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EMERGING TRANSITION FROM AC TO DC POWERED HOMES

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MASTER THESIS

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Declaration of Authorship

I, Fatma Serra ÇIFTÇI, declare that this thesis titled, 'Emerging Transition From AC to DC Powered Homes ' and the work presented in it are my own. I confirm that:

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"Görebildiğim kadar dağ görmek istiyorum. Yanlarından, içlerinden ve üstlerinden görmek ve her birine isterse birbirlerinin aynısı olsun, dünyanın bin bir meşakkatle varılan tek dağı gibi, elimde olmayan derin bir hayretle bakıyorum. Tıpkı kendi yavrularıma ve denize bakt ığım gibi. Tıpkı sayısız ve çabuk çabuk ve kolayca oluşuna rağmen uyuyabilmemize ve uyuduktan sonra uyanabilmemize duyduğum derin hayret gibi bir hayretle "

Cahit Zarifoglu

Emerging Transition From AC to DC Powered Homes

Fatma Serra Çiftçi

Abstract

Accelerating solar systems and increasing electronic appliances in residential buildings have caused researchers to assert rising application of direct current (DC) powered systems in homes. Thanks to this application, cost savings in electric bills, energy savings and reduction in CO2 emission have been provided in some projects in some countries such as America. In this paper, we state a scenario that a home with traditional alternating current (AC) powered appliances are replaced with DC devices. The location of the presented home is in Istanbul in Turkey. It is a 4-person home. Its electric is sourced from electricity grid supplied from natural gas power plants. However, in our projected scenario, the home gains its electricity from solar photovoltaic system. It is off-grid. It has solar panels, battery and charge controller. The questions which devices can be replaced, how much savings in terms of energy and electric bill is provided, what are economical, technical, social and environmental problems in this AC/DC transition and which system between DC and AC for residential buildings is more preferable based on the AHP method are answered in the presented study. Results show that 74.129-percentage cost saving in the electric bill is provided. However, the problems that nonexistence in some residential DC devices in the market, immaturity of DC system in terms of technical issue, added system costs, less information about DC by experts and related people and a public bias that DC is unsafe exist. In this study, based on these defined advantages and disadvantages of DC and AC system, criteria and sub-criteria have been determined for analytic hierarchy process (AHP) method. By the way of AHP, the result that DC system is more preferable than AC system for residential buildings has been reached ...

Keywords: Direct current, Alternating current, CO2 emission, Solar photovoltaic system, Off-grid, Analytic hierarchy process

AC ile Çalışan Evlerden DC ile Çalışan Evlere Geçiş

Fatma Serra Çiftçi

Öz

Artan güneş sistemleri uygulamaları ve evlerde kullanılan elektronik cihazların artması, araştırmacıların evlerde doğru akım (DC) ile çalışan sistemlerin artan uygulamalarını onaylamalarına neden oldu. Bu uygulama sayesinde, elektrik faturalarında maliyet tasarrufu, enerji tasarrufu ve CO2 emisyonunda azalma, Amerika gibi bazı ülkelerde bazı projelerde sağlanmıştır. Bu çalışmada, geleneksel alternatif akım (AC) ile çalışan cihazlara sahip bir evin DC cihazlarla değiştirildiği senaryosunu sunuyoruz. Sunulan konutun yeri, Türkiye'de İstanbul'dadır. Bu, 4 kişilik bir evdir. Evin elektriği, doğalgaz santrallerinden temin edilen elektrik şebekesinden sağlanmaktadır. Ancak, öngörülen senaryomuzda ev, elektriğini güneş fotovoltaik sisteminden üretmektedir. şebekeden bağımsızdır. Güneş panelleri, akü ve şarj kontrolörü vardır. Hangi cihazların değiştirilebileceği, enerji ve elektrik faturası açısından ne kadar tasarruf sağlandığı, bu AC/DC geçişinde ekonomik, teknik, sosyal ve çevresel sorunların neler olduğu ve konut binaları için DC ve AC arasında hangi sistemin daha fazla tercih edileceği soruları AHP yöntemine dayalı olarak sunulan çalışmada yanıtlanmıştır. Sonuçlar, elektrik faturasında yüzde 74.129 oranında maliyet tasarrufu sağlandığını göstermektedir. Bununla birlikte, piyasadaki bazı konutlara ait DC cihazlarının bulunmaması, DC sisteminin teknik konu açısından olgunlaşmaması, eklenen sistem maliyetleri, uzmanlar ve ilgili kişiler tarafından DC hakkında daha az bilgi sahibi olunması ve DC'nin güvenilir olmadığı konusunda kamuoyunda bir önyargının olması gibi problemler vardır. Bu çalışmada, DC ve AC sisteminin bu tanımlanmış avantaj ve dezavantajlarına dayanarak, analitik hiyerarşi süreci (AHP) yöntemi için kriterler ve alt kriterler belirlenmiştir. AHP yoluyla, DC sisteminin konut binaları için AC sisteminden daha fazla tercih edilebilir olduğu sonucuna ulaşılmıştır. . . .

Anahtar Sözcükler: Doğru akım, Alternatif akım, Güneş pil sistemleri, Analitik hiyerarşi süreci

To my twin sister, mother and father who make my life important ...

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Abbreviations

DC	**D**irect **C**urrent
AC	**AL**ternating **C**urrent

Chapter 1

Introduction

1.1 Solar Energy

From past to present, people pay attention to the fact that benefitting from energy resources in the most efficient way. Especially, taking advantage of the sun is a crucial point long since due to the fact that it is a source of renewable energy. It never comes to an end. It always exists in nature. Differently from fossil fuels, solar energy does not produce greenhouse gases which are dangerous for the environment. When we look at the history of solar energy, there were solar furnaces in villas in ancient greece. These villas were built by considering not to create a shadow in a location where the sun is an exact need. In the 19th century , providing solar access was a significant demand because of the industrial revolution. In 1891, Barcelona was designed by Cerda. It can be given as an example for a place which was constructed according to solar access. The width of the roads, the height of the buildings and the width of the buildings were measured in order to designate the optimal measurement for benefitting from the sun. All of them were determined as twenty meters. Consequently, they were built considering that result. Additionally, areas including houses have truncated corners in Barcelona, as it is presented in Fig. 1.1. It is because of taking advantage of the sun in the most efficient way as well.

Figure 1.1: Truncated corners in Barcelona

Knowles mentioned the pyramidal shapes in his book entitled “Energy and Form: an ecological approach to urban growth“. Pyramidal shapes were implemented to some buildings. This system was named as the solar envelope concept. The purpose of the concept was making buildings have no overshadow on adjacent sites. When actions in the past, that were done in the design stage of buildings in order to benefit from the sun efficiently, are analyzed, in 1910s, William Atkinson was the first architect who was interested in the formation of spaces with solar light. Also, in the 1930s, Helidon generated a basic device that was used for identifying the impacts of the sun on a building while it was at the design period [1]. When solar energy is historically observed in terms of producing electricity in today‘s context, the silicon photovoltaic cells come up, as it is shown in Fig. 1.2 [2]. Its invention belongs to Daryl Chapin, Calvin Fuller and Gerald Pearson at Bell Labs in 1954. Thanks to these solar cells, sunlight can be converted into direct current electricity which has been used by electrical devices since 1954 with increasing efficiency with the passing of time [3].

FIGURE 1.2: The silicon photovoltaic cells

In the modern sense, the first reason why silicon is mostly preferred among semiconductormaterials for solar photovoltaic cells is the fact that the second plentiful element in the earth is silicon; while the first one is oxygen. The second reason is the advantage that silicon makes solar cells more efficient, low-priced and long lived rather than the other materials. Therefore, ninety percent of the sold modules are made of silicon approximately [4]. On the other hand, generally, besides the type of semiconductor material in solar photovoltaic cells, the questions of which parts does a solar photovoltaic system consist of and how they fundamentally produce electricity come to mind. When the answers of these questions are examined, it can be benefitted from Fig. 1.3 [5].

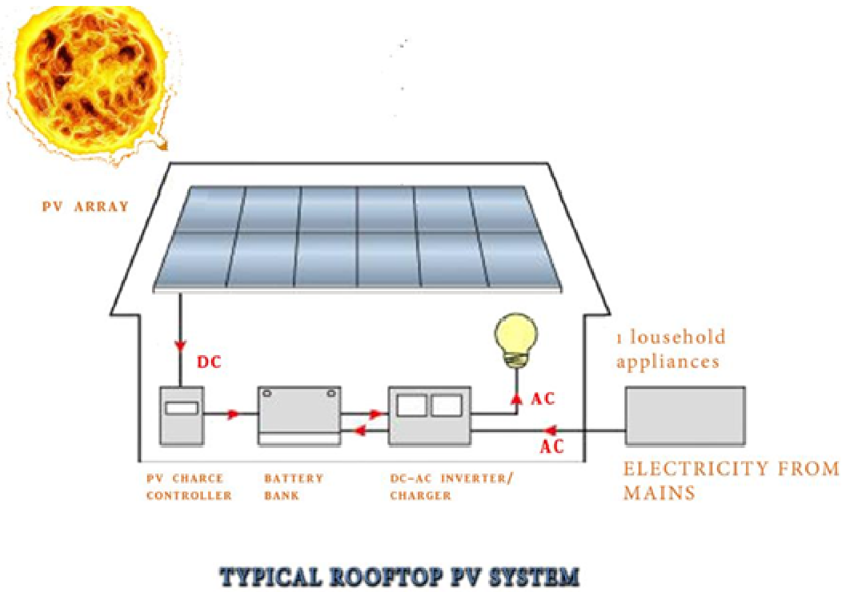

FIGURE 1.3: Basic components of solar photovoltaic system

The system essentially includes photovoltaic array, charge controller, battery bank and inverter. The photovoltaic array transforms solar light into direct current electricity. Actually, the array is composed of panels; while panels are composed of modules. Modules include cells as well. This connection can be seen in Fig. 1.4 [6].

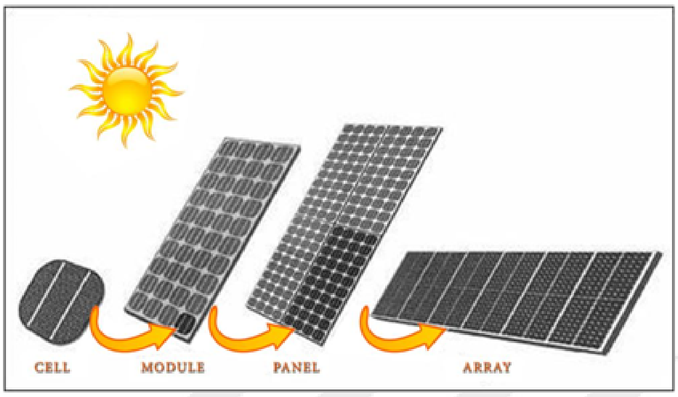

FIGURE 1.4: The relationship among cell, module, panel and array

In detail, one cell is composed of 2 silicon layers. One of them is n-type; while another one is p-type. When these two layers are put together, a p-n junction occurs between them. Actually, silicon is firstly needed to be transformed into n-type silicon and p-type silicon separately for the two layers. Hence, one of the group 5A elements should be added into silicon in order to make it n-type and one of the group 3A elements should be added into silicon to transform it into p-type. Because silicon has 4 electrons in its outer orbit and a 5A element has 5 electrons in its outer orbit, one free electron arises in the compound between silicon and the 5A element, as it is presented in Fig. 1.5 [7]. Therefore, due to these extra electrons, n-type silicon will be negatively charged in the p-n junction.

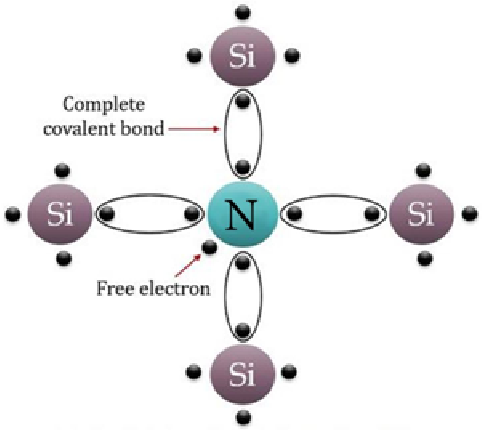

FIGURE 1.5: N-type silicon

Because silicon has 4 electrons in its outer orbit and a 3A element has 3 electrons in its outer orbit, one electron hole arises in the compound between silicon and the 3A element, as it is shown in Fig. 1.6. Therefore, due to these holes, p-type silicon will be positively charged in the p-n junction.

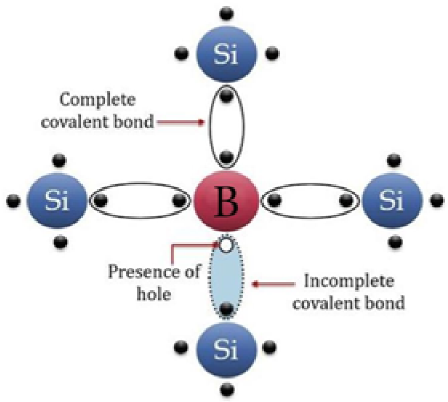

FIGURE 1.6: P-type silicon

Thanks to photons which come with solar rays to the p-n junction, electron-hole pairs are formed. Due to the electric field in the junction, these pairs are separated from each other. Thus, power output occurs at the ends of the solar cell. When a circuit is connected to the ends, a one-way current flow occurs in the circuit, as it is presented in Fig. 1.7 [8]. So, the electricity is produced for the loads.

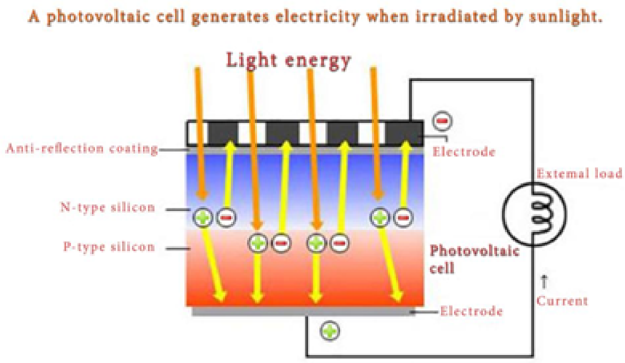

FIGURE 1.7: The generation of electricity in a photovoltaic cell

1.2 Stand Alone Solar Photovoltaic Systems

Stand alone solar photovoltaic systems are off-grid systems. The stand alone buildings or houses do not depend on the electric supply system of their region. They generate their own electricity and use it for their own electricity needs. The off-grid solar photovoltaic system is generally used for buildings far from the city or for people who do not want to be dependent on the utility grid in terms of the electric power. It has many benefits such as non dependence on energy, decrease in electric bill, prompt and more effortless installation, safety, long term back-up in the process of storage system and having access to electric power regardless of place and time [9].

1.3 Direct Current

In the future, when smart grids become widespread, DC systems may be implemented. Because direct current goes in a fixed direction, while alternating current shifts direction, the number of power conversion of DC systems is fewer than the number of power conversion of AC systems.

1.3.1 Benefits of Direct Current Systems

Low number of conversions can be given as the main advantage of DC systems. It provides cost and energy savings which becomes more of an issue in terms of sustainability [10]. In reference to Wunder, DC distribution eliminates fifty percent of power conversion losses and seventy percent of volume and weight in internal switch mode power supplies. According to Denkenberger, when market growth of DC products happens in the advancing years, then their cost will decrease. Therefore, direct current distribution will be cost effective for zero net energy buildings [11]. Also, DC distribution does not bring the problem of harmonics and reactive power. In addition, according to the research, AC distribution has more negative impacts on health when compared to DC distribution. If we proceed to mention the advantages of DC systems, efficiency of DC-DC converters for home electrical appliances (HEAs) can be given. Correspondingly, direct current electrical power is used in many fields. For instance, many systems of renewable energy such as wind turbines and photovoltaic solar systems generate DC electrical power. Electrical devices in homes such as computers,laptops and TV use DC electrical power. Also, sensitive electrical appliances in space and naval operations benefit from DC distribution. In addition, DC is a secondary power supply for energy storage systems [12]. When the economic feasibility study was done for using DC circuits in LEDs and fluorescents in commercial buildings, it was seen that it can reduce the total unsubsidized capital costs of the system. However, it is important that this system should be grid connected and solar photovoltaic [13]. To continue to mention about fields where DC electrical power is used, DC is beneficial in buildings with large battery capacity. In this process, batteries are used as sources of DC. Also, motors with changeable frequency drives operate internally on DC. Moreover, systems of DC distribution have been asserted and put into practise in data centers. In this way, 7-28% electricity has been saved for the 380 V DC distribution system by comparison with the 208 V AC distribution system. In addition, according to a comparison between DC distribution systems at varied voltage levels and AC distribution system at 230 V AC in terms of economical and technical situation, the distribution system at 326 V DC was the optimum from among the systems at 48 V DC, 120 V DC, 230 V DC, 326 V DC [14].

1.3.2 Problems of Direct Current Systems

Besides advantages of DC, it can be mentioned about its non-technical problems. According to a study elicited from seventeen experts, non-technical challenges of DC were determined. Non- existence of standards was given as the first problem. Secondly, narrow market for appliances and components of DC was asserted. This second problem actually results in another problem which is higher prices of DC appliances and components. Unclear utility interaction was the third one. In order to solve this problem, it was designated that bidirectional inverters and large rectifiers are required. They are devices that convert grid AC power to DC power. Also, another problem was determined as lack of knowledge about DC in industry professionals. Risk of shock and electrocution and risk of fire were given as additional problems. For avoiding the first type of risk, circuits carrying 24 V DC were suggested. Still, in general, it is not exactly known that which one of AC and DC has more shock or fire risk. Moreover, the challenge of power quality concerns was designated as a problem. Lastly, regulatory uncertainty was given a problem. To look at this uncertainty in more detail, there is no difference between AC circuits carrying less than 600 V and DC circuits carrying less than 600 V according to National Electric Code [15].

1.3.3 Residential and Commercial Buildings with Direct Current Systems

When we look at the side of residential buildings in terms of direct current, a study in 2016 uses 120 homes which have AC distribution in Texas in order to understand DC circuits technically and economically. Totally, there are ten scenarios. In the first case, DC distribution is given to all loads. In the second one, it is applied to the lighting circuit. Thirdly, DC distribution is given to a condensing unit. In the fourth and fifth case, it is applied to PEV charger and refrigerator respectively. All of 5 cases are applied with and without storage. So, the total number of scenarios is ten. Also, all of ten scenarios include solar PV. According to the results of the study, when there is battery storage, then energy savings is between 14-25 %. When there is not, then it is between 9-20%. To observe the economic results, converting all equipment to DC equipment makes levelized annual costs of electricity double. However, the only one scenario is cost-effective. It is transforming air conditioning condensing units to direct current. Thus, costs are decreased and energy savings of 7-16% is produced in that case. Averagely, for each home, a PV array makes levelized annual cost go up from $1200 to $2300. Also, the added costs of solar array, bidirectional inverter and DC devices are $770, $380 and $900 respectively and averagely. The financial advantage arising from PV generation and conversion to DC makes electric bill decline as approximately $950. However, it is too few in comparison to the added costs. When DC distribution is given to all loads, then the median of annual saved electrical energy per home is approximately 1400 kWh /yr without storage. When storage happens, then it is 1900 kWh/yr. Most of these energy savings is because of air conditioning condensing units. They produce savings of between 1100-1200 kWh/yr by oneself [16]. With reference to a techno-economic analysis of DC power distribution in commercial buildings, if an onsite solar system has a large capacity of battery storage, then this DC system can be financially advantageous. In this analysis, two different climate regions which are Los Angeles and San Francisco, three types of buildings which are office, restaurant and retail, two different market conditions that are current and future, six type of configurations (50% PV and no battery, 50% PV and 50% battery, 50% PV and 100% battery, 100% PV and no battery, 100% PV and 50% battery, 100% PV and 100% battery) are used. Therefore, this techno-economic analysis of DC power distribution has 72 (2*3*2*6) different scenarios. In the future market scenarios, the electricity tariff which is currently applied in Hawaii is benefited from. Since the fact that there will be increasing penetrations of solar generation in the future, Hawaii where takes higher insolation is observed. Again, in the future market scenarios, the question how electricity will be priced in the future is answered according to electricity price trends to the annual electricity bills in the U.S Energy Information Administration‘s Annual Energy Outlook. Also, in this study, PV capacity of the San Francisco buildings is higher than the buildings‘ PV capacity in Los Angeles because San Francisco has less sun exposure than Los Angeles in a year. Thus, balancing annual PV generation and load is provided. In all 72 scenarios, voltage level for HVAC, refrigeration and lighting is 380V in the modelled DC building, while the voltage level for electronics and other plug loads is 48V. In conclusion, for the current market scenario, offices and restaurants having DC systems and battery storage have positive life cycle cost savings and payback periods of four years. When they have maximum battery storage, then the buildings with DC systems have lower first cost than the same buildings with the AC system. Then, it creates instant payback periods. On the contrary, in most scenarios, when buildings with the DC system do not include battery storage, then they have negative life cycle cost savings and long payback periods. For the future market scenario, there will be improvements in converter efficiencies for AC systems as much as DC systems. So, the DC systems have lower efficiency savings in the future. To look at another conclusion of this analysis, if PV generation and load match with each other, then it will make efficiency savings and economic advantages increase.

1.3.4 Hybrid (AC and DC) Systems

Future hybrid microgrids have importance in terms of smart buildings. Since single DC or single AC models may not fulfill the diversified demand and they may not perform the efficient utilization of distributed generation, hybrid ac/dc microgrid is suggested in a study. In this suggested hybrid microgrid, traditional power converters having high cost, complicated structure and inefficient control are not proposed. The other way round, the solid state transformers are offered because they have efficient control, both dc and ac interfaces, transformation of voltage, electrical isolation and management of power quality. Additionally, in these hybrid microgrids, there is a suggested control system which is named as an internal model control system. It has simpler control structure, faster response speed and more powerful robustness rather than PI and PR control systems in conventional microgrids [17]. In another study, design of multiple microgrids with hybrid AC/DC connection is observed in terms of architecture and control. Thanks to this design, microgrids are operated and controlled coordinately. These microgrids are connected to the grid by way of AC interfaces and they are interconnected by way of DC interfaces. According to this study, if microgrids had been interconnected through AC interfaces, the system would have had less controllability, less flexibility during the change of operation modes and synchronization problems. There is a hybrid unit of common coupling which is HUCC. It employs MMC (modular multilevel converter). This converter is a voltage source and it can be controlled with a great number of possible different voltage levels. This suggested system works efficiently and effectively under discrete operation scenarios. There are totally three different scenarios in this study. They are grid-connected operation, islanded operation and emergency operation. In grid-connected operation, microgrids are connected to the host utility grid via AC interfaces. When there is excess power in multiple microgrids, it is taken by the host utility grid. However, when there is deficit power in multiple microgrids, it is supplied from the host utility grid. In the second scenario which is islanded operation, the connection to the host utility grid is cut off and only interconnection between multiple microgrids exists. It is still provided by DC interfaces. In this scenario, firstly, local power demand is satisfied. After that, excess power in microgrids is transmitted to microgrids which have deficit power through HUCCs. In the last scenario which is emergency operation, there are three situations. They are black start, microgrid islanding and microgrid recovery. When black start happens, there is no connection to the host utility grid and to other microgrids. When microgrid islanding and microgrid recovery happens, the isolated microgrid is islanded, while the other ones continue to be interconnected. In the scenario of emergency operation, it is important to decrease the effect of the temporary situation. In order to make it happen, it should be stayed within the power limits of the modular multilevel converters and energy storage systems [18].

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Chapter 2

Methodology

It seems that direct current will occupy an important place in the future based on the literature review. Considering this fact, it is worthy to research whether the entire electrical system of residential buildings can operate with direct current electricity or not. In the presented study, four analyzes have been performed as to transition to the DC life. Firstly, energy and cost savings have been calculated. Secondly, reduction in carbon-dioxide emissions has been calculated. Thirdly, problems that may be experienced have been determined. Fourthly, based on a method of multi criteria decision analysis, a decision has been reached as to whether a residential building should be operated with DC devices or not. We state a scenario that a home with traditional alternating current (AC) powered appliances are replaced with DC devices. The location of the presented home is in Istanbul in Turkey. It is a 4-person home. Its electricity is sourced from an electricity grid supplied from natural gas power plants. However, in our projected scenario, the home gains its electricity from the solar photovoltaic system. The reason why the solar photovoltaic system is selected for our scenario is that solar panels produce DC electricity and DC-powered electronic devices can directly use that type of electricity without inverting it to the AC electricity as AC systems do. It eliminates the need to use an inverter. The home in the scenario is off-grid. One of the reasons why it is stand-alone is preparedness for crisis situations. For instance, electrical appliances in the home in the scenario can be used when the electricity is cut in the region where it is located thanks to not being dependent on the grid of that region. Another reason is increase in energy prices. Looking at the past years, we can deduce that the energy prices have increased over the years. Also, the home in the scenario has solar panels, battery and charge controller.

2.1 Energy and Cost Saving

In the present state, the home has AC powered devices which have some values of power consumption, as it is shown in Table 2.1 [19].

Table 2.1: Energy consumption with the conventional AC devices in the home

Device	Operating hours	Device wattage	Number in home	Operating days per week	Weekly energy consumption
Air conditioner	4	2319.375 W	1	7	64942.5 Wh
Television	5	122 W	1	7	4270 Wh
Washing machine	3	2100 W	1	2	12600 Wh
Dish washer	2	1300 W	1	7	18200 Wh
Stove	3	910 W	1	7	19110 Wh
Refrigerator	24	1230 W	1	7	206640 Wh
Combi boiler	14	180 W	1	7	17640 Wh
Coffee maker	1/6	800 W	1	7	933.3 Wh
Kettle	1/2	2200 W	1	7	7700 Wh
Toaster	1/2	2000 W	1	2	2000 Wh
LED Bulb	6	10 W	6	7	2520 Wh
Iron	3	2400 W	1	1	7200 Wh
Laptop 1	2	120 W	1	7	1680 Wh
Laptop 2	2	45 W	1	7	630 Wh
Wireless modem	24	9.5 W	1	7	1596 Wh
Hair dryer	1/6	2000 W	1	7	2333.3 Wh
Vacuum cleaner	1	1400 W	1	2	2800 Wh
Iphone	3	5 W	1	7	105 Wh
Total					373293.85 Wh

According to the values of power consumption gained from the labels on the devices and user manuals, total weekly energy consumption is equal to 373293.85 Wh.

So, daily energy consumption is:

= 373293.85/7

= 53327.69 Wh/day

= 53.32769 kWh/day (53327.69/1000)

Thus, monthly energy consumption is:

= 53.32769*30

= 1599.8307 kWh/month

Since sale price of one kWh electricity is 0.14336486 TL in Istanbul, monthly electric bill of the presented home is 229.36 TL (1599.8307*0.14336486). Additively, operating time and operating days of the devices are defined based on household. When the market is examined for DC-powered appliances, the table of devices which can be substituted for existing AC-powered devices is given in Table 2.2 [20][21][22][23][24][25][26][27][28].

Table 2.2: Weekly energy consumption with substituted DC-powered devices

	Power consumption	Power consumption of corresponding AC-powered device	Weekly energy consumption	Weekly energy consumption of corresponding AC-powered device
DC air conditioner	545.75 W	2319.375 W	15281 Wh	64942.5 Wh
DC television	49 W	122 W	1715 Wh	4270 Wh
DC washing machine	320 W	2100 W	1920 Wh	12600 Wh
DC refrigerator	72 W	1230 W	12096 Wh	206640 Wh
DC coffee maker	140 W	800 W	163.3 Wh	933.3 Wh
DC kettle	150 W	2200 W	525 Wh	7700 Wh
DC iron	150 W	2200 W	450 Wh	7200 Wh
DC hair dryer	300 W	2000 W	350 Wh	2333.3 Wh
DC vacuum cleaner	100 W	1400 W	200 Wh	2800 Wh
Total			32700.3	309419.1

So, decrease in weekly energy consumption is:

309419.1 - 32700.3 = 276718.8

So, decrease in daily energy consumption is:

276718.8 / 7 = 39531.2 Wh/day

= 39.5312 kWh/day

Thus, decrease in monthly energy consumption is :

39.5312 * 30 = 1185.936 kWh/month

Therefore energy savings percentage is:

Saved energy / Original energy * 100 = 1185.936 / 1599.8307 * 100 = 74.129

Since sale price of one kWh electricity is 0.14336486 TL in Istanbul, decrease in monthly electric bill of the presented home is:

1185.936 * 0.14336486 = 170.0215 TL

Therefore cost savings percentage is:

Saved cost / Original cost * 100 = 170.0215 / 229.36 * 100 = 74.129

Even if only some parts of the devices are changed with DC-ones in the presented home due to the narrow market for DC devices, 74.129 percent cost savings is provided. It is a considerable saving in terms of decrease in the electric bill.

2.2 Reduction in Carbon dioxide Emissions

When AC-powered devices are replaced with DC-powered appliances, decrease in the energy consumed by electrical devices makes the annual amount of CO2 emissions reduce. The annual amount of CO2 emissions created per AC-powered devices can be seen in Table 2.3. The calculations for finding the value of CO2 emissions per a device are:

(Operating hours of the device per day) * (Operating days of the device per year) * (Device wattage) / 1000 = kWh

kWh * (Emission factor of Turkey) = (The annual amount of CO2 emissions per the device) [29].

Emission factor of Turkey is taken as 0.865664547 [30].

The annual amount of CO2 created per DC-powered devices can be seen in Table 2.4.

Table 2.3: The annual amount of CO2 created per AC-powered devices

Device	Operating hours per day	Operating days per week	Operating days per year	Device wattage	The annual amount of CO2 created per item
AC air conditioner	4	7	365	2319.375 W	2931.389 kg (CO2)
AC television	5	7	365	122 W	192.740 kg (CO2)
AC washing machine	3	2	104	2100 W	567.183 kg (CO2)
AC dish washer	2	7	365	1300 W	821.516 kg (CO2)
AC stove	3	7	365	910 W	862.591 kg (CO2)
AC refrigerator	24	7	365	1230 W	9327.362 kg (CO2)
AC combi boiler	14	7	365	180 W	796.238 kg (CO2)
AC coffee maker	1/6	7	365	800 W	42. 129 kg (CO2)
AC kettle	1/2	7	365	2200 W	347.564 kg (CO2)
AC toaster	1/2	2	104	2000 W	90.029 kg (CO2)
AC bulb	6	7	365	10 W	113.748 kg (CO2)
AC iron	3	1	52	2400 W	324.105 kg (CO2)
AC laptop 1	2	7	365	120 W	75.832 kg (CO2)
AC laptop 2	2	7	365	45 W	28.437 kg (CO2)
AC wireless modem	24	7	365	9.5 W	72.041 kg (CO2)
AC hair dryer	1/6	7	365	2000 W	105.322 kg (CO2)
AC vacuum cleaner	1	2	104	1400 W	126.041 kg (CO2)
AC smartphone 1	3	7	365	5 W	4.739 kg (CO2)
AC smartphone 2	3/2	7	365	12.5 W	17.773 kg (CO2)
Total					16846.779 kg (CO2)

Table 2.4: The annual amount of CO2 created per DC-powered devices

Device	Operating hours per day	Operating days per week	Operating days per year	Device wattage	The amount of CO2 created per item
DC air conditioner	4	7	365	545.75 W	689.757 kg (CO2)
DC television	5	7	365	49 W	77.412 kg (CO2)
DC washing machine	3	2	104	320 W	86.428 kg (CO2)
DC refrigerator	24	7	365	72 W	545.992 kg (CO2)
DC coffee maker	1/6	7	365	140 W	7.372 kg (CO2)
DC kettle	1/2	7	365	150 W	23.697 kg (CO2)
DC iron	3	1	52	150 W	20.256 kg (CO2)
DC hair dryer	1/6	7	365	300 W	15.798 kg (CO2)
DC vacuum cleaner	1	2	104	100 W	9.003 kg (CO2)
Total					1475.715 kg (CO2)

Thanks to the DC substitution, the value of the total annual amount of CO2 emissions decreases from 16846.779 kg to 1475.715 kg. So, it means 91.24 percent decrease in CO2 emissions. It is a considerable step for reducing global warming.

2.3 Potential Problems

In this presented study, the scenario that a home with traditional alternating current (AC) powered appliances are replaced with DC devices brings some technical, economical, social and environmental problems.

2.3.1 Technical Problems

All technical problems can be collected under two titles which are maturity problems and efficiency problems. Firstly, when DC system is observed in terms of maturity, it can be seen that it does not have a mature background because it has not been tested and applied for a long time. It is a new technology. Its market does not include practical devices for residential buildings as much as the market of AC system includes. In the market, DC-powered coffee makers, kettles and vacuum cleaners are produced for cars. For residential buildings, these types of DC-powered appliances do not take place. An individual living in Istanbul cannot get DC-powered coffee makers,kettles and vacuum cleaners, even from the internet because of the fact that there is a narrow market for DC appliances. However, this individual can obtain ones for cars and use them for his or her home.

DC refrigerators and DC washing machines can take a few items into themselves because both of them have less capacity than AC refrigerators and AC washing machines. When we examine the market, the value of the capacity for DC-powered refrigerators is between 100-200 liters including freezer capacity; while the volume of the AC refrigerator in the presented home is 443 liters. Generally, the capacity values for AC-powered refrigerators is between 300-500 liters. It means that DC powered refrigerators will approximately cool one third of items that AC-powered ones can do.

Also, electricians, experts and people in the industry in Turkey do not have information sufficiently about DC systems in residential buildings. However, when the future brings the fact that completely DC powered homes may be widespread, then related persons will be experienced with technical details.

Additionally, DC circuits have a risk of fire and there is no an appliance to decrease that risk of DC circuits. Only, AC circuits have. Apart from that, there is a challenge of power quality concerns about DC operated systems.

2.3.2 Economical Problems

The system of DC distribution has high technology cost. It includes initial purchase price, installation cost and maintenance cost of solar panels, battery, charge controller and DC devices in the system. Totally, decrease in the electric bill loses its meaning due to the higher technology cost. To find the initial purchase price of solar panels, it should be firstly calculated the number of required solar panels for the presented home. The lowest value of average daily sunshine hours for Istanbul is 2.4 hours. It is in the month of January [31]. Daily total energy consumption is equal to 53.32769 kWh/day.

So, 53.32769 / 2.4 = 22.199 kWh ≅ 23 kWh = 23000 Wh

Therefore, the capacity of solar panels should be in such a way to output 23000 W of power for a whole 60 minutes. Due to the cloud factor, high battery capacity, degradation of solar panels and change of solar radiation during the day, the correction factor is considered as 0.8. If a 385W solar panel is chosen for the home, the value of 385 should be multiplicated with 0.8:

385 * 0.8 = 308 W

So, the number of solar panels should be:

23000 W / 308 W = 74.675 (76)

Thus, 76 385W solar panels should be used to produce required electricity for the presented home [32]. The price of that type of panel is 1114 TL [33]. Since 76 panels should be bought, the total initial purchase price of solar panels for the observed home is:

76 * 1114 = 84664 TL

To find the initial purchase price of the battery, the capacity of the battery for the home should be calculated. Daily total energy consumption is equal to 53.32769 kWh/day. The cloud factor for Istanbul is 5.5 [34]. Since the correction factor is 0.8 and the battery efficiency is eighty percent, mathematical processes are applied to the value of daily energy consumption (53.32769) hereinbelow:

53.32769 * 5.5 / (0.8 * 0.8) = 458.285

If we choose a 48 V-370 Ah battery, then the power of the battery will be:

48 * 370 = 17760 Wh = 17.76 kWh

If we divide the value of 458.285 by the value of the power of the battery, we can find the required number of the batteries hereinbelow:

458.285 / 17.76 = 25.80 (26)

The price of that type of battery is 35626 TL (4770 Euro) [35]. Since 26 batteries should be bought, the total initial purchase price of batteries for the observed home is:

26 * 35626 = 926276 TL

To find the initial purchase price of the charge controller, current capacity of the charge controller for the home should be calculated.

ISCC = Short-circuit current of the selected panel = 9.72

NP = Number of the panels = 76

ICCC = Charging current of the charge controller

The value of (ISCC * 1.25 * NP) / 2 is less than or equal to the value of ICCC.

In the above-mentioned equation [36], the value of short-circuit current of the selected

Table 2.5: The total initial purchase prices of the devices in the solar system

The device	The initial purchase price	Number in the system	The total initial purchase price
Solar panel	1114 TL	76	84664 TL
Battery	35626 TL	26	926276 TL
Charge controller	1314.80 TL	8	10518.4 TL
Total			1021458.4 TL

panel is multiplied with 1.25 because that value will increase due to the increase in radiation and temperature. Also, the reason for the division process with 2 is the fact that 76 solar panels are connected to each other as 2 strings. In each string, there are 38 panels connected in parallel. These two strings are connected in series.
(9.72 * 1.25 * 76) / 2 = 461.7
The value of 461.7 should be less than or equal to the value of ICCC
So, the charging current of the charge controller should be at least 462A. Since the battery voltage of the system is 48V, then a 48V/462A charge controller is required to be selected for the presented home. Thus, 8 48V/60A charge controllers should suffice for the home. Because the price of a 48V/60A charge controller is 1314.80 TL [37], the total initial purchase price of charge controllers for the observed home is:
8* 1314.80 = 10518.4 TL
Therefore, the total initial purchase price of the devices in the solar system can be seen in Table 2.5.

When initial purchase prices of DC-powered electronic devices are observed, as it can be seen in Table 2.6 [37][38][39][40][41][42][43][44][45][46][47], 6 of 9 DC-powered devices have higher initial purchase prices than their corresponding AC-powered devices.

Table 2.6: DC-powered electronic devices by comparison with their corresponding AC-powered electronic devices in the matter of initial purchase price

DC-powered device	Initial purchase price	Initial purchase price of corresponding AC-powered device
DC air conditioner	13537 TL	4749 TL
DC television	2029 TL	899 TL
DC washing machine	1697 TL	3659 TL
DC refrigerator	1724 TL	2382 TL
DC coffee maker	984 TL	109 TL
DC kettle	638 TL	249 TL
DC iron	2769 TL	599 TL
DC hair dryer	353 TL	130 TL
DC vacuum cleaner	340 TL	1499 TL

2.3.3 Social Problems

There is a public bias that DC is unsafe and foreign since direct current systems are not practices excessively seen in the world. So, the problem of this public bias is valid for Turkey, as the other countries of the world.

2.3.4 Environmental Problems

Thanks to DC powered devices, less power is consumed than AC powered appliances do. It means that less carbon dioxide emissions will be made with the presented scenario.

Therefore, high carbon dioxide emission can be given as a problem for pre-scenario situation, not for the scenario.

2.4 Multi-criteria Decision Analysis

In this presented study, analytic hierarchy process (AHP), which is one of the multi criteria decision analyses, has been applied to make a decision as to whether DC system is preferable or not. In this situation, the decision that DC system is not preferable means that conventional AC system is preferable for residential buildings than DC system. Since AHP is the most widely-used technique in renewable energy planning and proposed system is related to both renewable energy and energy planning, this technique is appropriate for the presented study [48]. The proposed AHP model is presented in Fig. 2.1 [49].

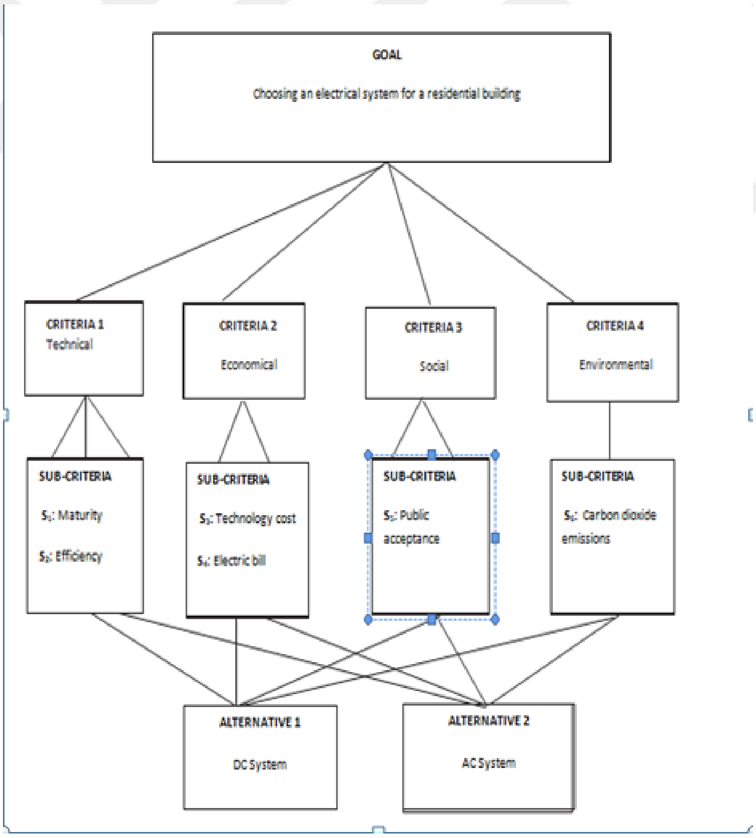

FIGURE 2.1: The proposed AHP method

Three decision makers, who are experts about energy planning, answered 21 questions separately. Each question has 9 choices that one of them has been chosen by each decision maker. All questions and choices have been determined according to the table 2.7.

Table 2.7: The proposed criteria with their descriptions

Criteria	Sub-criteria	Description	References
Technical	Maturity	Having long-standing background in terms of the facts that the system has been tested,applied for a long time and reached a broad market with practical device	[15,48]
	Efficiency	Energy-efficient due to having low power appliances	[10,16,48]
Economical	Technology cost	Expenditure on devices in the system and installation	[15,16,48]
	Electric bill	Decrease in electric bill because of low power appliances	
Social	Public acceptance	Perception that the system is safe and familiar	[15,48]
Environmental	CO2 emission reduction	Reduction in CO2 emission thanks to low power appliances	[49]

2.4.1 The First Decision Maker's Decision

According to the first decision maker, answers of the 21 questions can be seen as follows:

1. (a) **Maturity and efficiency are of equal importance**
   (b) Maturity is weakly more important than efficiency
   (c) Maturity is strongly more important than efficiency
   (d) Maturity is very strongly more important than efficiency
   (e) Maturity is absolutely more important than efficiency
   (f) Efficiency is weakly more important than maturity
   (g) Efficiency is strongly more important than maturity
   (h) Efficiency is very strongly more important than maturity
   (i) Efficiency is absolutely more important than maturity

1. (a) Maturity and low technology cost are of equal importance
   (b) Maturity is weakly more important than low technology cost
   (c) **Maturity is strongly more important than low technology cost**
   (d) Maturity is very strongly more important than low technology cost
   (e) Maturity is absolutely more important than low technology cost
   (f) Low technology cost is weakly more important than maturity
   (g) Low technology cost is strongly more important than maturity
   (h) Low technology cost is very strongly more important than maturity
   (i) Low technology cost is absolutely more important than maturity

1. (a) Maturity and low electric bill are of equal importance
   (b) Maturity is weakly more important than low electric bill
   (c) Maturity is strongly more important than low electric bill
   (d) Maturity is very strongly more important than low electric bill
   (e) Maturity is absolutely more important than low electric bill
   (f) **Low electric bill is weakly more important than maturity**

(g) Low electric bill is strongly more important than maturity

(h) Low electric bill is very strongly more important than maturity

(i) Low electric bill is absolutely more important than maturity

1. (a) Maturity and public acceptance are of equal importance

    (b) Maturity is weakly more important than public acceptance

    (c) Maturity is strongly more important than public acceptance

    (d) Maturity is very strongly more important than public acceptance

    (e) Maturity is absolutely more important than public acceptance

    (f) Public acceptance is weakly more important than maturity

    (g) **Public acceptance is strongly more important than maturity**

    (h) Public acceptance is very strongly more important than maturity

    (i) Public acceptance is absolutely more important than maturity

1. (a) Maturity and CO2 emission reduction are of equal importance

    (b) Maturity is weakly more important than CO2 emission reduction

    (c) Maturity is strongly more important than CO2 emission reduction

    (d) Maturity is very strongly more important than CO2 emission reduction

    (e) Maturity is absolutely more important than CO2 emission reduction

    (f) CO2 emission reduction is weakly more important than maturity

    (g) **CO2 emission reduction is strongly more important than maturity**

    (h) CO2 emission reduction is very strongly more important than maturity

    (i) CO2 emission reduction is absolutely more important than maturity

1. (a) Efficiency and low technology cost are of equal importance

    (b) Efficiency is weakly more important than low technology cost

    (c) **Efficiency is strongly more important than low technology cost**

    (d) Efficiency is very strongly more important than low technology cost

    (e) Efficiency is absolutely more important than low technology cost

(f) Low technology cost is weakly more important than efficiency

(g) Low technology cost is strongly more important than efficiency

(h) Low technology cost is very strongly more important than efficiency

(i) Low technology cost is absolutely more important than efficiency

1. (a) Efficiency and low electric bill are of equal importance

   (b) Efficiency is weakly more important than low electric bill

   (c) **Efficiency is strongly more important than low electric bill**

   (d) Efficiency is very strongly more important than low electric bill

   (e) Efficiency is absolutely more important than low electric bill

   (f) Low electric bill is weakly more important than efficiency

   (g) Low electric bill is strongly more important than efficiency

   (h) Low electric bill is very strongly more important than efficiency

   (i) Low electric bill is absolutely more important than efficiency

1. (a) **Efficiency and public acceptance are of equal importance**

   (b) Efficiency is weakly more important than public acceptance

   (c) Efficiency is strongly more important than public acceptance

   (d) Efficiency is very strongly more important than public acceptance

   (e) Efficiency is absolutely more important than public acceptance

   (f) Public acceptance is weakly more important than efficiency

   (g) Public acceptance is strongly more important than efficiency

   (h) Public acceptance is very strongly more important than efficiency

   (i) Public acceptance is absolutely more important than efficiency

1. (a) Efficiency and CO2 emission reduction are of equal importance

   (b) Efficiency is weakly more important than CO2 emission reduction

   (c) **Efficiency is strongly more important than CO2 emission reduction**

   (d) Efficiency is very strongly more important than CO2 emission reduction

(e) Efficiency is absolutely more important than CO_2 emission reduction

(f) CO_2 emission reduction is weakly more important than efficiency

(g) CO_2 emission reduction is strongly more important than efficiency

(h) CO_2 emission reduction is very strongly more important than efficiency

(i) CO_2 emission reduction is absolutely more important than efficiency

1. (a) Low technology cost and low electric bill are of equal importance

   (b) Low technology cost is weakly more important than low electric bill

   (c) Low technology cost is strongly more important than low electric bill

   (d) Low technology cost is very strongly more important than low electric bill

   (e) Low technology cost is absolutely more important than low electric bill

   (f) Low electric bill is weakly more important than low technology cost

   (g) **Low electric bill is strongly more important than low technology cost**

   (h) Low electric bill is very strongly more important than low technology cost

   (i) Low electric bill is absolutely more important than low technology cost

1. (a) Low technology cost and public acceptance are of equal importance

   (b) Low technology cost is weakly more important than public acceptance

   (c) Low technology cost is strongly more important than public acceptance

   (d) Low technology cost is very strongly more important than public acceptance

   (e) Low technology cost is absolutely more important than public acceptance

   (f) Public acceptance is weakly more important than low technology cost

   (g) **Public acceptance is strongly more important than low technology cost**

   (h) Public acceptance is very strongly more important than low technology cost

   (i) Public acceptance is absolutely more important than low technology cost

1. (a) Low technology cost and CO_2 emission reduction are of equal importance

   (b) Low technology cost is weakly more important than CO_2 emission reduction

(c) Low technology cost is strongly more important than CO2 emission reduction

(d) Low technology cost is very strongly more important than CO2 emission reduction

(e) Low technology cost is absolutely more important than CO2 emission reduction

(f) CO2 emission reduction is weakly more important than low technology cost

(g) **CO2 emission reduction is strongly more important than low technology cost**CO2 emission reduction is strongly more important than low technology cost

(h) CO2 emission reduction is very strongly more important than low technology cost

(i) CO2 emission reduction is absolutely more important than low technology cost

1. (a) Low electric bill and public acceptance are of equal importance

(b) Low electric bill is weakly more important than public acceptance

(c) Low electric bill is strongly more important than public acceptance

(d) Low electric bill is very strongly more important than public acceptance

(e) Low electric bill is absolutely more important than public acceptance

(f) Public acceptance is weakly more important than low electric bill

(g) **Public acceptance is strongly more important than low electric bill**

(h) Public acceptance is very strongly more important than low electric bill

(i) Public acceptance is absolutely more important than low electric bill

1. (a) Low electric bill and CO2 emission reduction are of equal importance

(b) Low electric bill is weakly more important than CO2 emission reduction

(c) Low electric bill is strongly more important than CO2 emission reduction

(d) Low electric bill is very strongly more important than CO2 emission reduction

(e) Low electric bill is absolutely more important than CO2 emission reduction

(f) CO2 emission reduction is weakly more important than low electric bill

(g) **CO2 emission reduction is strongly more important than low electric bill**
(h) CO2 emission reduction is very strongly more important than low electric bill
(i) CO2 emission reduction is absolutely more important than low electric bill

1. (a) Public acceptance and CO2 emission reduction are of equal importance
(b) Public acceptance is weakly more important than CO2 emission reduction
(c) Public acceptance is strongly more important than CO2 emission reduction
(d) **Public acceptance is very strongly more important than CO2 emission reduction**
(e) Public acceptance is absolutely more important than CO2 emission reduction
(f) CO2 emission reduction is weakly more important than public acceptance
(g) CO2 emission reduction is strongly more important than public acceptance
(h) CO2 emission reduction is very strongly more important than public acceptance
(i) CO2 emission reduction is absolutely more important than public acceptance

1. (a) In terms of maturity, DC system and AC system are equally preferable
(b) In terms of maturity, DC system is weakly more preferable than AC system
(c) In terms of maturity, DC system is strongly more preferable than AC system
(d) In terms of maturity, DC system is very strongly more preferable than AC system
(e) In terms of maturity, DC system is absolutely more preferable than AC system
(f) In terms of maturity, AC system is weakly more preferable than DC system
(g) **In terms of maturity, AC system is strongly more preferable than DC system**
(h) In terms of maturity, AC system is very strongly more preferable than DC system
(i) In terms of maturity, AC system is absolutely more preferable than DC system

1. (a) In terms of efficiency, DC system and AC system are equally preferable

(b) In terms of efficiency, DC system is weakly more preferable than AC system

(c) **In terms of efficiency, DC system is strongly more preferable than AC system**

(d) In terms of efficiency, DC system is very strongly more preferable than AC system

(e) In terms of efficiency, DC system is absolutely more preferable than AC system

(f) In terms of efficiency, AC system is weakly more preferable than DC system

(g) In terms of efficiency, AC system is strongly more preferable than DC system

(h) In terms of efficiency, AC system is very strongly more preferable than DC system

(i) In terms of efficiency, AC system is absolutely more preferable than DC system

1. (a) In terms of low technology cost, DC system and AC system are equally preferable

   (b) In terms of low technology cost, DC system is weakly more preferable than AC system

   (c) In terms of low technology cost, DC system is strongly more preferable than AC system

   (d) In terms of low technology cost, DC system is very strongly more preferable than AC system

   (e) In terms of low technology cost, DC system is absolutely more preferable than AC system

   (f) In terms of low technology cost, AC system is weakly more preferable than DC system

   (g) **In terms of low technology cost, AC system is strongly more preferable than DC system**

   (h) In terms of low technology cost, AC system is very strongly more preferable than DC system

   (i) In terms of low technology cost, AC system is absolutely more preferable than DC system

1. (a) In terms of low electric bill, DC system and AC system are equally preferable

(b) In terms of low electric bill, DC system is weakly more preferable than AC system

(c) **In terms of low electric bill, DC system is strongly more preferable than AC system**

(d) In terms of low electric bill, DC system is very strongly more preferable than AC system

(e) In terms of low electric bill, DC system is absolutely more preferable than AC system

(f) In terms of low electric bill, AC system is weakly more preferable than DC system

(g) In terms of low electric bill, AC system is strongly more preferable than DC system

(h) In terms of low electric bill, AC system is very strongly more referable than DC system

(i) In terms of low electric bill, AC system is absolutely more preferable than DC system

1. (a) **In terms of public acceptance, DC system and AC system are equally preferable**

   (b) In terms of public acceptance, DC system is weakly more preferable than AC system

   (c) In terms of public acceptance, DC system is strongly more preferable than AC system

   (d) In terms of public acceptance, DC system is very strongly more preferable than AC system

   (e) In terms of public acceptance, DC system is absolutely more preferable than AC system

   (f) In terms of public acceptance, AC system is weakly more preferable than DC system

   (g) In terms of public acceptance, AC system is strongly more preferable than DC system

(h) In terms of public acceptance, AC system is very strongly more preferable than DC system

(i) In terms of public acceptance, AC system is absolutely more preferable than DC system

1. (a) **In terms of CO2 emission reduction, DC system and AC system are equally preferable**

   (b) In terms of CO2 emission reduction, DC system is weakly more preferable than AC system

   (c) In terms of CO2 emission reduction, DC system is strongly more preferable than AC system

   (d) In terms of CO2 emission reduction, DC system is very strongly more preferable than AC system

   (e) In terms of CO2 emission reduction, DC system is absolutely more preferable than AC system

   (f) In terms of CO2 emission reduction, AC system is weakly more preferable than DC system

   (g) In terms of CO2 emission reduction, AC system is strongly more preferable than DC system

   (h) In terms of CO2 emission reduction, AC system is very strongly more preferable than DC system

   (i) In terms of CO2 emission reduction, AC system is absolutely more preferable than DC system

Based on answers of the first decision maker, scores have been determined in table 2.8, table 2.9, table 2.10, table 2.11, table 2.12, table 2.13 and table 2.14 [48].

So, according to the first decision maker, DC system in residential buildings is more preferable than AC system in residential buildings, as it can be seen in Fig. 2.2.

Table 2.8: Sub-criteria comparison for the first decision maker

	S1	S2	S3	S4	S5	S6	Eigenvalues
S1	1	1	5	1/3	1/5	1/5	0.1073
S2	1	1	5	5	1	5	0.2618
S3	1/5	1/5	1	1/5	1/5	1/5	0.0345
S4	3	1/5	5	1	1/5	1/5	0.0989
S5	5	1	5	5	1	7	0.3301
S6	5	1/5	5	5	1/7	1	0.1674
Sum	15.2	3.6	26	16.53	2.7428	13.6	

Table 2.9: S1 sub-criteria comparison for the first decision maker

	A1	A2	Eigenvalues
A1	1	1/5	0.1667
A2	5	1	0.8333
Sum	6	1.2	

Table 2.10: S2 sub-criteria comparison for the first decision maker

	A1	A2	Eigenvalues
A1	1	5	0.8333
A2	1/5	1	0.1667
Sum	1.2	6	

Table 2.11: S3 sub-criteria comparison for the first decision maker

	A1	A2	Eigenvalues
A1	1	1/5	0.1667
A2	5	1	0.8333
Sum	6	1.2	

Table 2.12: S4 sub-criteria comparison for the first decision maker

	A1	A2	Eigenvalues
A1	1	5	0.8333
A2	1/5	1	0.1667
Sum	1.2	6	

TABLE 2.13: S5 sub-criteria comparison for the first decision maker

	A1	A2	Eigenvalues
A1	1	1	0.5
A2	1	1	0.5
Sum	2	2	

TABLE 2.14: S6 sub-criteria comparison for the first decision maker

	A1	A2	Eigenvalues
A1	1	1	0.5
A2	1	1	0.5
Sum	2	2	

	S_1	S_2	S_3	S_4	S_5	S_6
A_1	0.1667	0.8333	0.1667	0.8333	0.5	0.5
A_2	0.8333	0.1667	0.8333	0.1667	0.5	0.5

Sub-criteria ranking

$$* \begin{pmatrix} 0.1073 \\ 0.2618 \\ 0.0345 \\ 0.0989 \\ 0.3301 \\ 0.1674 \end{pmatrix} = \begin{array}{|c|} \hline A_1 \\ \hline A_2 \\ \hline \end{array} \begin{pmatrix} 0.57295937 \\ 0.42704063 \end{pmatrix}$$

FIGURE 2.2: Getting the first decision maker‘s decision

2.4.2 The Second Decision Maker's Decision

According to the second decision maker, answers of the 21 questions can be seen as follows:

1. (a) Maturity and efficiency are of equal importance
   (b) Maturity is weakly more important than efficiency
   (c) Maturity is strongly more important than efficiency
   (d) Maturity is very strongly more important than efficiency
   (e) Maturity is absolutely more important than efficiency
   (f) Efficiency is weakly more important than maturity
   (g) **Efficiency is strongly more important than maturity**
   (h) Efficiency is very strongly more important than maturity
   (i) Efficiency is absolutely more important than maturity

1. (a) Maturity and low technology cost are of equal importance
   (b) Maturity is weakly more important than low technology cost
   (c) Maturity is strongly more important than low technology cost
   (d) Maturity is very strongly more important than low technology cost
   (e) Maturity is absolutely more important than low technology cost
   (f) Low technology cost is weakly more important than maturity
   (g) **Low technology cost is strongly more important than maturity**
   (h) Low technology cost is very strongly more important than maturity
   (i) Low technology cost is absolutely more important than maturity

1. (a) Maturity and low electric bill are of equal importance
   (b) Maturity is weakly more important than low electric bill
   (c) Maturity is strongly more important than low electric bill
   (d) Maturity is very strongly more important than low electric bill
   (e) Maturity is absolutely more important than low electric bill

(f) Low electric bill is weakly more important than maturity

(g) Low electric bill is strongly more important than maturity

(h) **Low electric bill is very strongly more important than maturity**

(i) Low electric bill is absolutely more important than maturity

1. (a) Maturity and public acceptance are of equal importance

   (b) Maturity is weakly more important than public acceptance

   (c) Maturity is strongly more important than public acceptance

   (d) Maturity is very strongly more important than public acceptance

   (e) Maturity is absolutely more important than public acceptance

   (f) Public acceptance is weakly more important than maturity

   (g) **Public acceptance is strongly more important than maturity**

   (h) Public acceptance is very strongly more important than maturity

   (i) Public acceptance is absolutely more important than maturity

1. (a) **Maturity and CO2 emission reduction are of equal importance**

   (b) Maturity is weakly more important than CO2 emission reduction

   (c) Maturity is strongly more important than CO2 emission reduction

   (d) Maturity is very strongly more important than CO2 emission reduction

   (e) Maturity is absolutely more important than CO2 emission reduction

   (f) CO2 emission reduction is weakly more important than maturity

   (g) CO2 emission reduction is strongly more important than maturity

   (h) CO2 emission reduction is very strongly more important than maturity

   (i) CO2 emission reduction is absolutely more important than maturity

1. (a) Efficiency and low technology cost are of equal importance

   (b) Efficiency is weakly more important than low technology cost

   (c) Efficiency is strongly more important than low technology cost

   (d) **Efficiency is very strongly more important than low technology cost**

(e) Efficiency is absolutely more important than low technology cost

(f) Low technology cost is weakly more important than efficiency

(g) Low technology cost is strongly more important than efficiency

(h) Low technology cost is very strongly more important than efficiency

(i) Low technology cost is absolutely more important than efficiency

1. (a) Efficiency and low electric bill are of equal importance

   (b) Efficiency is weakly more important than low electric bill

   (c) Efficiency is strongly more important than low electric bill

   (d) Efficiency is very strongly more important than low electric bill

   (e) Efficiency is absolutely more important than low electric bill

   (f) Low electric bill is weakly more important than efficiency

   (g) Low electric bill is strongly more important than efficiency

   (h) Low electric bill is very strongly more important than efficiency

   (i) **Low electric bill is absolutely more important than efficiency**

1. (a) Efficiency and public acceptance are of equal importance

   (b) Efficiency is weakly more important than public acceptance

   (c) **Efficiency is strongly more important than public acceptance**

   (d) Efficiency is very strongly more important than public acceptance

   (e) Efficiency is absolutely more important than public acceptance

   (f) Public acceptance is weakly more important than efficiency

   (g) Public acceptance is strongly more important than efficiency

   (h) Public acceptance is very strongly more important than efficiency

   (i) Public acceptance is absolutely more important than efficiency

1. (a) Efficiency and CO2 emission reduction are of equal importance

   (b) Efficiency is weakly more important than CO2 emission reduction

   (c) **Efficiency is strongly more important than CO2 emission reduction**

(d) Efficiency is very strongly more important than CO_2 emission reduction

(e) Efficiency is absolutely more important than CO_2 emission reduction

(f) CO_2 emission reduction is weakly more important than efficiency

(g) CO_2 emission reduction is strongly more important than efficiency

(h) CO_2 emission reduction is very strongly more important than efficiency

(i) CO_2 emission reduction is absolutely more important than efficiency

1. (a) Low technology cost and low electric bill are of equal importance

   (b) Low technology cost is weakly more important than low electric bill

   (c) Low technology cost is strongly more important than low electric bill

   (d) Low technology cost is very strongly more important than low electric bill

   (e) Low technology cost is absolutely more important than low electric bill

   (f) Low electric bill is weakly more important than low technology cost

   (g) **Low electric bill is strongly more important than low technology cost**

   (h) Low electric bill is very strongly more important than low technology cost

   (i) Low electric bill is absolutely more important than low technology cost

1. (a) Low technology cost and public acceptance are of equal importance

   (b) Low technology cost is weakly more important than public acceptance

   (c) **Low technology cost is strongly more important than public acceptance**

   (d) Low technology cost is very strongly more important than public acceptance

   (e) Low technology cost is absolutely more important than public acceptance

   (f) Public acceptance is weakly more important than low technology cost

   (g) Public acceptance is strongly more important than low technology cost

   (h) Public acceptance is very strongly more important than low technology cost

   (i) Public acceptance is absolutely more important than low technology cost

1. (a) Low technology cost and CO_2 emission reduction are of equal importance

(b) Low technology cost is weakly more important than CO_2 emission reduction

(c) Low technology cost is strongly more important than CO_2 emission reduction

(d) **Low technology cost is very strongly more important than CO_2 emission reduction**

(e) Low technology cost is absolutely more important than CO_2 emission reduction

(f) CO_2 emission reduction is weakly more important than low technology cost

(g) CO_2 emission reduction is strongly more important than low technology cost

(h) CO_2 emission reduction is very strongly more important than low technology cost

(i) CO_2 emission reduction is absolutely more important than low technology cost

1. (a) Low electric bill and public acceptance are of equal importance

   (b) Low electric bill is weakly more important than public acceptance

   (c) **Low electric bill is strongly more important than public acceptance**

   (d) Low electric bill is very strongly more important than public acceptance

   (e) Low electric bill is absolutely more important than public acceptance

   (f) Public acceptance is weakly more important than low electric bill

   (g) Public acceptance is strongly more important than low electric bill

   (h) Public acceptance is very strongly more important than low electric bill

   (i) Public acceptance is absolutely more important than low electric bill

1. (a) Low electric bill and CO_2 emission reduction are of equal importance

   (b) Low electric bill is weakly more important than CO_2 emission reduction

   (c) **Low electric bill is strongly more important than CO_2 emission reduction**

   (d) Low electric bill is very strongly more important than CO_2 emission reduction

   (e) Low electric bill is absolutely more important than CO_2 emission reduction

   (f) CO_2 emission reduction is weakly more important than low electric bill

(g) CO_2 emission reduction is strongly more important than low electric bill

(h) CO_2 emission reduction is very strongly more important than low electric bill

(i) CO_2 emission reduction is absolutely more important than low electric bill

1. (a) Public acceptance and CO_2 emission reduction are of equal importance

   (b) Public acceptance is weakly more important than CO_2 emission reduction

   (c) Public acceptance is strongly more important than CO_2 emission reduction

   (d) Public acceptance is very strongly more important than CO_2 emission reduction

   (e) Public acceptance is absolutely more important than CO_2 emission reduction

   (f) **CO_2 emission reduction is weakly more important than public acceptance**

   (g) CO_2 emission reduction is strongly more important than public acceptance

   (h) CO_2 emission reduction is very strongly more important than public acceptance

   (i) CO_2 emission reduction is absolutely more important than public acceptance

1. (a) In terms of maturity, DC system and AC system are equally preferable

   (b) In terms of maturity, DC system is weakly more preferable than AC system

   (c) In terms of maturity, DC system is strongly more preferable than AC system

   (d) In terms of maturity, DC system is very strongly more preferable than AC system

   (e) In terms of maturity, DC system is absolutely more preferable than AC system

   (f) **In terms of maturity, AC system is weakly more preferable than DC system**

   (g) In terms of maturity, AC system is strongly more preferable than DC system

   (h) In terms of maturity, AC system is very strongly more preferable than DC system

   (i) In terms of maturity, AC system is absolutely more preferable than DC system

1. (a) In terms of efficiency, DC system and AC system are equally preferable

(b) In terms of efficiency, DC system is weakly more preferable than AC system

(c) In terms of efficiency, DC system is strongly more preferable than AC system

(d) **In terms of efficiency, DC system is very strongly more preferable than AC system**

(e) In terms of efficiency, DC system is absolutely more preferable than AC system

(f) In terms of efficiency, AC system is weakly more preferable than DC system

(g) In terms of efficiency, AC system is strongly more preferable than DC system

(h) In terms of efficiency, AC system is very strongly more preferable than DC system

(i) In terms of efficiency, AC system is absolutely more preferable than DC system

1. (a) In terms of low technology cost, DC system and AC system are equally preferable

(b) In terms of low technology cost, DC system is weakly more preferable than AC system

(c) In terms of low technology cost, DC system is strongly more preferable than AC system

(d) **In terms of low technology cost, DC system is very strongly more preferable than AC system**

(e) In terms of low technology cost, DC system is absolutely more preferable than AC system

(f) In terms of low technology cost, AC system is weakly more preferable than DC system

(g) In terms of low technology cost, AC system is strongly more preferable than DC system

(h) In terms of low technology cost, AC system is very strongly more preferable than DC system

(i) In terms of low technology cost, AC system is absolutely more preferable than DC system

1. (a) In terms of low electric bill, DC system and AC system are equally preferable

(b) In terms of low electric bill, DC system is weakly more preferable than AC system

(c) **In terms of low electric bill, DC system is strongly more preferable than AC system**

(d) In terms of low electric bill, DC system is very strongly more preferable than AC system

(e) In terms of low electric bill, DC system is absolutely more preferable than AC system

(f) In terms of low electric bill, AC system is weakly more preferable than DC system

(g) In terms of low electric bill, AC system is strongly more preferable than DC system

(h) In terms of low electric bill, AC system is very strongly more referable than DC system

(i) In terms of low electric bill, AC system is absolutely more preferable than DC system

1. (a) In terms of public acceptance, DC system and AC system are equally preferable

(b) In terms of public acceptance, DC system is weakly more preferable than AC system

(c) In terms of public acceptance, DC system is strongly more preferable than AC system

(d) **In terms of public acceptance, DC system is very strongly more preferable than AC system**

(e) In terms of public acceptance, DC system is absolutely more preferable than AC system

(f) In terms of public acceptance, AC system is weakly more preferable than DC system

(g) In terms of public acceptance, AC system is strongly more preferable than DC system

(h) In terms of public acceptance, AC system is very strongly more preferable than DC system

(i) In terms of public acceptance, AC system is absolutely more preferable than DC system

1. (a) In terms of CO2 emission reduction, DC system and AC system are equally preferable

   (b) In terms of CO2 emission reduction, DC system is weakly more preferable than AC system

   (c) **In terms of CO2 emission reduction, DC system is strongly more preferable than AC system**

   (d) In terms of CO2 emission reduction, DC system is very strongly more preferable than AC system

   (e) In terms of CO2 emission reduction, DC system is absolutely more preferable than AC system

   (f) In terms of CO2 emission reduction, AC system is weakly more preferable than DC system

   (g) In terms of CO2 emission reduction, AC system is strongly more preferable than DC system

   (h) In terms of CO2 emission reduction, AC system is very strongly more preferable than DC system

   (i) In terms of CO2 emission reduction, AC system is absolutely more preferable than DC system

Based on answers of the second decision maker, scores have been determined in table 2.15, table 2.16, table 2.17, table 2.18, table 2.19, table 2.20 and table 2.21 [48].

TABLE 2.15: Sub-criteria comparison for the second decision maker

	S1	S2	S3	S4	S5	S6	Eigenvalues
S1	1	1/5	1/5	1/7	1/5	1	0.0357
S2	5	1	7	1/9	5	5	0.2328
S3	5	1/7	1	1/5	5	7	0.1711
S4	7	9	5	1	5	5	0.4262
S5	5	1/5	1/5	1/5	1	1/3	0.0697
S6	1	1/5	1/7	1/5	3	1	0.0645
Sum	24	10.7428	13.5428	1.8540	19.2	19.3	

TABLE 2.16: S1 sub-criteria comparison for the second decision maker

	A1	A2	Eigenvalues
A1	1	1/3	0.25
A2	3	1	0.75
Sum	4	4/3	

Table 2.17: S2 sub-criteria comparison for the second decision maker

	A1	A2	Eigenvalues
A1	1	7	0.875
A2	1/7	1	0.125
Sum	8/7	8	

Table 2.18: S3 sub-criteria comparison for the second decision maker

	A1	A2	Eigenvalues
A1	1	7	0.875
A2	1/7	1	0.125
Sum	8/7	8	

Table 2.19: S4 sub-criteria comparison for the second decision maker

	A1	A2	Eigenvalues
A1	1	5	0.8333
A2	1/5	1	0.1667
Sum	6/5	6	

TABLE 2.20: S5 sub-criteria comparison for the second decision maker

	A1	A2	Eigenvalues
A1	1	7	0.875
A2	1/7	1	0.125
Sum	8/7	8	

TABLE 2.21: S6 sub-criteria comparison for the second decision maker

	A1	A2	Eigenvalues
A1	1	5	0.8333
A2	1/5	1	0.1667
Sum	6/5	6	

	S_1	S_2	S_3	S_4	S_5	S_6
A_1	0.25	0.875	0.875	0.8333	0.875	0.8333
A_2	0.75	0.125	0.125	0.1667	0.125	0.1667

Sub-criteria ranking

$$\ast \begin{pmatrix} 0.0357 \\ 0.2328 \\ 0.1711 \\ 0.4262 \\ 0.0697 \\ 0.0645 \end{pmatrix} = \begin{array}{|c|} \hline A_1 \\ \hline A_2 \\ \hline \end{array} \begin{pmatrix} 0.83222531 \\ 0.16777469 \end{pmatrix}$$

FIGURE 2.3: Getting the second decision maker's decision

So, according to the second decision maker, DC system in residential buildings is more preferable than AC system in residential buildings, as it can be seen in Fig. 2.3.

2.4.3 The Third Decision Maker's Decision

According to the third decision maker, answers of the 21 questions can be seen as follows:

1. (a) Maturity and efficiency are of equal importance
   (b) Maturity is weakly more important than efficiency
   (c) Maturity is strongly more important than efficiency
   (d) **Maturity is very strongly more important than efficiency**
   (e) Maturity is absolutely more important than efficiency
   (f) Efficiency is weakly more important than maturity
   (g) Efficiency is strongly more important than maturity
   (h) Efficiency is very strongly more important than maturity
   (i) Efficiency is absolutely more important than maturity

1. (a) Maturity and low technology cost are of equal importance
   (b) **Maturity is weakly more important than low technology cost**
   (c) Maturity is strongly more important than low technology cost
   (d) Maturity is very strongly more important than low technology cost
   (e) Maturity is absolutely more important than low technology cost
   (f) Low technology cost is weakly more important than maturity
   (g) Low technology cost is strongly more important than maturity
   (h) Low technology cost is very strongly more important than maturity
   (i) Low technology cost is absolutely more important than maturity

1. (a) Maturity and low electric bill are of equal importance
   (b) Maturity is weakly more important than low electric bill
   (c) Maturity is strongly more important than low electric bill

    (d) Maturity is very strongly more important than low electric bill
    (e) Maturity is absolutely more important than low electric bill
    (f) **Low electric bill is weakly more important than maturity**
    (g) Low electric bill is strongly more important than maturity
    (h) Low electric bill is very strongly more important than maturity
    (i) Low electric bill is absolutely more important than maturity

1. (a) Maturity and public acceptance are of equal importance
   (b) Maturity is weakly more important than public acceptance
   (c) **Maturity is strongly more important than public acceptance**
   (d) Maturity is very strongly more important than public acceptance
   (e) Maturity is absolutely more important than public acceptance
   (f) Public acceptance is weakly more important than maturity
   (g) Public acceptance is strongly more important than maturity
   (h) Public acceptance is very strongly more important than maturity
   (i) Public acceptance is absolutely more important than maturity

1. (a) Maturity and CO2 emission reduction are of equal importance
   (b) Maturity is weakly more important than CO2 emission reduction
   (c) **Maturity is strongly more important than CO2 emission reduction**
   (d) Maturity is very strongly more important than CO2 emission reduction
   (e) Maturity is absolutely more important than CO2 emission reduction
   (f) CO2 emission reduction is weakly more important than maturity
   (g) CO2 emission reduction is strongly more important than maturity
   (h) CO2 emission reduction is very strongly more important than maturity
   (i) CO2 emission reduction is absolutely more important than maturity

1. (a) Efficiency and low technology cost are of equal importance
   (b) Efficiency is weakly more important than low technology cost

   (c) **Efficiency is strongly more important than low technology cost**
   (d) Efficiency is very strongly more important than low technology cost
   (e) Efficiency is absolutely more important than low technology cost
   (f) Low technology cost is weakly more important than efficiency
   (g) Low technology cost is strongly more important than efficiency
   (h) Low technology cost is very strongly more important than efficiency
   (i) Low technology cost is absolutely more important than efficiency

1. (a) **Efficiency and low electric bill are of equal importance**
   (b) Efficiency is weakly more important than low electric bill
   (c) Efficiency is strongly more important than low electric bill
   (d) Efficiency is very strongly more important than low electric bill
   (e) Efficiency is absolutely more important than low electric bill
   (f) Low electric bill is weakly more important than efficiency
   (g) Low electric bill is strongly more important than efficiency
   (h) Low electric bill is very strongly more important than efficiency
   (i) Low electric bill is absolutely more important than efficiency

1. (a) Efficiency and public acceptance are of equal importance
   (b) Efficiency is weakly more important than public acceptance
   (c) Efficiency is strongly more important than public acceptance
   (d) **Efficiency is very strongly more important than public acceptance**
   (e) Efficiency is absolutely more important than public acceptance
   (f) Public acceptance is weakly more important than efficiency
   (g) Public acceptance is strongly more important than efficiency
   (h) Public acceptance is very strongly more important than efficiency
   (i) Public acceptance is absolutely more important than efficiency

1. (a) Efficiency and CO2 emission reduction are of equal importance

(b) Efficiency is weakly more important than CO2 emission reduction
(c) **Efficiency is strongly more important than CO2 emission reduction**
(d) Efficiency is very strongly more important than CO2 emission reduction
(e) Efficiency is absolutely more important than CO2 emission reduction
(f) CO2 emission reduction is weakly more important than efficiency
(g) CO2 emission reduction is strongly more important than efficiency
(h) CO2 emission reduction is very strongly more important than efficiency
(i) CO2 emission reduction is absolutely more important than efficiency

1. (a) Low technology cost and low electric bill are of equal importance
   (b) Low technology cost is weakly more important than low electric bill
   (c) Low technology cost is strongly more important than low electric bill
   (d) Low technology cost is very strongly more important than low electric bill
   (e) Low technology cost is absolutely more important than low electric bill
   (f) Low electric bill is weakly more important than low technology cost
   (g) **Low electric bill is strongly more important than low technology cost**
   (h) Low electric bill is very strongly more important than low technology cost
   (i) Low electric bill is absolutely more important than low technology cost

1. (a) Low technology cost and public acceptance are of equal importance
   (b) Low technology cost is weakly more important than public acceptance
   (c) Low technology cost is strongly more important than public acceptance
   (d) **Low technology cost is very strongly more important than public acceptance**
   (e) Low technology cost is absolutely more important than public acceptance
   (f) Public acceptance is weakly more important than low technology cost
   (g) Public acceptance is strongly more important than low technology cost
   (h) Public acceptance is very strongly more important than low technology cost
   (i) Public acceptance is absolutely more important than low technology cost

1. (a) Low technology cost and CO_2 emission reduction are of equal importance
   (b) **Low technology cost is weakly more important than CO_2 emission reduction**
   (c) Low technology cost is strongly more important than CO_2 emission reduction
   (d) Low technology cost is very strongly more important than CO_2 emission reduction
   (e) Low technology cost is absolutely more important than CO_2 emission reduction
   (f) CO_2 emission reduction is weakly more important than low technology cost
   (g) CO_2 emission reduction is strongly more important than low technology cost
   (h) CO_2 emission reduction is very strongly more important than low technology cost
   (i) CO_2 emission reduction is absolutely more important than low technology cost

1. (a) Low electric bill and public acceptance are of equal importance
   (b) Low electric bill is weakly more important than public acceptance
   (c) Low electric bill is strongly more important than public acceptance
   (d) Low electric bill is very strongly more important than public acceptance
   (e) **Low electric bill is absolutely more important than public acceptance**
   (f) Public acceptance is weakly more important than low electric bill
   (g) Public acceptance is strongly more important than low electric bill
   (h) Public acceptance is very strongly more important than low electric bill
   (i) Public acceptance is absolutely more important than low electric bill

1. (a) Low electric bill and CO_2 emission reduction are of equal importance
   (b) Low electric bill is weakly more important than CO_2 emission reduction
   (c) **Low electric bill is strongly more important than CO_2 emission reduction**

(d) Low electric bill is very strongly more important than CO2 emission reduction

(e) Low electric bill is absolutely more important than CO2 emission reduction

(f) CO2 emission reduction is weakly more important than low electric bill

(g) CO2 emission reduction is strongly more important than low electric bill

(h) CO2 emission reduction is very strongly more important than low electric bill

(i) CO2 emission reduction is absolutely more important than low electric bill

1. (a) Public acceptance and CO2 emission reduction are of equal importance

   (b) Public acceptance is weakly more important than CO2 emission reduction

   (c) Public acceptance is strongly more important than CO2 emission reduction

   (d) Public acceptance is very strongly more important than CO2 emission reduction

   (e) Public acceptance is absolutely more important than CO2 emission reduction

   (f) CO2 emission reduction is weakly more important than public acceptance

   (g) CO2 emission reduction is strongly more important than public acceptance

   (h) **CO2 emission reduction is very strongly more important than public acceptance**

   (i) CO2 emission reduction is absolutely more important than public acceptance

1. (a) In terms of maturity, DC system and AC system are equally preferable

   (b) In terms of maturity, DC system is weakly more preferable than AC system

   (c) In terms of maturity, DC system is strongly more preferable than AC system

   (d) In terms of maturity, DC system is very strongly more preferable than AC system

   (e) In terms of maturity, DC system is absolutely more preferable than AC system

   (f) In terms of maturity, AC system is weakly more preferable than DC system

   (g) In terms of maturity, AC system is strongly more preferable than DC system

   (h) **In terms of maturity, AC system is very strongly more preferable than DC system**

   (i) In terms of maturity, AC system is absolutely more preferable than DC system

1. (a) In terms of efficiency, DC system and AC system are equally preferable
   (b) In terms of efficiency, DC system is weakly more preferable than AC system
   (c) In terms of efficiency, DC system is strongly more preferable than AC system
   (d) In terms of efficiency, DC system is very strongly more preferable than AC system
   (e) In terms of efficiency, DC system is absolutely more preferable than AC system
   (f) In terms of efficiency, AC system is weakly more preferable than DC system
   (g) **In terms of efficiency, AC system is strongly more preferable than DC system**
   (h) In terms of efficiency, AC system is very strongly more preferable than DC system
   (i) In terms of efficiency, AC system is absolutely more preferable than DC system

1. (a) In terms of low technology cost, DC system and AC system are equally preferable
   (b) In terms of low technology cost, DC system is weakly more preferable than AC system
   (c) In terms of low technology cost, DC system is strongly more preferable than AC system
   (d) **In terms of low technology cost, DC system is very strongly more preferable than AC system**
   (e) In terms of low technology cost, DC system is absolutely more preferable than AC system
   (f) In terms of low technology cost, AC system is weakly more preferable than DC system
   (g) In terms of low technology cost, AC system is strongly more preferable than DC system
   (h) In terms of low technology cost, AC system is very strongly more preferable than DC system
   (i) In terms of low technology cost, AC system is absolutely more preferable than DC system

1. (a) In terms of low electric bill, DC system and AC system are equally preferable
   (b) In terms of low electric bill, DC system is weakly more preferable than AC system
   (c) **In terms of low electric bill, DC system is strongly more preferable than AC system**
   (d) In terms of low electric bill, DC system is very strongly more preferable than AC system
   (e) In terms of low electric bill, DC system is absolutely more preferable than AC system
   (f) In terms of low electric bill, AC system is weakly more preferable than DC system
   (g) In terms of low electric bill, AC system is strongly more preferable than DC system
   (h) In terms of low electric bill, AC system is very strongly more referable than DC system
   (i) In terms of low electric bill, AC system is absolutely more preferable than DC system

1. (a) In terms of public acceptance, DC system and AC system are equally preferable
   (b) In terms of public acceptance, DC system is weakly more preferable than AC system
   (c) In terms of public acceptance, DC system is strongly more preferable than AC system
   (d) **In terms of public acceptance, DC system is very strongly more preferable than AC system**
   (e) In terms of public acceptance, DC system is absolutely more preferable than AC system
   (f) In terms of public acceptance, AC system is weakly more preferable than DC system
   (g) In terms of public acceptance, AC system is strongly more preferable than DC system

(h) In terms of public acceptance, AC system is very strongly more preferable than DC system

(i) In terms of public acceptance, AC system is absolutely more preferable than DC system

1. (a) In terms of CO2 emission reduction, DC system and AC system are equally preferable

   (b) In terms of CO2 emission reduction, DC system is weakly more preferable than AC system

   (c) In terms of CO2 emission reduction, DC system is strongly more preferable than AC system

   (d) **In terms of CO2 emission reduction, DC system is very strongly more preferable than AC system**

   (e) In terms of CO2 emission reduction, DC system is absolutely more preferable than AC system

   (f) In terms of CO2 emission reduction, AC system is weakly more preferable than DC system

   (g) In terms of CO2 emission reduction, AC system is strongly more preferable than DC system

   (h) In terms of CO2 emission reduction, AC system is very strongly more preferable than DC system

   (i) In terms of CO2 emission reduction, AC system is absolutely more preferable than DC system

Based on answers of the third decision maker, scores have been determined in table 2.22, table 2.23, table 2.24, table 2.25, table 2.26, table 2.27 and table 2.28 [48].

TABLE 2.22: Sub-criteria comparison for the third decision maker

	S1	S2	S3	S4	S5	S6	Eigenvalues
S1	1	7	3	1/3	5	5	0.2772
S2	1/7	1	5	1	7	5	0.2144
S3	1/3	1/5	1	1/5	7	3	0.0966
S4	3	1	5	1	9	5	0.3214
S5	1/5	1/7	1/7	1/9	1	1/7	0.0234
S6	1/5	1/5	1/3	1/5	7	1	0.0670
Sum	4.8762	9.5429	14.4761	2.8444	36	19.1429	

TABLE 2.23: S1 sub-criteria comparison for the third decision maker

	A1	A2	Eigenvalues
A1	1	1/7	0.125
A2	7	1	0.875
Sum	8	8/7	

Table 2.24: S2 sub-criteria comparison for the third decision maker

	A1	A2	Eigenvalues
A1	1	1/5	0.1667
A2	5	1	0.8333
Sum	6	6/5	

Table 2.25: S3 sub-criteria comparison for the third decision maker

	A1	A2	Eigenvalues
A1	1	7	0.875
A2	1/7	1	0.125
Sum	8/7	8	

Table 2.26: S4 sub-criteria comparison for the third decision maker

	A1	A2	Eigenvalues
A1	1	5	0.8333
A2	1/5	1	0.1667
Sum	6/5	6	

TABLE 2.27: S5 sub-criteria comparison for the third decision maker

	A1	A2	Eigenvalues
A1	1	7	0.875
A2	1/7	1	0.125
Sum	8/7	8	

TABLE 2.28: S6 sub-criteria comparison for the third decision maker

	A1	A2	Eigenvalues
A1	1	7	0.875
A2	1/7	1	0.125
Sum	8/7	8	

	S_1	S_2	S_3	S_4	S_5	S_6
A_1	0.125	0.1667	0.875	0.8333	0.875	0.875
A_2	0.875	0.8333	0.125	0.1667	0.125	0.125

Sub-criteria ranking

$$* \begin{pmatrix} 0.2772 \\ 0.2144 \\ 0.0966 \\ 0.3214 \\ 0.0234 \\ 0.0670 \end{pmatrix} = \begin{array}{|c|} \hline A_1 \\ \hline A_2 \\ \hline \end{array} \begin{pmatrix} 0.5018381 \\ 0.4981619 \end{pmatrix}$$

FIGURE 2.4: Getting the third decision maker‘s decision

So, according to the third decision maker, DC system in residential buildings is more preferable than AC system in residential buildings, as it can be seen in Fig. 2.4.

2.5 Results

Based on the proposed AHP method, 3 decision makers have taken their votes for determining their preferences about two alternatives which are DC and AC system. At the end of this technique, the same result has been reached for the three decision makers separately. The first result for the first decision maker is:

$$\begin{pmatrix} 0.57295937 \\ 0.42704063 \end{pmatrix} = \begin{array}{|l|} \hline \text{DC} \\ \hline \text{AC} \\ \hline \end{array}$$

FIGURE 2.5: Getting the first decision maker‘s result

It means that DC system, which has a percentage of 57.3, is more preferable than AC system which has a percentage of 42.7. The second result for the second decision maker is:

$$\begin{pmatrix} 0.83222531 \\ 0.16777469 \end{pmatrix} = \begin{array}{|l|} \hline \text{DC} \\ \hline \text{AC} \\ \hline \end{array}$$

FIGURE 2.6: Getting the second decision maker‘s result

It means that DC system, which has a percentage of 83.22, is more preferable than AC system which has a percentage of 16.78.

The third result for the third decision maker is:

$$\begin{pmatrix}0.5018381\\0.4981619\end{pmatrix} = \begin{array}{|c|}\hline \text{DC} \\ \hline \text{AC} \\ \hline\end{array}$$

FIGURE 2.7: Getting the third decision maker's result

It means that DC system, which has a percentage of 50.2, is more preferable than AC system which has a percentage of 49.8. Totally, these 3 seperate results create a consensus in terms of the experts' decision. As a result of AHP method, it can be said that DC system is more preferable than AC system.

Chapter 3

Conclusion and Recommendations

In the presented study, based on a scenario that a residential building with conventional AC devices turns into a residential building generating its electricity as a direct current from solar PV panels and using it directly by DC electronic devices without converting it to AC, potential advantages such as energy saving, low electric bill and CO2 emission reduction and potential problems such as maturity problem, high technology cost and low public acceptance have been defined. Thanks to literature and these defined advantages and problems, criteria and sub-criteria are determined for the proposed AHP method. With this method, 3 decision makers have reached the same result that DC system is more preferable than AC system. Direct current can be produced from eco-friendly renewable energy sources such as solar energy, wind energy and hydropower. Also, it causes reduction of electricity bill thanks to decreasing power conversions and reduction in CO2 emission thanks to low power DC devices. However, for a long time, alternating current has been used so that electricity can be transmitted to long distances. It has a broad market in terms of its own devices. It has been tested and applied for a long time. Nevertheless, in the future, when detached and nature-friendly houses become widespread, when houses produce their own electricity and when technology cost of DC system gets low by way of growing market of DC devices and when experts have enough technical information about DC system, the most preferable current system may be DC, as our decision makers in the presented study have indicated. This study may be an inspiration for people who want to study on the topic of direct current in residential buildings. They may benefit from the proposed AHP method with more criteria than the criteria of this study. They may diversify these used criteria in the study and also they may benefit from more decision makers than decision makers of this study.

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