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Energy Management and Measurement of Computer Controlled Solar House Model for Rize City

Rize İli için Bilgisayar Kontrollü Güneş Evi Modelinin Enerji Yönetimi ve Ölçümü

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Abstract
The Rize city of Turkey is located in the East Black Sea region and covered with forests and high mountains. The hilly terrain prevents the distribution of electricity to remote locations. Therefore, plateau living and tourism services are restricted to certain areas. Depend on, some mountain places still could not use electricity in the region and the requirements of renewable energy sources are increasing every past day. In this study, a solar house model that contains a solar cell panel was designed and supported with computer control. Also, necessary calculations were performed for the system enlarged to use in residential. Regional meteorological data were taken into account for these calculations. Also, the energy obtained from the photovoltaic panel and stored in the battery was measured. Visual Basic software was used to provide communication between the line printer (parallel port) and the solar house model device control unit for basic and special applications. The software supplies a management algorithm to use energy more efficiently. Measurements showed that the solar energy potential of Rize city is competitive in terms of system efficiency, applicability, and repeatability.

Keywords: Computer Control with a Parallel Port, Energy Storage, Energy Management and Measurement, Photovoltaic Solar House Model

Öz
Türkiye'nin Rize şehri, Doğu Karadeniz bölgesinde bulunmakta ve ormanlarla ve yüksek dağlarla kaplıdır. Engebeli arazi, elektriğin uzak yerlere dağıtımını önler. Bu nedenle plato yaşam ve turizm hizmetleri bazı alanlarla sınırlıdır. Buna bağlı olarak, bazı dağlık alanlar bölgede hala elektrik kullanamamaktadır ve yenilenebilir enerji kaynaklarının gereksinimleri her geçen gün artmaktadır. Bu çalışmada güneş paneli içeren bir güneş evi modeli tasarlanmış ve bilgisayar kontrolü ile desteklenmiştir. İlave olarak sistemin gerçek bir evde kullanılması için gerekli hesaplamalar yapılmıştır. Bölgesel meteorolojik verilerde bu hesaplama için dikkate alınmıştır. Yine güneş panelinden ve aküye depolanan enerji hesaplanmıştır. Visual Basic programı LPT paralel portu ile güneş evi modeli arasındaki haberleşmeyi sağlamak ve temel ve özel uygulamalar için kullanılır. Yazılım enerjiyi daha verimli kullanmak için akıllı bir denetim algoritması sağlar. Ölçüm sonuçları Rize ilinin enerji potansiyelinin sistem verimi, uygulanabilirliği ve tekrarlanabilirliği yönünden uygun olduğunu göstermiştir.

***Anahtar kelimeler**: Paralel Port ile Bilgisayar Kontrolü, Enerji Depolama, Enerji Ölçümü ve Yönetimi, Fotovoltaik Güneş Evi Modeli*

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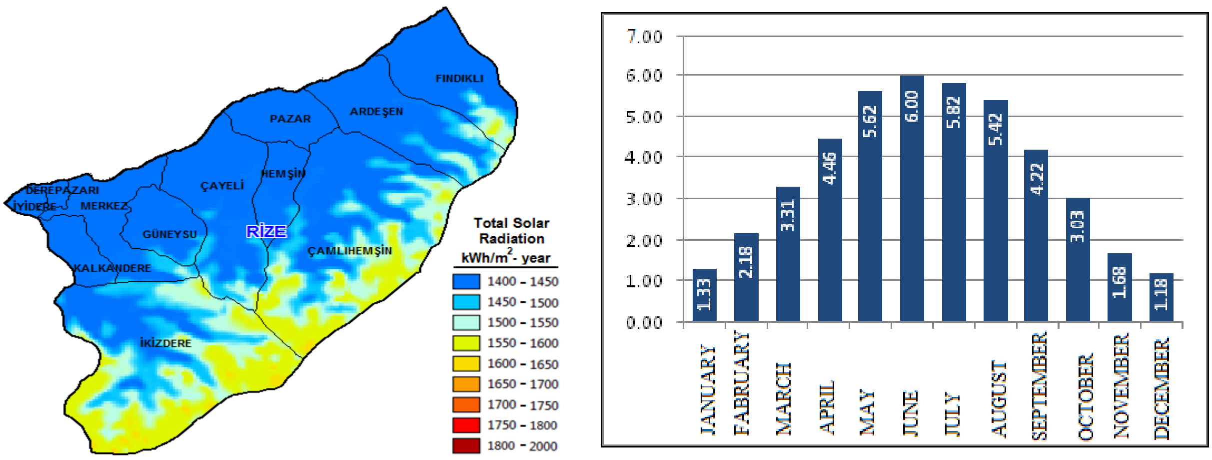
1. Introduction

Solar energy is one of the most widely used renewable energy sources wherever it is economical. The obtained energy from the solar cells heavily depends on the meteorological data and sun radiation. On the other hand, energy consumption depending on the loads is very important for the management of the system perfectly (Shakeri, 2018). A smart home demand-side management system is getting popular for the solar photovoltaic generation today (Baldauf, 2015). Also, while the world is going to industry 4.0, computers are inevitably included in energy management systems (Tohănean, 2018; Villa, 2018). Therefore, energy management with computer control, homes and grids are getting important in today.

Some attempts have been made in a few studies to assess the features of rural electrification and the feasibility of photovoltaic solar home systems in India and Egypt (Ahmad, 2002; Cucchiella, 2012). Also, in some studies analyses the photovoltaic solar energy capacity of residential rooftops in Andalusia (Spain) and photovoltaic electricity production in a residential house on the island of Réunion (Franch) using the measured solar data (Ordóñez, 2010; Bojic, 2013). This study aims to investigate the feasibility of solar energy applications in a North-eastern city of Turkey, Rize. The total solar radiation and global solar radiation values were the consideration for Rize city. The total sun radiation map for the Rize city is shown in Figure 1 (a). This map shows that mountainous areas are sunnier than coastal areas. By the comparison of global sun energy values, it is seen that the summer months are approximately three times sunnier than the winter months as shown in Figure 1 (b). These values are very important to design a self-contained off-grid system. Also, they are necessary to calculate the solar power requirement for the designed system (Aksungur et al., 2013; URL-1, 2018). Therefore, this study will be supplied pre-information about the solar energy potential of the Rize city and will be a guide for the investors and researcher who will study similar matters.



(a) (b)

Figure 1. (a) Total solar radiation (kWh/m^2-year) map for Rize city, (b) Global solar radiation values (kWh/m^2-day) (Aksungur et al., 2013; URL-1, 2018).

If compared to the Rize city with the other cities of Turkey in terms of sunshine duration and solar radiation value (kWh/m².year) per year, average values show that the Rize city has the minimum values. These results are shown in Table 1 for comparison. On the other hand, there are no differences with other cities in the Black Sea region such as Trabzon and Samsun. This situation shows the lower solar energy value limit for Turkey. So it can be said that this system which for Rize city can be used all around the country easily (URL-1, 2018; URL-2, 2018).

The studies in the literature are searched and related studies are given in this section. One of the first studies is a patent in the US, which is a plan on the control of the house lightening system with a computer, but not includes a photovoltaic system and experimental part (Taylor, 1998). Another study is about planning the photovoltaic systems for houses in Japan without does not include an experimental part and computer controlling (Kuwano, 1998). The other study researched photovoltaic systems in residential houses in Malaysia past, present, and future

(Firduas, 2011). In addition, in some studies searched agent-based electrical power management for the photovoltaic system (Kanomori, 2011; Oden et al, 2018), and used some different photovoltaic applications, for example, water pumping and automatic irrigations system (Altaş, 1999; Thana et al., 2006; Senpınar, 2018; Şahin et al., 2018; Fıratoğlu, 2019;). Although the same idea or application is not found in literature so detailed, some specific studies on real-time measurement about solar radiation are found (Guo, 2011; Lazzaroni et al., 2015; Öztürk et al., 2016; Senpınar, 2018). This paper is developed by the authors based on previous studies where only the theory and basic parts presented. (Şahin et al., 2010; Bingöl, 2012, Eroğlu, 2012). Although some similar commercial products can be found in the market for restricted applications, this study aims to expand the basic idea and investigate it more detailed.

Table 1. The sunshine duration and solar radiation values per year in some cities of turkey

Some Cities of Turkey	Adana	Ankara	Bursa	Kars	Kocaeli	Rize	Trabzon	Samsun	Van
Sunshine Duration (Hour/year)	2953	2611	2515	2537	2373	2124	2132	2314	3070
Solar Radiation Value (kWh/m^2-year)	1564	1473	1393	1472	1329	1403	1394	1335	1652

On the other side battery, combined Photovoltaic house systems and their control and management are investigated in some studies. The merit of battery combined photovoltaic generation system for residential house, cooperative home energy management using batteries for a photovoltaic system considering the diversity of households is investigated in two studies (Iga, 2004; Iwafune, 2015). Fuzzy logic based economic analysis of photovoltaic energy management for a photovoltaic solar home is investigated (Ciabattoni, 2015; Chekired, 2017). Nonlinear predictive energy management of residential buildings with photovoltaics & batteries and stochastic control of smart home energy management with plug-in electric vehicle battery energy storage and photovoltaic array are proposed as a different study (Wu, 2016; Sun, 2016).

This paper aims to investigate the feasibility of solar energy applications in a North-eastern city of Turkey, Rize. The total solar radiation and global solar radiation values were the consideration for Rize city which is the rainier city of Turkey at the same time. For this aim designed and energy management and measurement of computer-controlled solar house model for Rize city. The photovoltaic panel characteristics, charge circuit design and battery selection, computer control, voltage measurement, and graphical user interface and general structure of the designed model system are given in material and methods. This material and methods are combined that rarely found the information's in literature and includes a lot of useful practical design information to inspire the researchers and designers. The experimental results give some useful information about the residential PV-computer control design applications and Rize city energy potential measurement also.

2. Material Method

2.1. Photovoltaic Panel

In this study, a silicon monocrystal solar panel with a surface area of 800 cm^2 was used. This is an optic transparent structure solar panel in the infrared wave dimensions as seen in Figure 2 (a). The manufacturer and parameters of the solar panel are not known. So, as a result of voltage-current characteristics investigation, the fill factor was found as 0.81 from solar cells voltage-current curves. At this result, the panel output power for the system was measured approximately 5 Watt and efficiency was calculated as 11.7% (Fıratoğlu et al., 2009; Şahin et al., 2010). The solar panels open-circuit voltage V_{oc} = 25 V and closed-circuit current I_{sc}=330 mA are measured for maximum efficiency. The photovoltaic panel current-voltage (I-V) and power-voltage (P-V) curves are shown in Figure 2 (b), (c) respectively. This photovoltaic panel consists of 36 pieces of series mono crystal cells to supply necessary voltage and low output current since it is not including parallel cells. This photovoltaic panel is suitable for charging 12 V batteries by working at 15-20 V maximum power point voltage with a simple charger (Chen et al., 2006; Şahin et al., 2016; Souleyman, 2016). The study and measurements are made in Rize/Turkey in May and September 2015.

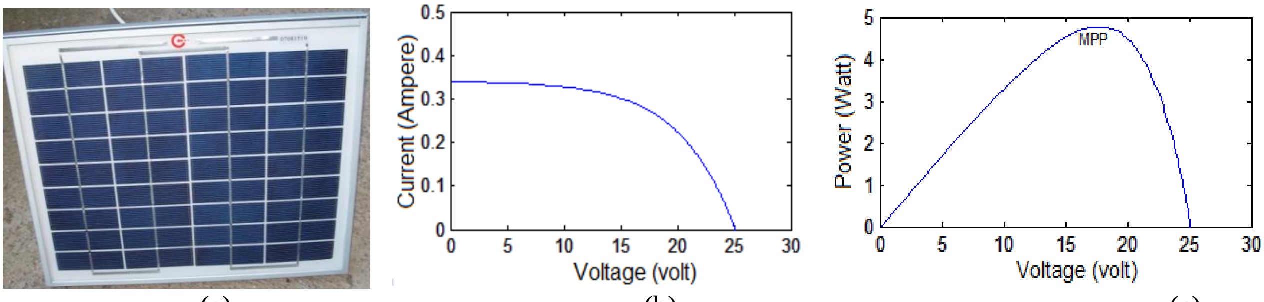


Figure 2. (a) The used solar panel, (b) I-V curve of this panel, (c) P-V curve of this panel.

2.2. Charge Circuit Design and Battery Selection

Because of the solar panels' output voltage is 15-20 V for maximum powerpoint, a battery having 12 V nominal voltage is selected. Battery power and current value that is selected depending on solar panel I-V characteristic and the maximum power absorbed from the system. In this model 12 V and 1.3 Ah a battery was used and aimed to supply all energy of the system devices for three hours unceasingly. If the solar panel works full efficiency, the battery will be charged in four hours. According to solar radiation, this duration can be shorter or longer. To prevent these problems, auxiliary batteries can be added to the system (Altaş, 2009).

A simple battery charger circuit is designed for charging and protecting the battery group. Two input diodes protect the solar panel in this circuit from reverse current. The difference circuit restricts the current absorbed from the battery by the transistor switching. The aim of this restriction is protecting the battery against the voltage drop under catalog limit values to be charged again. The designed battery charge circuit is shown in Figure 3.

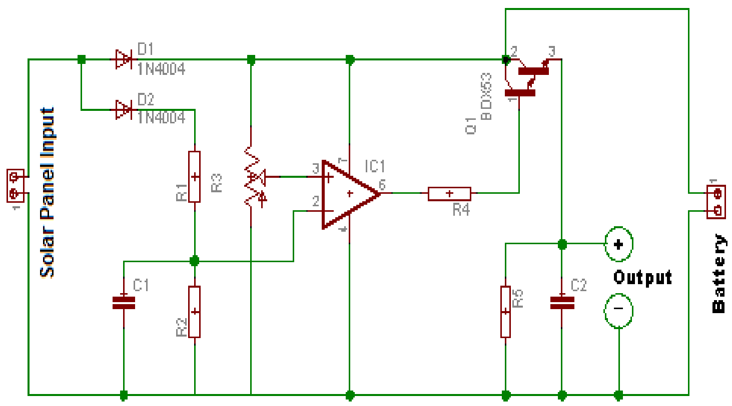
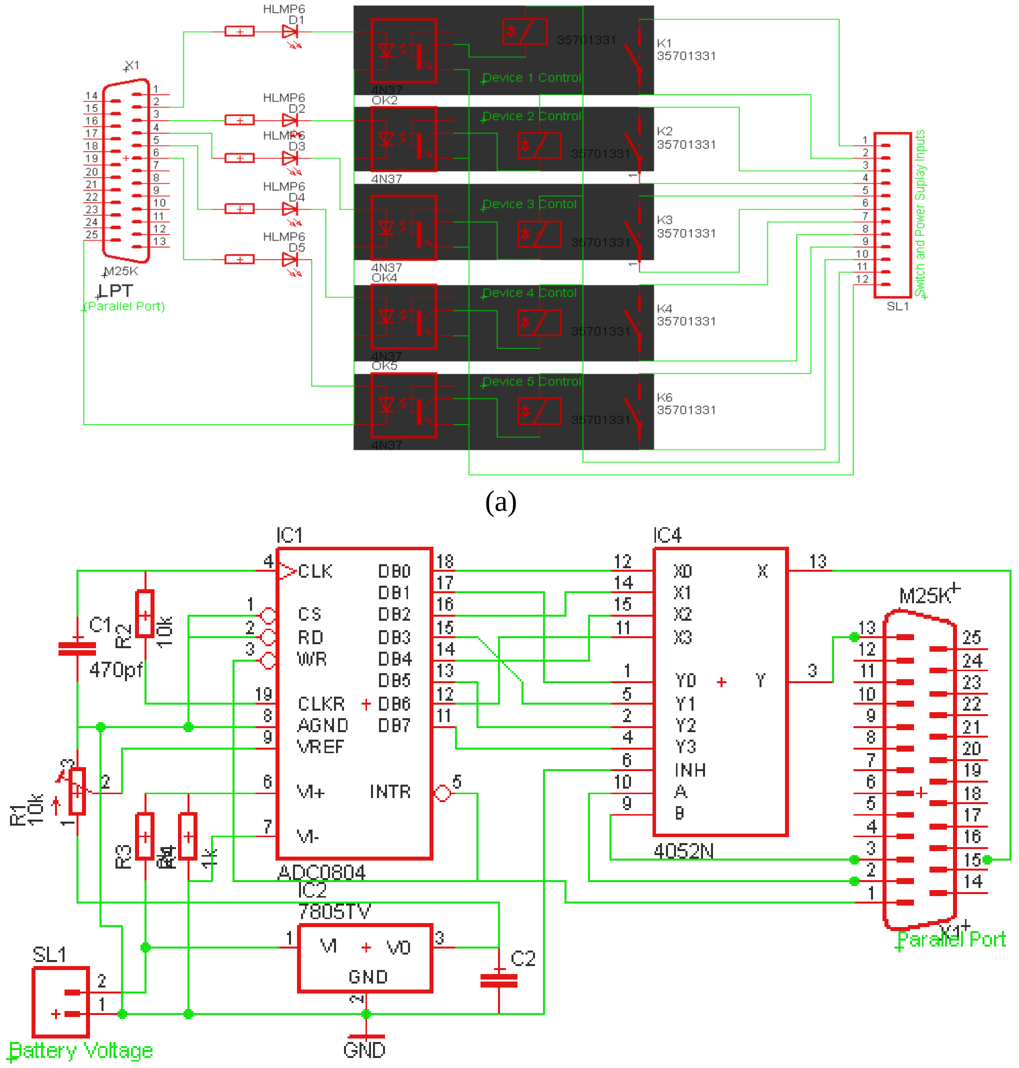


Figure 3. Designed a battery charge circuit.

2.3. The Computer Control of Solar House Model

A parallel port connection was used for the computer control of the system. This parallel port connection (LPT) has 25 pin and pin specifications as shown in Figure 4 (a). The pins from 2 to 9 are data output pins. The pins from 10 to 13 and 15 are data input pins. 1, 14, 16, 17 number pins are for data input and output. The other pins from 18 to 25 are designed as ground pins (Kevin, 2000; Cora et al., 2008).

The designed interface in Visual Basic software using parallel port outputs drives the relays amplifying the signals. The circuit in Figure 4 (a) shows the computer controller circuit design to control five different devices. This circuit includes five equivalent circuits that isolate and amplifies the out pins signals to drive relays. The other connection port shows parallel port inputs and switching signals connection ports (Güçlü, 2007; Axelson, 2008). After completion of these circuit connections with the computer, devices are energized and the control with a computer is supplied



(a)

(b)

Figure 4. (a) Designed computer control circuit, (b) voltage measurement circuit for parallel port

2.4. Voltage Measurement and Graphical User Interface

The battery voltage level and State of Charge (SOC) give us information about the stored energy depending on the battery charge characteristic (Sharaf, 2017). To process this information need to communication between battery and computer. Although the battery voltage is measured as analog, the computer needs digital information to process. An Analog-Digital Converter (ADC) circuit is designed which includes additional components for this purpose. This ADC circuit is shown in Figure 4(b). The battery voltage is converted to digital information using an ADC0804 integrated circuit which has an 8-bit resolution and 100 msec. transform period (URL-3, 2018). The eight-bit information pins from the output of ADC are connected to 74HC4052 Multiplexer as a switching integrated circuit. This integrated circuit separates the 8 bit ADC output information to two four-bit information (URL-4, 2018). The WR (pin 3) and INTR (pin 5) of ADC are combined and connected to parallel ports' control pin (pin 1). The X (pin 13) and Y (pin 3) of Multiplexer are connected to the parallel ports' status ports pins 13 and pins 15, respectively. A (pin 10) and B (pin 9) selective inputs of the multiplexer are connected to the parallel ports' data ports pins 2 and pins 3, respectively (Axelson, 2000; Güçlü, 2007; Eroğlu, 2013).

A graphical user interface is necessary to control these circuits and to show the measurement results by the computer. It is possible to find some different programs to solve this problem in the market. Microsoft Visual Basic software is used in this study because it is used commonly, accessed easily and has a database. It is necessary to locate the "inpout32.dll" file in the "c:\windows\system" folder for the system connection with parallel port and control with Visual Basic software. After these processes, it is necessary to write the codes opening a module page which will be used in software (Bredley et al., 2003). The codes can be written as given below for each input and output command;

```
Private Sub Command1_Click()
address = &H378
Out Val(address), 8
End Sub
Private Sub Command11_Click()
read = Inp(&H378)
Text1.Text = read
End Sub
```

The connection between the computer and the parallel port is ready after complete writing these codes is completed. Then, the system can be controlled by the software. The designed Visual Basic interface is shown in Figure 5 (a).

The computer-controlled house energy management system needs control of the interface, an algorithm which is given in Appendix 1 and needs to write the codes on the module page in the software. This algorithm is developed to use energy more efficiently, and it can be developed for more parameters. Besides, it is possible to occur the load shift operation which is mentioned in Figure 8 with this algorithm.

2.5. The General Structure of the Designed Model System

The computer-controlled solar house general model whose roof is covered with photovoltaic panels, a charging circuit which is used to charge battery, measurement and control circuits, and five electricity device connected to the battery is shown in Figure 8 single line diagram. All devices are connected with a computer control circuit and a manual control panel. Also, a DC/AC inverter for computer power supply is used which is energized from the battery.

The system's energy can be controlled by the computer or manually as shown in Figure 5(b). LED illumination was used in the designed system mainly. This illumination is very efficient than the others as seen from the experimental results. Besides, a helicopter runway illumination was thought for the regions difficult to reach. Besides, the computer control of the system enables us to easy and smart control of the system. Connecting the computer with communication devices enables us the remote control of the system where is difficult to reach. The general view of the designed model system is given in Figure 5 (c).

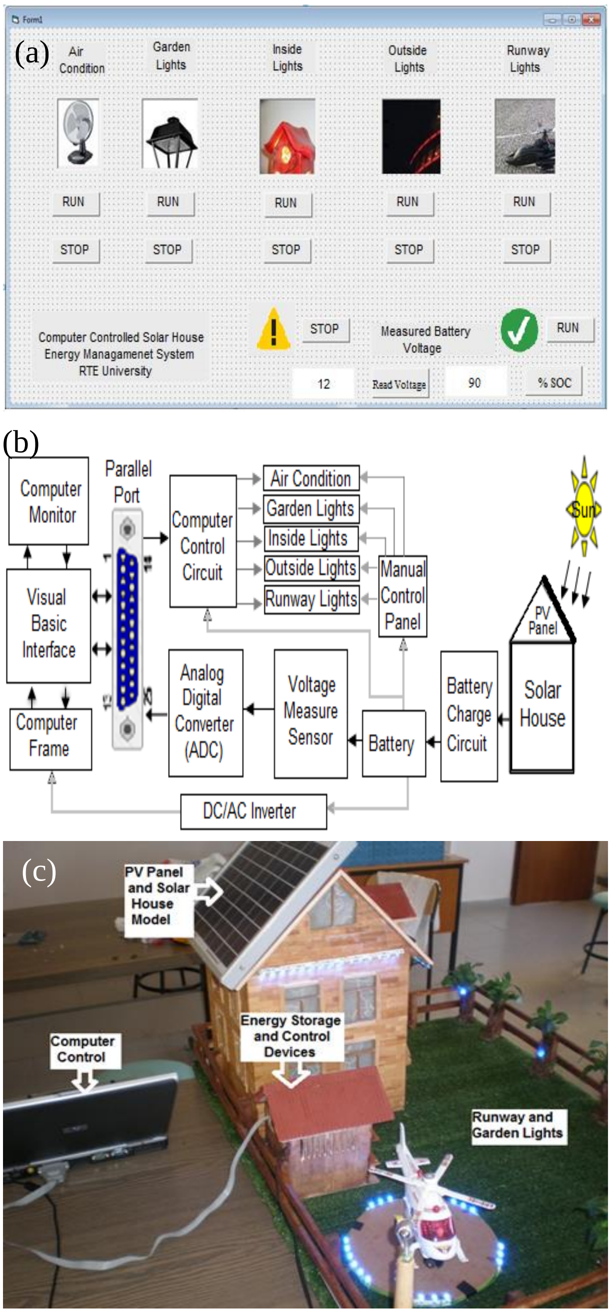


Figure 5. (a) The designed Visual Basic interface, (b) Single line diagram of the designed system, (c) The general view of the designed model system.

3. Experimental Results

In this section, the experimental results are measured and compared. The maximum power which can be received from the solar panel is P = 5 Watt as seen in Figure 2 curves. The maximum power which can be received from the battery is defined $P = VI$ and calculated $P = (12\ V) \times (1.3\ Ah)$ = 15.6 Watt from the catalog of the used battery. According to these results, the solar panel charges the battery approximately in three hours on a sunny day. The total power stored in the system is calculated by measuring the voltage and the current which flow from photovoltaic panel to battery. The total power consumption is calculated using measured currents and voltages on the equipment. These results are shown in Table 2.

Table 2. The equipment's total power consumption

Power-Consuming Devices	Measured Voltage (Volt)	Measured Current (Ampere)	Power Consumption P=V*I (Watt)
Air condition	12	0.14	1.68
Garden lightning	12	0.12	1.44
Interior lightning	12	0.12	1.44
Outside lightning	12	0.16	1.92
Runway lighting	12	0.1	1.2
Total power consumption	-	-	7.68
Battery specification	12	1.3	15.6

These measurement results are not enough to define how much energy is received from the solar panel and how much energy is charged to the battery. The energy variation with time, and position of solar panel and how does depend on the weather condition are shown below with the measurement results and graphics for different times and different conditions.

Firstly, the new battery, which is charged in a factory, is discharged using some devices in the designed model for four hours. During this time, these devices consume 12.21 Watt power from the battery until the voltage level decreases to the lowest limit, 9.5V. After that, this empty battery is charged in a partially cloudy on a September day for six hours with a solar panel. During this time, the battery charges 11.46 Watt power from the solar panel. These measurement results are shown in Figure 6 (a) and (b). The current and power values are seen as expected for the partial cloudly day in Figure 6 (a). The battery charged with high current and power firstly because it was empty. The battery voltage is increasing with time and it is fixed nearly 12V nominal voltage. The battery discharge power and current decreases with time linearly as seen in Figure 6 (b). Also, the discharge voltage decreases around the nominal voltage as expected in battery characteristics. The accuracy and validation of charge and discharge characteristics are seen as reasonable.

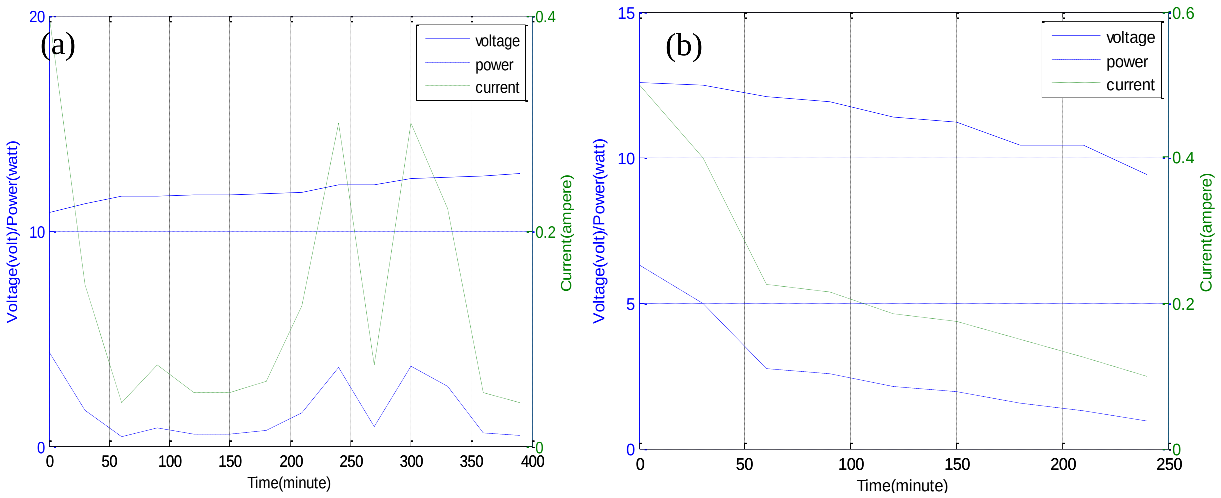


Figure 6. First measurement results (September), (a) battery charge, (b) battery discharge.

Secondly, the fully charged battery with a solar panel was discharged using some of the electrical devices in the designed model for seven hours. During this time, these devices consume 17.05 Watt power from the battery until the voltage level is decreased 11 V. This level is not the lowest voltage level for the battery. The battery worked for two hours more for the electrical devices at lower voltage consumption. This empty battery is charged on a sunny May day for six hours. During this time, the battery is charged 17.54 Watt power from the solar panel. These measurement results are shown in Figure 7 (a) and (b). The current and power values are seen as expected for a sunny day in Figure 7 (a). The battery charged with high current and power in the afternoon without a sun tracking system. The battery voltage is increasing with time and it is fixed nearly 12V nominal voltage again. The battery discharge power and current decreases with time linearly as seen in Figure 7 (b). Also, the discharge voltage decreases around the nominal voltage as expected in battery characteristics. The accuracy and validation of charge and discharge characteristics are seen as reasonable. The differences between the two discharge figure are caused by measurement errors.

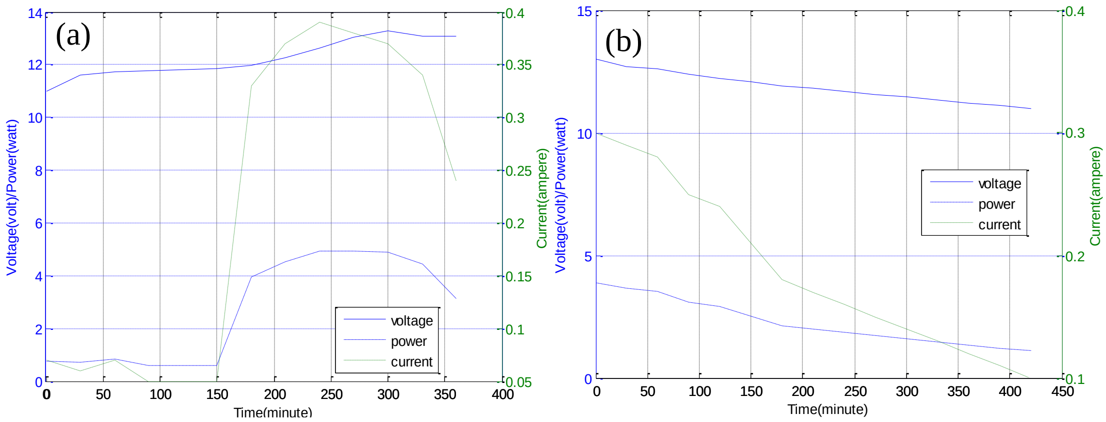


Figure 7. Second measurement results (May), (a) battery charge, (b) battery discharge.

As a result, this system is a model system that can be enlarged to use in residential. If these calculations converted to real dimensions; designing this kind of system according to the electrical data minimum installed power is accepted 10 kWh and average consumption is accepted as 5 kWh/day. Using the solar radiation values per year in Table 1 for Rize city, average solar radiation is found 3.85 kWh/m^2/day. The panel efficiency was calculated as 11.7 % previously in the introduction part. The photovoltaic panels generated energy is calculated by 0.45 kWh/m^2/day. Energy consumption per month is calculated 150 kWh/month. In the next step the energy generation is calculated for a 2 m^2 PV panel in one month as below;

The energy generation per month = Solar radiation*panel area* panel efficiency* average days per month

The energy generation per month (kWh) = 3.85*2 *0.117*(365/12) =13.7 kWh/panel

The panel value is calculated dividing the energy consumption per month to energy generation per month and find 11 panels required. The total panel area is found approximately 22 m^2. According to these calculations, 5 kWh energy storage capacity rechargeable battery group and 22 m^2 solar panel at least necessary for this system. It is possible to increase the received energy from solar panels depend on the efficiency and control of PV panels (Ceylan, 2012).

On the other side, some studies are focused on intelligent load control and shift the operation of some flexible loads to times with high PV generation today. This case study is given here to inform the readers of a plan of the designed system. The red dashed frame in Figure 8 (a) shows a load peak in the evening hours. This load peak is caused by such a washing machine or one other flexible load switching manually in the evening. The peak load can be shifted to the afternoon as shown in the red frame in Figure 8 (b). This process can be done with the designed computer-controlled management system easily. The software is designed to develop applications for energy management efficiently.

4. Conclusion

Energy management and measurement of the computer-controlled solar house model is aimed for Rize city in this study. A solar house model was designed and constructed to investigate the effects of seasons, and solar panel location on the stored energy. As a result, the extended model of this system is suitable for use on roofs in hilly and agricultural lands. If the use of the PV system on roofs as covering, this will reduce the roofing cost and the general cost will reduce too. This use also increases the light intensity reaching the solar panel by the light crash angle, so the efficiency of the system increases.

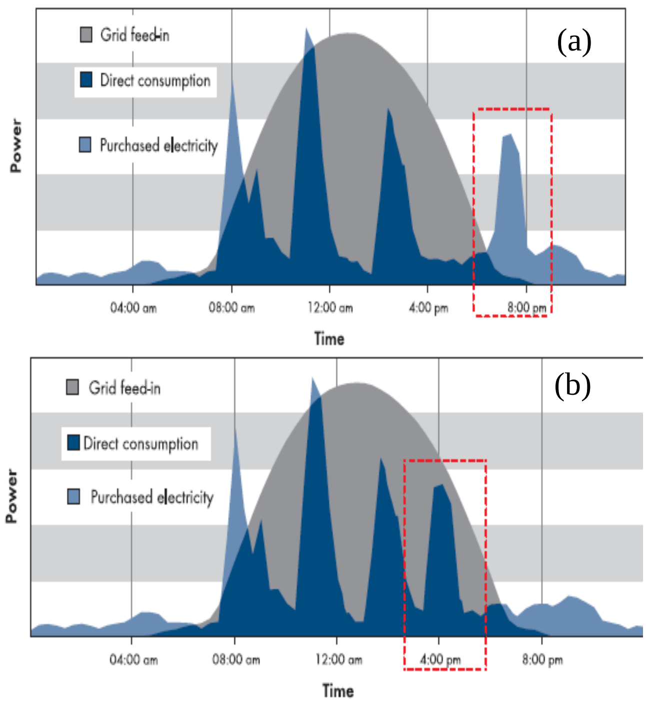


Figure 8. Daily profile of a PV system, consumption, and self-consumption, (a) without load control, (b) with load control (URL-5, 2016)

The electricity requirement will be supplied with this system easily for different places difficult to reach in the region or the world. On electricity transmission lines and transformation the power losses will not occur too. The control of the system by computer will supply energy management, during the time that it is difficult to communicate, especially in winter.

In these measurements the solar panel angle is constant. To increase solar panels absorption sun-tracking systems high-efficiency solar panels, and MPPT controllers can be designed. Another solution to decrease the energy cost and to increase the efficiency of the electricity system is to change the loads more efficiently such as power LEDs for illumination. As a result, the applicability of this study for energy measurement and management is possible with some attachments or adjustments. Also, a model system is proposed for different aims and applications with simple components and software. This study combined rarely find the information's in literature and includes a lot of useful practical design information to inspire the researchers and designers. Also, gives some useful information about the residential PV- computer control design applications and Rize city energy potential measurement.

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Appendix 1: A control algorithm for the energy management of the computer control house.