tested in Kahramanmaraş Sütçü İmam University (KSU) during the July-November period of the 2019. The daily average solar radiation data recorded at KSU were compared with the data measured in the same period at the Eastern Mediterranean Transition Area Agricultural Research Institute (DAGTEM), located 10 km away. The daily average solar radiation data measured in KSU and DAGTEM varied between 3.63-33.48 MJ m^{-2} day^{-1} and 3.00-33.00 MJ m^{-2} day^{-1}, respectively. Five-month averages of daily solar radiation data measured at both regions were determined 20.20 MJ m^{-2} day^{-1} and 19.64 MJ m^{-2} day^{-1}, respectively. The difference between the mean of KSU and DAGTEM data groups was not found to be statistically significant ($p > 0.05$). This result revealed that the daily average solar radiation values measured in both regions can be used interchangeably. As an expression of the deviation between data groups measured in both regions, the MAPE and RMSE were determined as 14.57% and 2.68 MJ m^{-2} day^{-1}. The compatibility level of the data groups was obtained as "good" (MAPE= 10-20%). It was concluded that SRMS could measure the daily average solar radiation with high accuracy and could be used in sensitive measurements.

Keywords: Automation, Climate station, Codesys, Evapotranspiration, PLC, Pyranometer, Solar radiation

[1]***Sorumlu Yazar/Corresponding Author:** Selçuk USTA, Van Yüzüncü Yıl University, Van Vocational School, Department of Construction, 65090 Van, Turkey. E-mail: susta@yyu.edu.tr OrcID: 0000-0001-8970-7333
[2] Cafer GENÇOĞLAN, Kahramanmaraş Sütçü İmam University, Faculty of Agriculture, Department of Biosystem Engineering, 46040 Kahramanmaraş, Turkey. E-mail: gencoglan@ksu.edu.tr OrcID: 0000-0002-4559-4354
[3] Serpil GENÇOĞLAN, Kahramanmaraş Sütçü İmam University, Faculty of Agriculture, Department of Biosystem Engineering, 46040 Kahramanmaraş, Turkey. E-mail: sgencoglan@ksu.edu.tr OrcID: 0000-0002-7390-8365
Atıf/Citation: Usta, S., Gençoğlan, C., Gençoğlan, S. Creating a Solar Radiation Measuring System (SRMS) Operated by a Programmable Logic Controller (PLC). *Journal of Tekirdag Agricultural Faculty,* 18 (4), 675-688.

Öz

Bu çalışmada, kırsal alanlarda kullanılabilecek PLC kontrollü bir SRMS oluşturulması amaçlanmıştır. İlk olarak güç kaynağı, PLC, analog modül ve piranometre birimlerinden oluşan bir SRMS donanımı hazırlanmıştır. Daha sonra verileri ölçmek, kaydetmek ve donanımı PLC ile kontrol etmek amacıyla CODESYS programlama dili kullanılarak bir SRMS yazılımı yazılmıştır. SRMS yazılımı, ilk olarak bir günlük süre boyunca her 30 dakikada bir ölçüm yaparak solar radyasyonu kümülatif olarak toplamış ve günlük toplam solar radyasyonu belirlemiştir. Daha sonra günlük toplam solar radyasyonu ölçüm sayısına bölerek, günlük ortalama solar radyasyonu hesaplamıştır. Günlük toplam ve ortalama solar radyasyon miktarlarını SD karta kaydetmiştir. SRMS, Kahramanmaraş Sütçü İmam Üniversitesi'nde (KSÜ) 2019 yılı Temmuz-Kasım dönemi boyunca test edilmiştir. KSÜ'de kaydedilen günlük ortalama solar radyasyon verileri 10 km uzaklıkta bulunan Doğu Akdeniz Geçit Kuşağı Tarımsal Araştırma Enstitüsünde (DAGTEM) aynı dönemde ölçülen günlük veriler ile karşılaştırılmıştır. KSÜ ve DAGTEM'de ölçülen günlük ortalama solar radyasyon verileri sırasıyla 3.63-33.48 MJ m^{-2} $gün^{-1}$ ve 3,00-33,00 MJ m^{-2} $gün^{-1}$ arasında değişmiştir. Her iki bölgede ölçülen günlük ortalama solar radyasyon verilerinin beş aylık ortalamaları sırasıyla 20.20 MJ m^{-2} $gün^{-1}$ ve 19.64 MJ m^{-2} $gün^{-1}$ olarak belirlenmiştir. KSU ve DAGTEM veri gruplarının ortalamaları arasındaki fark istatistiksel olarak önemli bulunmamıştır ($p > 0.05$). Bu sonuç her iki bölgede ölçülen günlük ortalama solar radyasyon değerlerinin birbirlerinin yerine kullanılabileceğini ortaya koymuştur. Her iki bölgede ölçülen veri grupları arasındaki sapmanın bir ifadesi olarak MAPE ve RMSE sırasıyla %14.57 ve 2.68 MJ m^{-2} $gün^{-1}$ olarak belirlenmiştir. Veri gruplarının uyumluluk düzeyi "iyi" olarak elde edilmiştir (MAPE=% 10-20). SRMS'nin günlük ortalama solar radyasyonu yüksek doğrulukla ölçebileceği ve hassas ölçümlerde kullanılabileceği sonucuna ulaşılmıştır.

Anahtar Kelimeler: Otomasyon, İklim istasyonu, Codesys, Evapotranspirasyon, PLC, Piranometre, Solar radyasyon

1. Introduction

The total amount of radiation reaching the earth by direct or indirect ways from the sun by propagation and effects of the horizontal plane is defined as global solar radiation or solar radiation. Solar radiation, expressed as the sum of direct radiation reaching the earth through the atmosphere without interruption and the diffuse radiation that reaches the earth by indirect ways due to the factors such as clouds, particles in the atmosphere and the topography, constitutes the basic data of many engineering and architectural applications (Kökey, 2013). However, due to the decrease of fossil fuel reserves in the world, and as these fuels cause to damage the environment, accordingly, solar radiation becomes more important as a renewable clean energy source.

The main data in determining the amount of irrigation water to be applied to crops is evapotranspiration, which is called crop water consumption. Evapotranspiration, an important component of both the meteorological and hydrological cycle, is a highly effective parameter in hydrological and ecological fields and uses three-fifths of solar radiation (Wang and Dickinson, 2012; Wild et al., 2013; Bora et al., 2015). Solar radiation plays an important role in determining the amount of evapotranspiration. It is the most important parameter that controls the net short wavelength radiation coming from the sun, the net long wavelength radiation going from the earth, the amount of net radiation affecting on the plant surface and the heat flux change in the soil (Rosenberg et al., 1983). It is stated that some parameters that are effective on crop development, such as photosynthesis, water requirement, nutrient intake and transpiration rate, are closely related to solar radiation (Adams, 1992). In addition, Deveci et al. (2019) reported that along with moisture conditions in the soil, solar radiation, temperature and precipitation changes are the most important parameters affecting crop yield. It is stated that there is a strong relationship between the amount of solar radiation held by the crop canopy and transpiration, and therefore the amount of solar radiation held by the canopy can be used as a trigger in activating automatic irrigation systems (Casedesus et al., 2011). Solar radiation can be used as a parameter in the preparation of irrigation programs (Jovicich and Cantliffe, 2007). Solar radiation is of great importance in agricultural production structures, especially in greenhouses. In order to be able to be grown crops in greenhouse, soil temperature, carbon dioxide concentration and relative humidity should be provided in sufficient quantities besides nutrients and water, environmental factors such as radiation energy, air temperature in the greenhouse (Yağcıoğlu et al., 2004). The amount of solar radiation incoming into the greenhouses varies depending on the location, dimensions, drection of the greenhouse, and especially the covering material. The most important factor in the selection of greenhouse cover materials is the amount of solar radiation directly affecting crop development (Giacomelli and Ting, 1999). In addition, Koluman et al. (2013) reported that animals are easily stressed in barns where solar radiation is directly effective, so some structural precautions should be taken.

Solar radiation is measured by a device called pyranometer, and the accuracy and precision of this measurement are the most critical parameters in efficiency calculations (Ergün et al., 2019). Many studies were carried out to develop devices that can be used to measure solar radiation. Martínez et al. (2009) developed a photodiode-based pyranometer and compared it with a standard pyranometer. In this study, MAPE was obtained as 1.54% as an expression of the deviation between the solar radiation values measured by both pyranometers. Badran et al. (2010), Avallone et al. (2018) and Tohsing et al. (2019) designed pyranometers controlled by a microcontroller. It was stated that these pyranometers were cheaper than standard pyranometers and could be used in sensitive measurements. Kimothi et al. (2004) stated that solar radiation can be measured with calibrated pyranometer, but considering the shortcomings such as the area where the pyranometer is established was not enough to represent a region, the data measured with the pyranometer should be compared with the data measured by the meteorological stations at most 50 km away, and the accuracy levels should be evaluated.

The agriculture sector with a rate of 70% is the sector with the highest water consumption. It is estimated that this sector will have the highest rate in the next decades (Aksoy et al., 2014). In order to increase water savings by ensuring the sustainable use of water resources in the agricultural sector, it is necessary to determine when and how much water should be given to the crop by preparing sensitive irrigation programs. In the preparation of sensitive irrigation programs, daily evapotranspiration quantities calculated with the daily meteorological data measured in the local conditions are needed (Jensen et al., 1990). In this study, it is aimed to develop a PLC controlled solar radiation measurement system (SRMS) that can be used to measure the daily amounts of solar radiation needed in daily evapotranspiration calculations in the local conditions.

2. Materials and Methods

2.1. Study area

This study was carried out in the research field on Campus of KSU, in Kahramanmaraş, Turkey. The altitude of the research field is 508 m. It is geographically located between 37º 35' 36" North latitude and 36º 49' 20" East longitude. Firstly, SRMS's hardware was created, which was operated by the PLC-based automation system. Later, code of software was written in the CODESYS language and loaded into PLC, and then tested with the SRMS hardware during the July-November period of the 2019. The solar radiation data measured by SRMS was compared with the data measured in DAGTEM. The location of the research field and the DAGTEM are shown in *Figure 1*.

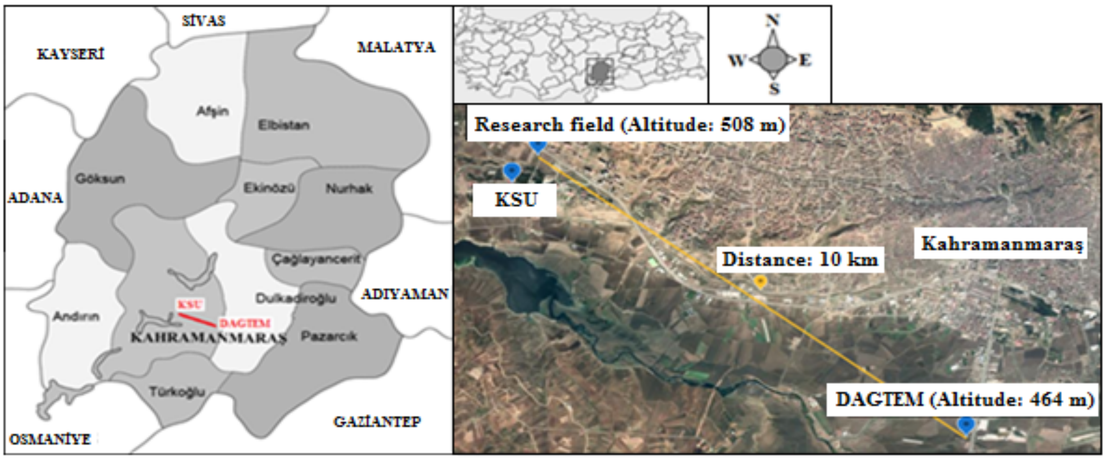

Figure 1. Google Earth Map of SRMS research field and DAGTEM

2.2. Creation of SRMS hardware

SRMS hardware (panel) consists of power supply, PLC, analogue module and a solar radiation sensor. PM 590 ETH PLC was used as central processing unit (CPU) in the SRMS (Anonim, 2018a). An analog output pyranometer was used as a solar radiation sensor (Anonim, 2018b). The pyranometer was mounted on the climate station established in the research field *(Figure 2).* The climate station consisted of wind speed (1), pyranometer (2), temperature and humidity (3), wind direction (4), precipitation (5) sensors and platform (6).

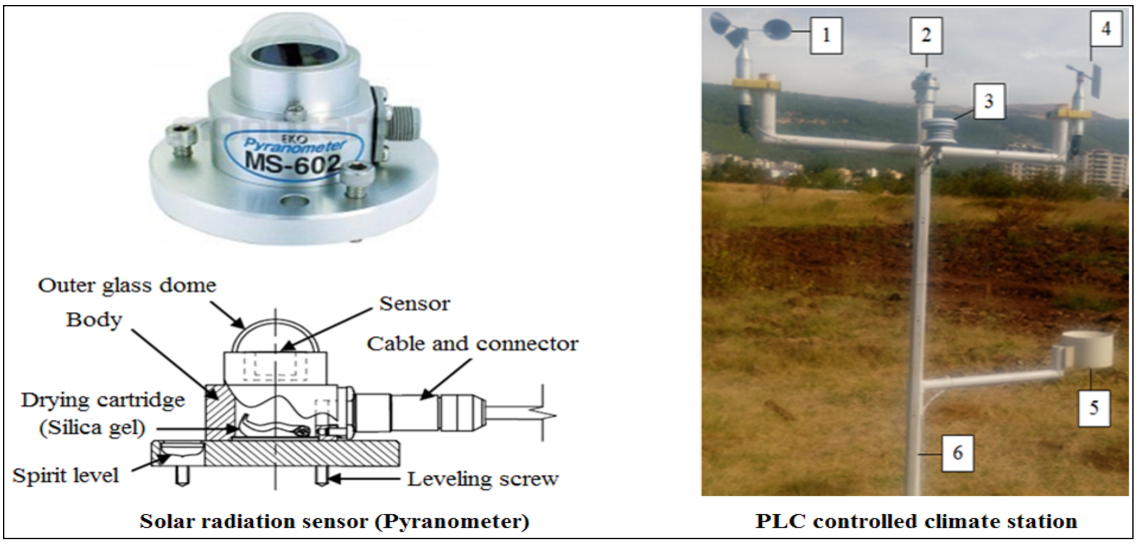

Figure 2. Pyranometer and climate station

AX 522 analog module was added to the PLC in order to provide communication between the pyranometer and the PLC (Anonim, 2018a). A panel project was prepared for the SRMS and, a panel was created in accordance with this project. Within the scope of this project, panel energy input was shown in *Figure 3*, and the connection of PLC (CPU.1) and pyranometer (AI-0) to the analogue module (IOM.1) was shown in *Figure 4*.

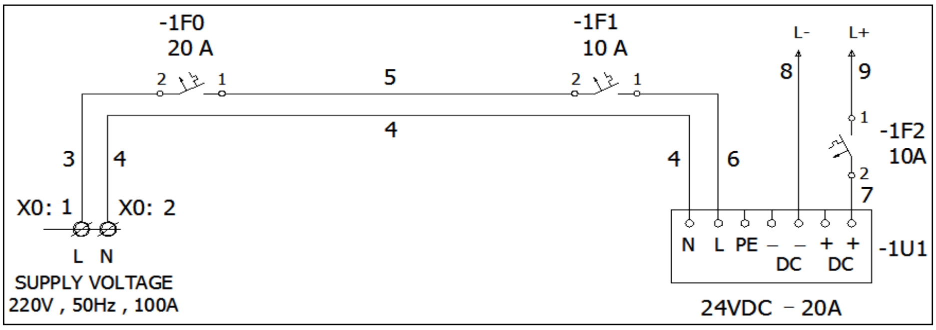

Figure 3. The connection of panel energy input and power supply

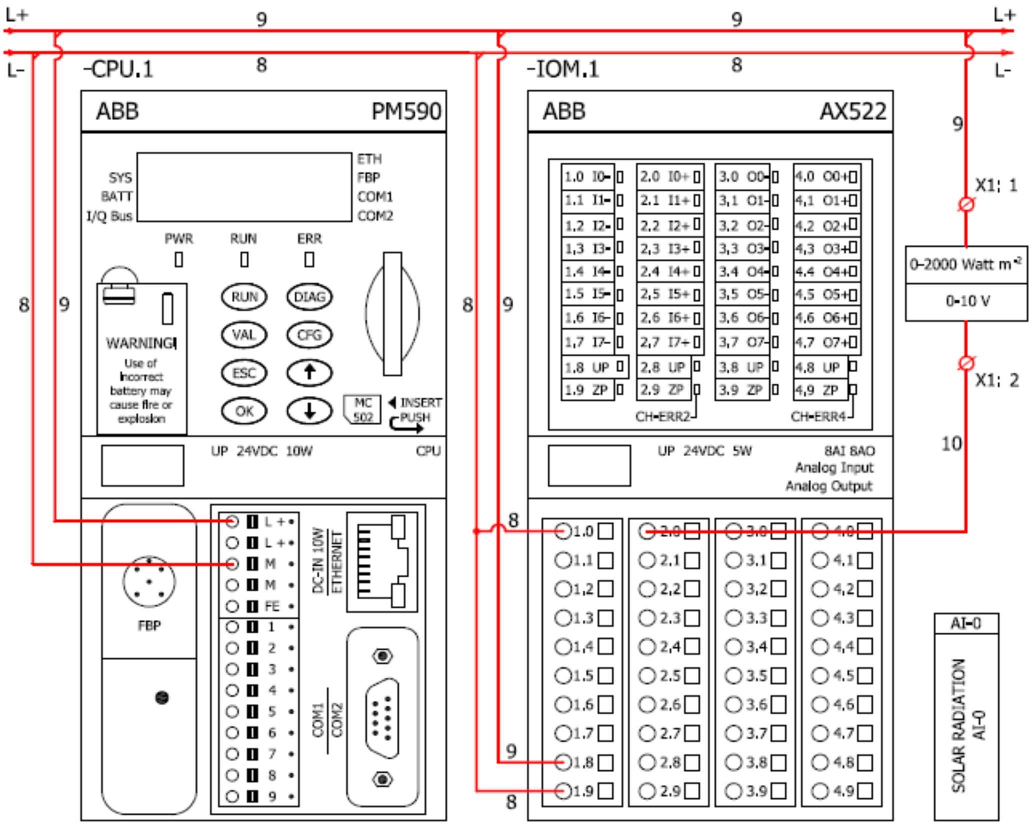

Figure 4. The connection of PLC and the pyranometer to the analogue module

2.3. PLC - hardware configuration

In order to ensure compatibility between SRMS hardware and software, the PLC - hardware was configured using the Automation Panel Builder program (Anonim, 2018c). The configuration process started with the selection of the PLC. PM 590 ETH was chosen as the PLC *(Fiqure 5).* Then, the AX 522 analogue module was added to the PLC *(Figure 6)*. Within the software, the pyrm variable was assigned to the pyranometer and added to the analogue module. Communication between pyranometer and PLC was provided through the IW0 channel of analogue module *(Figure 7)*.

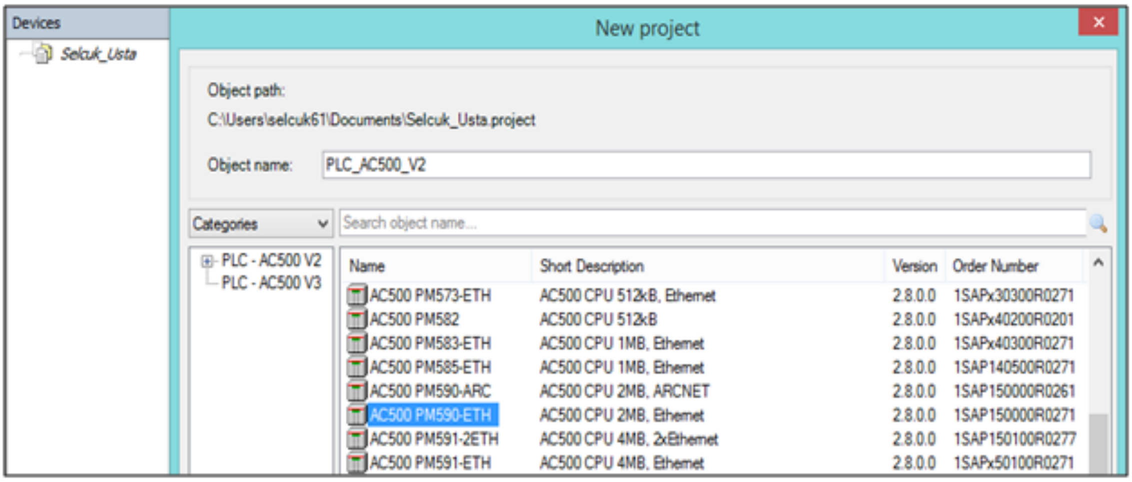

Figure 5. Selecting the PM 590 ETH PLC

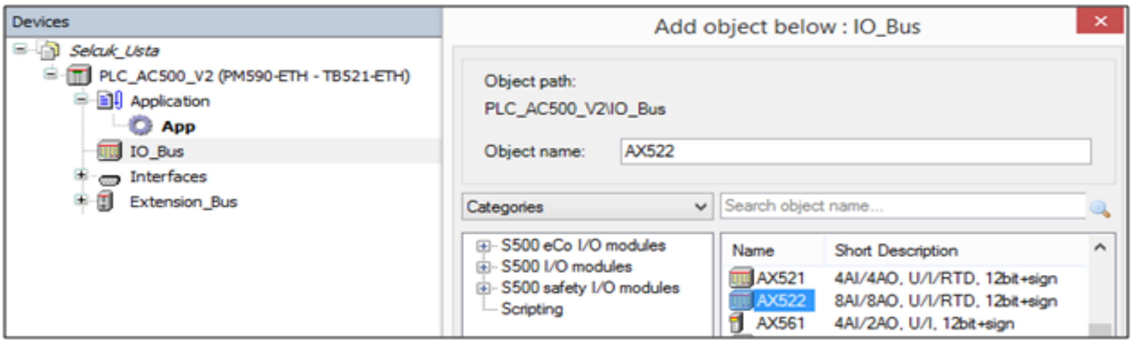

Figure 6. Selecting the AX 522 analogue module

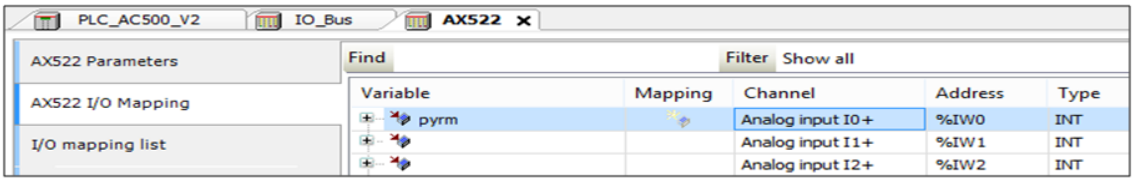

Figure 7. Connecting pyranometer to the analogue module and selecting channel configuration

2.4. Creation of SRMS software

SRMS software was written in the CODESYS programming language and loaded into the PLC. PLC controlled SRMS collected the solar radiation (solar_rad) in cumulatively by measuring every 30 minutes during the one-day period between 08.59.30 on the previous day and 08.59.30 on the following day. The analog output pyranometer produced signals ranging from 0-10 V for solar_rad values. The PLC produced digital values (pyrm) ranging from 1-27648 as a response to these signals. In order to convert the pyrm values to solar_rad values, a calibration was done using the calibration certified digital pyranometer. The solar_rad values measured by the digital pyranometer and the pyrm values produced by the PLC were recorded at the same time in 30 minutes intervals. The calibration equation given in Equation (1) was obtained by performing first order linear regression analysis between these values. The daily total and average solar radiation amounts were determined using Equation (2) and Equation (3), respectively.

solar_rad:=a*(pyrm) + b (Eq. 1)

Total_Rs:=Total_Rs + solar_rad (Eq. 2)

Average_Rs=[0.0864 (Total_Rs)]*48^{-1} (Eq. 3)

Where; solar_rad: solar radiation measured every 30 minutes (Watt m^{-2}), a and b: calibration coefficients, pyrm: digital value produced by PLC, Total_Rs: daily total solar radiation (Watt m^{-2}), Average_Rs: daily average solar radiation (MJ m^{-2} day^{-1}).

2.5. Comparison of solar radiation data measured by SRMS and DAGTEM

MAE, MAPE and RMSE were taken into account as an expression of deviation amounts between SRMS and DAGTEM data. These values were calculated using Equation (4-6). Lewis's (1982) interpretation of MAPE results is a means to judge the level of compatibility between SRMS and DAGTEM data — less than 10% is an "excellent" compatibility, 10% to 20% is a "good" compatibility, 20% to 50% is a "reasonable" compatibility, and 50% or more is an "inaccurate" compatibility. In order to determine whether the difference between the averages of the SRMS and DAGTEM data groups is statistically significant or not, an unpaired T test was performed using the Microsoft Excel program.

$$MAE=\frac{1}{n}\sum_{i=1}^{n}\left(\left|Y_i-\hat{Y}_i\right|\right) \quad \text{(Eq. 4)}$$

$$MAPE=\frac{1}{n}\sum_{i=1}^{n}\left(\frac{\left|Y_i-\hat{Y}_i\right|}{Y_i}100\right) \quad \text{(Eq. 5)}$$

$$RMSE=\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(Y_i-\hat{Y}_i\right)^2} \quad \text{(Eq. 6)}$$

Where; MAE: mean absolute error (MJ m^{-2} day^{-1}), MAPE: mean absolute percentage error (%), RMSE: root mean square error (MJ m^{-2} day^{-1}), Y_i and $\hat{Y}_i$: the data measured by SRMS and DAGTEM, respectively (MJ m^{-2} day^{-1}), n: number of observations.

3. Results and Discussion

SRMS software consisted of the PLC_PRG [PRG] main program, solar_radiation_measurement [PRG], solar_radiation_record [PRG], sd_card_data_write [PRG] subprograms and write_sd_card [FB] function block. These programs were run together via the CODESYS interface given in *Figure 8*.

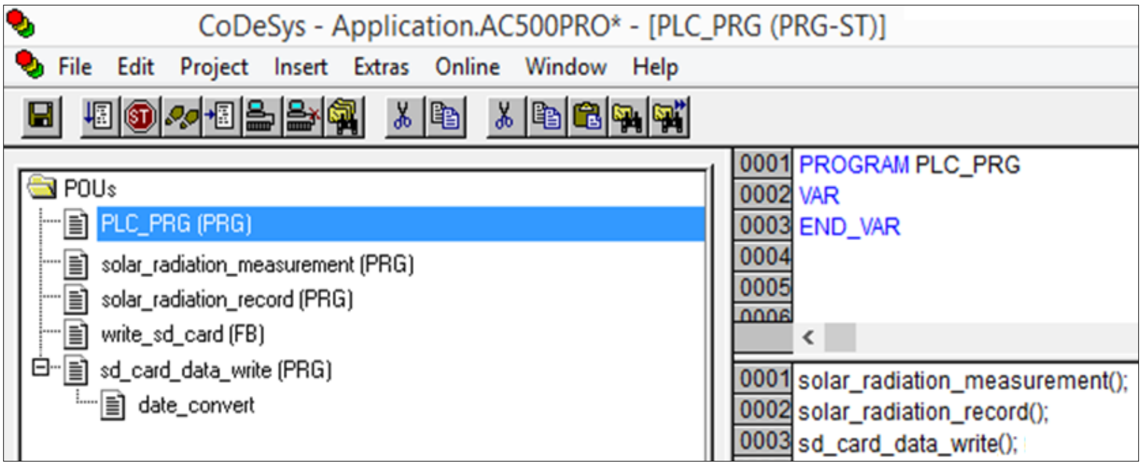

Figure 8. SRMS programs and CODESYS interface

An action named date_convert was defined under the program sd_card_data_write [PRG]. Some variables were defined in WORD, BYTE and REAL variable types in solar_radiation_measurement [PRG] and solar_radiation_record [PRG], which form the basis of the SRMS software, and were converted to STRING variables in this action. Within the scope of the preparation of the SRMS software, local (VAR) and global variables used primarily in the programs were defined *(Fiqure 9)*. Later, the codings of the programs were written using the programming language CODESYS. A struct named Radiation_data was defined in order to facilitate the follow-up of daily measurement processes. In this structure, the day was assigned to the day variable, and Rs_Total to the daily total solar radiation (Total_Rs), and Rs_Average to the daily average solar radiation (Average_Rs) *(Figure 9)*.

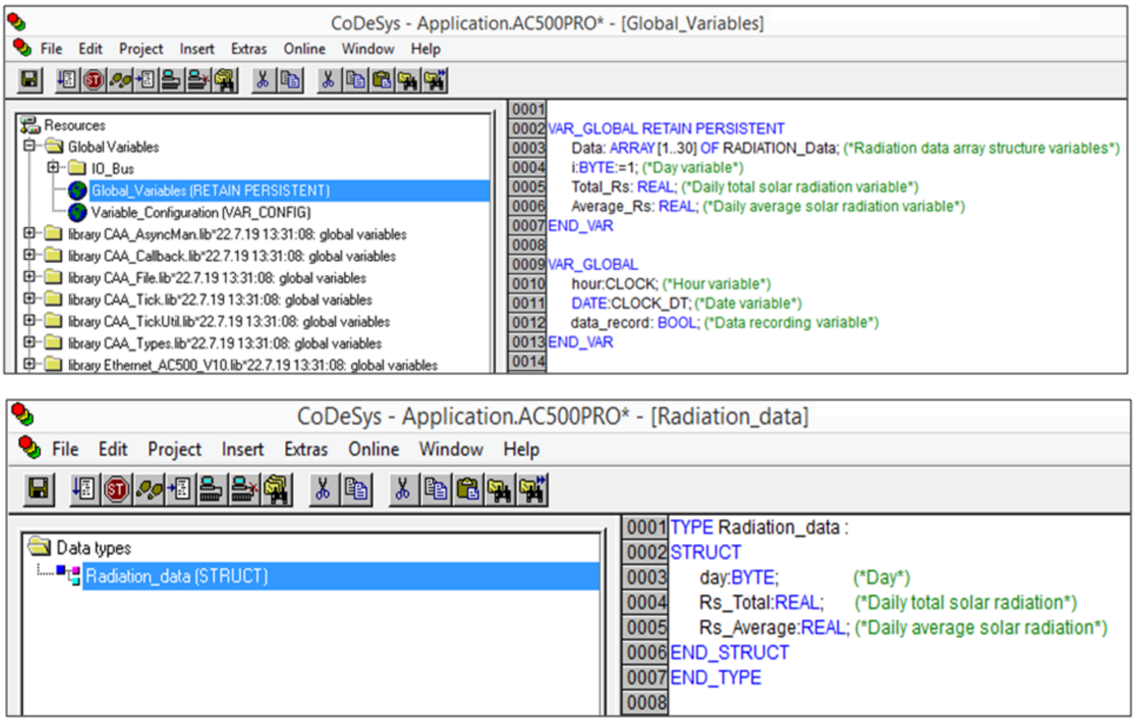

Figure 9. Global variables and Radiation_data [STRUCT] variables

The results of the calibration process were given in *Figure 10*. The relationship between solar_rad and pyrm variables was revealed by the equation "solar_rad= 0.268 * (pyrm) +84.04". The ratio in which the change in solar_rad values could be explained by pyrm values was determined as 99.25% (R^2= 0.9925).

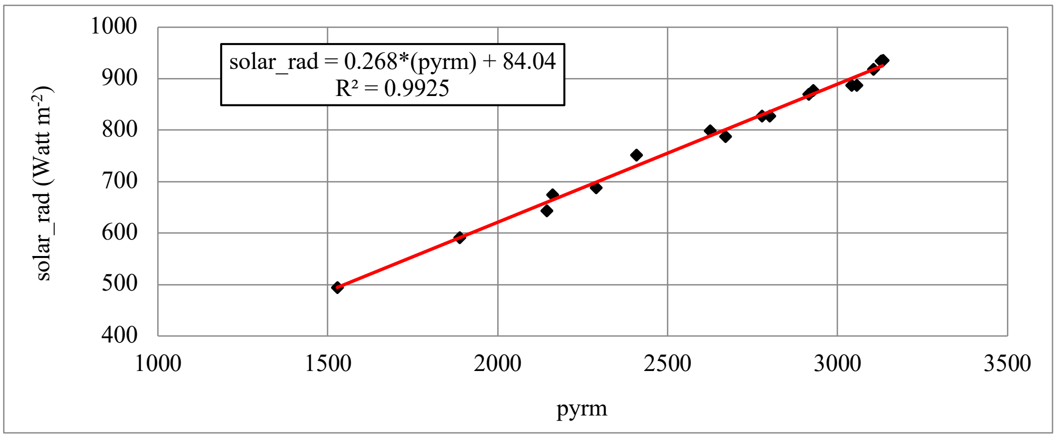

Figure 10. Relationship between solar_rad and pyrm values

Daily solar radiation measurement operations were carried out by solar_radiation_ measurement [PRG]. The flow chart of this program was given in *Figure 11*. Firstly, local variables (VAR) were defined and then, daily measurement operations were carried out using these local variables. pyrm values produced by PLC were converted to solar_rad values using the calibration equation every 30 minutes, and solar_rad values were collected cumulatively. These operations were performed sensitively by trigger variable named trg1. Total_Rs and Average_Rs values were calculated sensitively by trigger variable named trg 2 at 08.59.30 at the end of day.

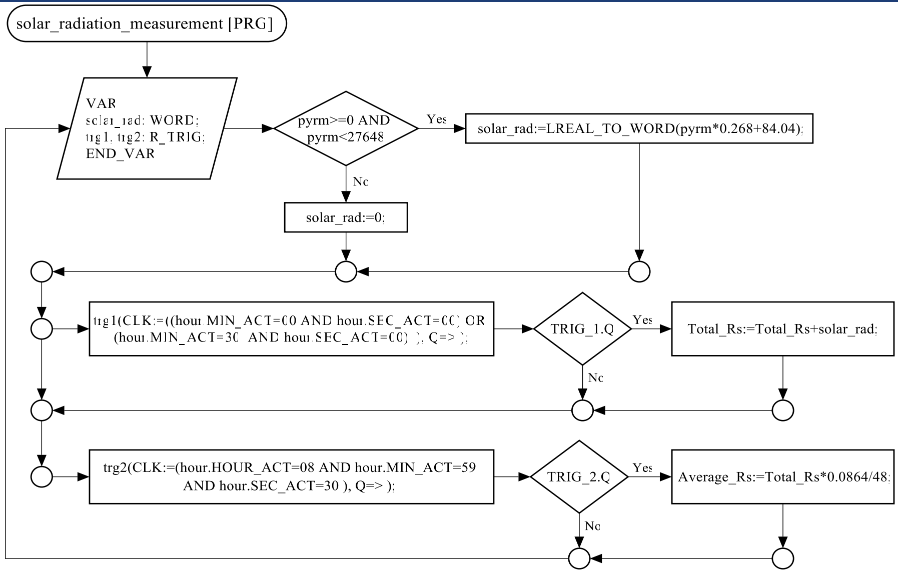

Figure 11. solar_radiation_measurement [PRG] flow chart

The daily Total_Rs and Average_Rs values were recorded in the array structure variables by solar_radiation_record [PRG] at the end of day. The flow chart of this program was given in *Figure 12.*

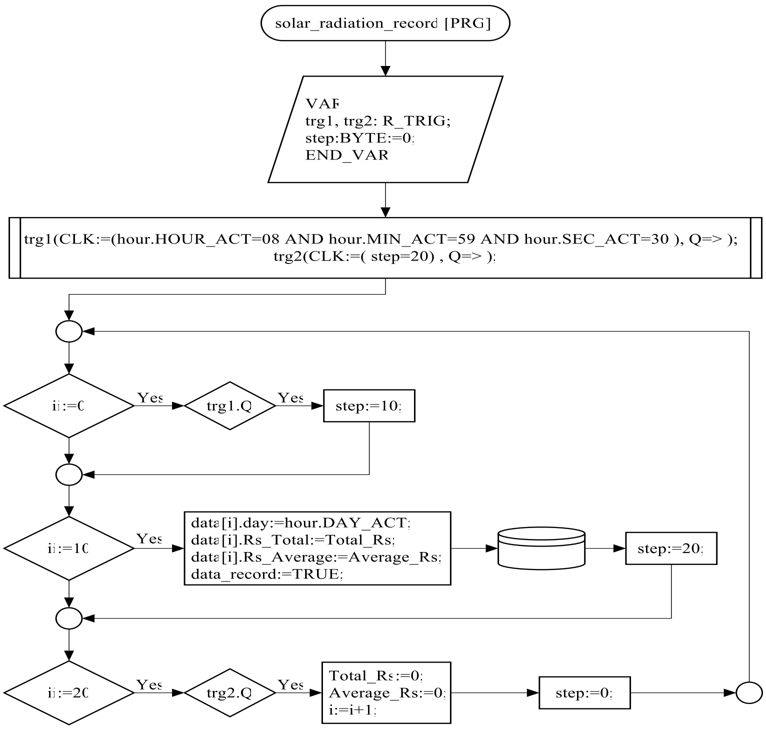

Figure 12. solar_radiation_record [PRG] flow chart

The process of recording daily solar radiation data was started with the step “0”. When the trg1 trigger is active every day at 08.59.30, the step variable was directed to step “10”. In this step, firstly hour of the day (hour.DAY_ACT) was assigned to the “data[i].day” array structure variable on which the measurement operations are performed. Then, the daily Total_Rs and Average_Rs values were assigned to the “data[i].Rs_Total” and “data[i].Rs_Average” array structure variables. Finally, the data recording process was activated, and the step variable was directed to step “20”. In this step, when the trg2 trigger is active, Total_Rs and Average_Rs values were reset, day variable (i) was increased by one and, the step variable was directed to step “0” to perform the next day’s measurements.

Daily Total_Rs and Average_Rs values assigned to the array structure variables every day at 08.59.30 were taken by the sd_card_data_write [PRG] at the same hour, and written on the SD card. The flow chart of this program was given in *Figure 13*. A rising edge function named R_TRIG_record was defined within the program. When the rising edge function is active every day at 08.59.30, the step variable was directed to step "10". In this step, act_day, act_month and act_year variables were combined with a semicolon (;), and the step variable was directed to step "20". In this step, Rs_Total and Rs_Average values were added to the variables that combined in step "10". After this process, the step variable was directed to step "30". In this step, the data was written to file of the solar_radiation_data.csv on the SD card via the write_sd_card [FB]. A part of this data file for July is given in *Figure 14*. Date, Rs_Total and Rs_Average values were written in columns A, B and C in this data file.

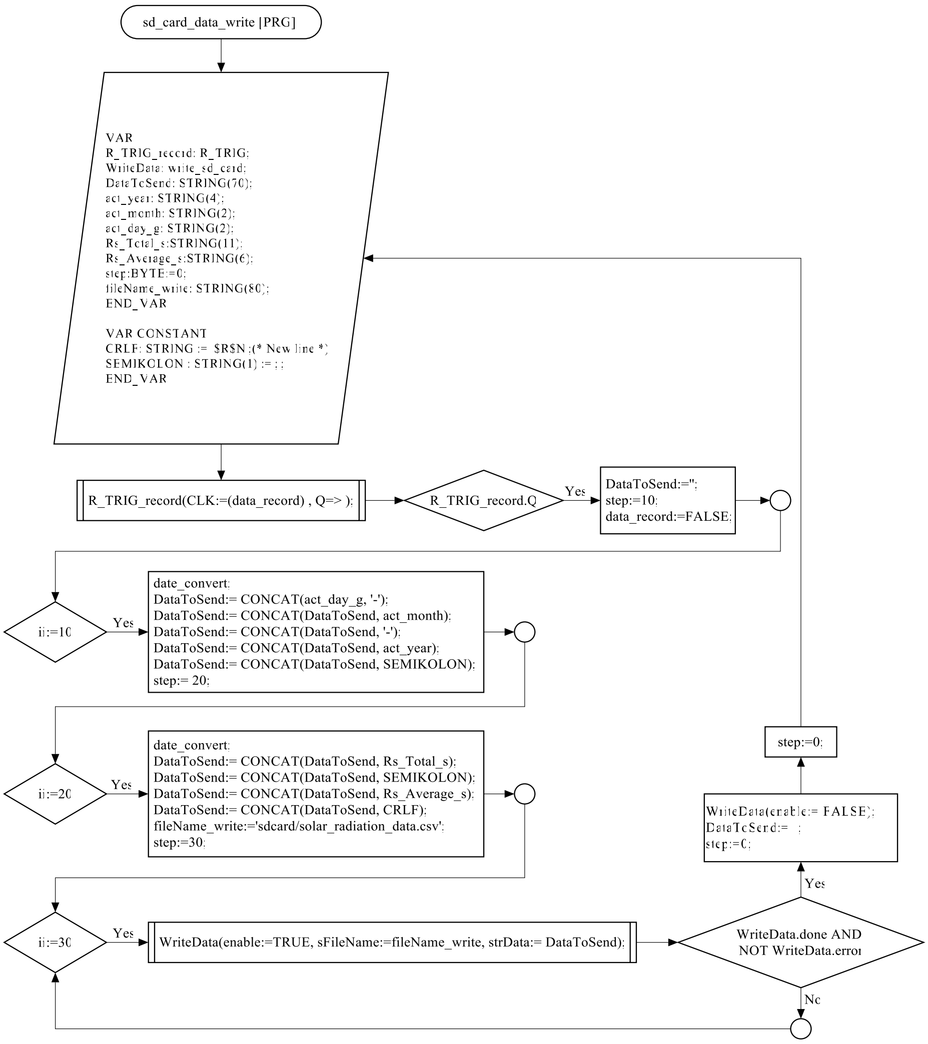

Figure 13. *sd_card_data_write [PRG] flow chart*

Microsoft Excel - solar_radiation_data.csv.xlsx

	A	B	C
1	Date	Rs_Total	Rs_Average
2	1.7.2019	15483.33	27.87
3	2.7.2019	16988.89	30.58
4	3.7.2019	18600.00	33.48
5	4.7.2019	15638.89	28.15
6	5.7.2019	16466.67	29.64
7	6.7.2019	15961.11	28.73
8	7.7.2019	16144.44	29.06
9	8.7.2019	14244.44	25.64
10	9.7.2019	16122.22	29.02

Figure 14. The part of the data file solar_radiaition_data.csv for July

Rs_Average data measured by SRMS at KSU in July-November period of the 2019 was compared with Rs_Average data measured at DAGTEM in the same period. Rs_Average data measured in both regions were given in Figure 15. Daily data measured in KSU and DAGTEM varied between 3.63-33.48 MJ m^{-2} day^{-1} and 3.00-33.00 MJ m^{-2} day^{-1}, respectively. Five-month averages of daily solar radiation data measured in both regions were determined as 20.20 MJ m^{-2} day^{-1} and 19.64 MJ m^{-2} day^{-1}, respectively. According to the analysis made by taking into account all the daily data measured in both regions; as an expression of the deviation amounts between the SRMS and DAGTEM data, MAE was obtained as 2.06 MJ m^{-2} day^{-1}, MAPE 14.57%, and RMSE 2.68 MJ m^{-2} day^{-1}. The level of compatibility between SRMS and DAGTEM data groups was obtained as "good" (MAPE= 10-20%). The difference between the mean of SRMS and DAGTEM daily data groups was not found to be statistically significant (p> 0.05).

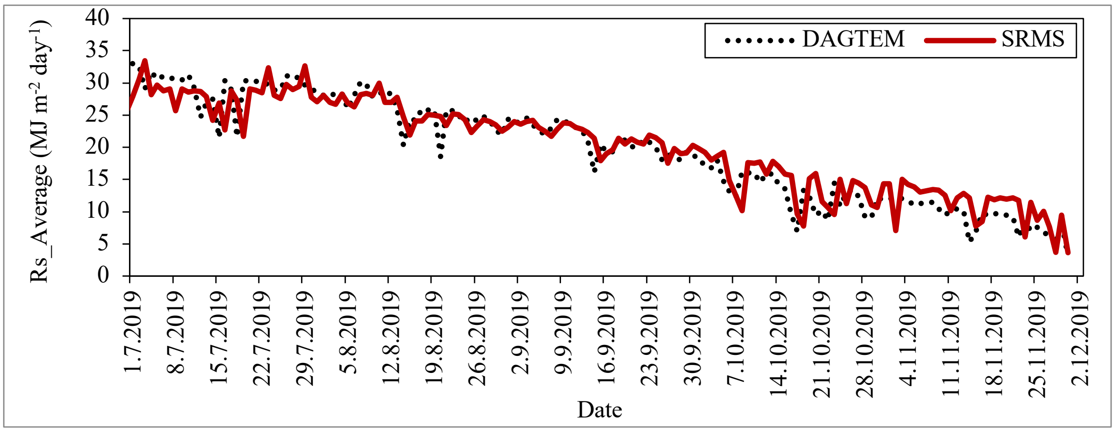

Figure 15. Daily average solar radiation data measured by DAGTEM and SRMS

The statistical relationships between the daily data groups for each month was determined separately and, given in *Table 1*. It is seen in Table 1 that the differences between the averages of the data groups were not found to be statistically significant in July, August, September and October (p> 0.05), when evapotranspiration and the amount of irrigation water determined accordingly are of great importance for the crops. In these months, the Rs_Average data measured by SRMS and DAGTEM can be considered the same. The level of compatibility between SRMS and DAGTEM data groups was determined as "excellent" (MAPE<10%) in July, August, September, and "reasonable" (MAPE= 20-50%) in October and November. The difference between the averages of data groups was found to be statistically significant in November (p< 0.05).

Table 1. Statistical relationships between SRMS and DAGTEM daily data for each month

Month	**MAE (MJ m^{-2} day^{-1})**	**MAPE (%)**	**RMSE (MJ m^{-2} day^{-1})**	**Compatibility level**	**P**
July	2.76	9.67	3.44	Excellent	0.104
August	1.35	5.58	1.86	Excellent	0.700
September	1.00	4.81	1.44	Excellent	0.517
October	2.68	20.39	3.18	Reasonable	0.087
November	2.50	23.72	2.90	Reasonable	0.012

Brown and Russel (2001) stated that the surface characteristics and topography of the land around the climate station could affect the climate data at rates approaching 20%. Due to the fact that the land surface around the climate station in KSU is covered with heavy vegetation and is more rugged than DAGTEM, there were deviations ranging from 4.81-23.72% between the Rs_Average data measured in both regions. Pinto et al. (2006) compared climate parameters measured in three different regions of the city in a study they conducted in São Paulo, Brazil. As a result of this study, they revealed that there were found to be statistically significant differences between the relative humidity and wind speed data (p <0.05), and the differences between air temperature and solar radiation data were not found to be statistically significant (p> 0.05). Similarly, it is clearly seen in *Table 1* that the differences between the daily average solar radiation data measured in two regions at 10 km distance in Kahramanmaraş province are not found to be statistically significant (p> 0.05).

Monthly average values of Rs_Average data measured in both regions were given in *Table 2*. In this table, it is clearly seen that the SRMS data is lower than the DAGTEM data in July and August, and higher in September, October and November. This situation is thought to be due to the different wind speeds and altitude difference in both regions. Anjos et al. (2015), Bett and Thornton (2016) stated that although there was a weak statistical relationship between wind speed and solar radiation, solar radiation generally tended to increase during periods when wind speed tended to decrease. During the July-August period, the daily average wind speed was measured as 3.08 m s^{-1} in the DAGTEM, and 3.20 m s^{-1} in the research field. The mean Rs_Average in this period was determined as 27.60 MJ m^{-2} day^{-1} in the DAGTEM and, 26.90 MJ m^{-2} day^{-1} in the research field. As the daily average wind speeds in DAGTEM were lower in these months compared to the research area, it has been observed that the measured Rs_Average data in this region were higher. During the September-November period, the daily average wind speed was measured as 1.76 m s^{-1} in the DAGTEM, and 1.45 m s^{-1} in the research field. The means of Rs_Average in this period were determined as 14.25 MJ m^{-2} day^{-1} in the DAGTEM and, 15.65 MJ m^{-2} day^{-1} in the research field. As the daily average wind speeds in DAGTEM were higher in these months compared to the research area, it has been observed that the measured Rs_Average data in this region were lower. Blumthaler et al. (1997) stated that solar radiation increased by 15-20% every 1000 meters depending on altitude. The altitudes of the research field and the DAGTEM are 508 m and 464 m, respectively. It is considered that the Rs_Average values in the research field are 1.00% higher than the values in DAGTEM due to the altitude difference.

Table 2. Monthly average values of Rs_Average data measured by SRMS and DAGTEM

Month	**Rs_Average (MJ m^{-2} day^{-1})**	
	SRMS	**DAGTEM**
July	28.32	29.40
August	25.50	25.73
September	21.46	21.11
October	14.61	13.21
November	10.88	8.44

4. Conclusions

In this study, a SRMS controlled by the PLC-based automation system was created. The SRMS measured the solar radiation every 30 minutes for one-day periods, and collected cumulatively, and determined the Rs_Total at the end of the day. It calculated the Rs_Average by dividing the Rs_Total by the number of measurements. Rs_Average data measured by SRMS at KSU in July-November period of 2019 was compared with data measured at DAGTEM in the same period. Five-month averages of Rs_Average data measured in both regions were determined as 20.20 MJ m^{-2} day^{-1} and 19.64 MJ m^{-2} day^{-1}. There was a deviation of 14.57% between Rs_Average values measured in both regions due to wind speed and altitude difference. The level of compatibility between SRMS and DAGTEM data groups was determined as "good" (MAPE= 10-20%). The difference between the mean of both daily data groups was not found to be statistically significant ($p > 0.05$). It is concluded that SRMS can measure the Rs_Average with high accuracy and can be used in sensitive solar radiation measurements. It has been observed that SRMS saves labour and time used for solar radiation measurement and minimizes human-induced measurement errors.

References

Adams, P. (1992). Crop nutrition in hydroponics. *Acta Horticulturae* 323: 289–305

Aksoy, A., Demir, N.F., Öztürk, F.G. (2014). Agricultural Water Use and Sustainability in Turkey. *11th national agricultural economics congress*. 3-5 September, P.462-469. Samsun, Turkey

Anjos, P.S., Silva, A.S.A., Stošić, B., Stošić, T. (2015). Long-term correlations and cross-correlations in wind speed and solar radiation temporal series from Fernando de Noronha Island, Brazil. *Physica A: Statistical Mechanics and its Applications* 424: 90–96

Anonim (2018a). Detailed information for: PM590 ETH, AX522 and DX561, https://new.abb.com/products, (Accessed date: 03.02.2018)

Anonim (2018b). Pyranometers MS-802/402/410/602-instruction manual, https://media. eko-eu.com/assets/media/MS-402_Manual.pdf, (Accessed date: 12.06.2018)

Anonim (2018c). Automation Builder V1.2.2 basic software installation, https://new.abb. com/plc/automationbuilder/platform/software, (Accessed date: 03.02.2018)

Avallone, E., Mioralli, P.C., Scalon, V.L., Padilha, A., Oliveira, S.D.O. (2018). Thermal pyranometer using the open hardware arduino platform. *International Journal of Thermodynamics* 21 (1): 1-5

Badran, O., Al Salaymeh, A., El Tous, Y., Abdala, W. (2010). Design and testing of an innovative solar radiation measurement device. *Energy Conversion and Management* 51: 1616–1620

Bett, P.E., Thornton, H.E. (2016). The climatological relationships between wind and solar energy supply in Britain. *Renewable Energy* 87: 96–110

Blumthaler, M., Ambach, W., Ellinger, R. (1997). Increase in solar UV radiation with altitude. *Journal of Photochemistry and Photobiology B: Biology* 39 (2): 130–134

Bora, E., Tekeli, M., Etöz, M. (2015). Temporal variations of reference evapotranspiration and measured solar radiation in the Menemen Plain. *Journal of AARI* 25 (2): 65–76

Brown, P., Russel, B. (2001). Siting and maintenance of weather stations. *The University of Arizona, Cooperative Extension, Turf Irrigation Management Series* 3: 1–5

Casadesus, J., Mata, M., Marsal, J., Girona, J. (2011). Automated irrigation of apple trees based on measurements of light interception by the canopy. *Biosystems Engineering* 108: 220–226

Deveci, H., Konukcu, F., Altürk, B. (2019). Effect of Climate Change on Wheat Grown Soil Moisture Profile in Thrace District. *Journal of Tekirdag Agricultural Faculty* 16 (2): 202–218

Ergün, A., Ceylan, İ., Aydın, M., Gürel, A.E., Koçbulut, G. (2019). Solarmeter design for high solar radiation measurement and experimental validation. *El-CezerîJournal of Science and Engineering* 6 (3): 726–735

Giacomelli, G.A., Ting, K.C. (1999). Horticultural and engineering considerations for the design of integrated greenhouse plant production systems. *Acta Horticulturae* 481: 475–481

Jensen, M.E., Burman, R.D., Allen, R.G. (1990). Evapotranspiration and Irrigation Water Requirements, ASCE, Reston, USA

Jovicich, E., Cantliffe, D.J. (2007). Bell pepper fruit yield and quality as influenced by solar radiation–based irrigation and container media in a passively ventilated greenhouse. *HortScience* 42 (3): 642–652

Kimothi, S., Bhattacharya, B., Semalty, P.D., Pandey, V.K., Dadhwal, V.K. (2004). Estimation of ground insolation using METEOSAT data over India. *Current science* 86 (9): 1308–1312

Koluman, N., Daşkıran, İ., Şener, B. (2013). The Heat Strees Effect on T4 (Thyroxin), T3 (Triiodothyronine), Costisol Hormones of Goats in Rearing Extensive Systems. *Journal of Tekirdag Agricultural Faculty* 10 (3): 29–136

Kökey, İ. (2013). Güneş Enerji Santrallerinin Kurulumunda Güneş Ölçümünün Önemi ve Türkiye'de Yasal Mevzuat. *Ölçübilim Kongresi*. 26-28 Eylül, P.1-7. Kocaeli, Turkey

Lewis, C.D. (1982). Industrial and Business Forecasting Methods: A Practical Guide to Exponential Smoothing and Curve Fitting, Butterworths Scientific, London

Martínez, M.A., Andújar, J.M., Enrique, J.M. (2009). A new and inexpensive pyranometer for the visible spectral range. *Sensors* 9: 4615–4634

Pinto, H.S., Pellegrino, G.Q., Fonsechi, D.B., Coral, G., Caramoni P.H., De Ávila, A.M. (2006). Comparison between Daily Meteorological Data Collected by Automatic and Conventional Stations. *4th International Conference on Experiences with Automatic Weather Stations*, 24-26 May, P.1-9. Lisboa, Portugal

Rosenberg, N.J., Blad, B.L., Werma, S.B. (1983). Microclimate-The Biological Environment, Wiley, New York

Tohsing, K., Phaisathit, D., Pattarapanitchai, S., Masiri, I., Buntoung, S., Aumporn, O., Wattan, R. (2019). A development of a low-cost pyranometer for measuring broadband solar radiation. *Journal of Physics: Conference Series* 1380: 1–4

Wang, K., Dickinson, R.E. (2012). A review of global terrestrial evapotranspiration: observation, modeling, climatology and climatic variability. *Reviews of Geophysics* 50 (2): 1–54

Wild, M., Folini, D., Schär, C., Loeb, N., Dutton, E.G., König-Langlo, G. (2013). The global energy balance from a surface perspective. *Climate Dynamics* 40: 3107–3134

Yağcıoğlu, A., Demir, V., Günhan, T. (2004). A computation procedure for estimating the effective transmitted sun radiation into the greenhouse - Part I. *Journal of Agriculture Faculty of Ege University* 41 (2): 143–154