International Journal of Innovative Research and Scientific Studies, 4(2) 2021, pages: 120-125

IJIRSS
International Journal of Innovative Research & Scientific Studies

ISSN: 2617-6548

URL: www.ijirss.com

Feasibility of solar air conditioning system for Afghanistan's climate

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Abstract

Among the broad varieties of power supply in Afghanistan such as city power produced from water dams, fuel generators, and imported electricity from neighboring countries, solar energy production is growing at a noticeable pace. Its preference is because of cost and sustainability perimeters. Given the climate of the country air conditioning inside buildings is required throughout the year, which is an important requirement for the comfort of its residents. Because it requires a great amount of energy, therefore, most companies are working on different principles to provide new products of solar air conditioning systems. The solar air conditioning system provides heating and cooling by utilizing solar energy. Recently, climate change and air pollution proved to be a major challenge for humans, and the current rate of resource consumption will result in a total depletion of natural energy resources in the earth. In this paper, we are assessing the feasibility study of solar-powered air conditioner technology in Afghanistan. Considering the weather of the country, there exists enormous potential for solar energy production. Afghanistan receives 4 – 6.5 kWh/m2/day solar insolation on average with 300 sunny days a year. In conclusion, the air conditioning complication which can be addressed by solar energy production is sustainable, cost-effective, and environment-friendly manner in Afghanistan.

Keywords: Solar Energy, Air Conditioning, Thermal, Photovoltaic.

DOI: 10.53894/ijirss.v4i2.65
Funding: This study received no specific financial support.
History: **Received:** 8 January 2021/**Revised:** 12 February 2021/**Accepted:** 23 February 2021/**Published:** 30 March 2021

Acknowledgement: Both authors contributed to the conception and design of the study.
Competing Interests: The authors declare that they have no conflict of interests.
Transparency: The authors confirm that the manuscript is an honest, accurate, and transparent account of the study was reported; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained.
Ethical: This study follows all ethical practices during writing.

1. Introduction

Because of the natural tendency of human beings for seeking comfort, comfortable living and working space are the desired condition of everyone. To provide a relaxed environment, from an air conditioning perspective, a considerable amount of energy is needed. Air conditioning demand increases rapidly due to global warming and the alteration of the climate. If the governments and other executive entities do not take urgent action to reduce the impacts of air conditioning usage, global air conditioning demand in the 21st century will negatively affect the climate [1]. The demand for air conditioning rapidly increased in developed countries in the 20th century, particularly in hot and humid regions, such as India, Brazil, and Middle Eastern nations [1]. The air conditioning system is the most energy consumption sector in the

world, i.e. In the European Union about half of the total energy for buildings and industry is consumed by cooling and heating systems [2]. In Saudi Arabia, about 70% of the supplied energy for buildings is consumed by air conditioning during the summer [3]. Currently, conventional energy resources used in the world are limited, expensive, and cause environmental pollution [4]. Renewable energy is sustainable energy to be used instead of conventional energy resources. By using renewable energy resources such as solar, wind, hydro, geothermal, and biomass, we can save money and keep the environment clean. Solar energy is an appropriate option for space heating and cooling among the renewable energies for the subtropical climate regions [5]. The global horizontal irradiance in Afghanistan is reported 4 – 6.5 kWh/m^2/day with 300 sunny days per year [6]. Afghanistan has a high solar energy potential, which is suitable for photovoltaic systems installation across the country. An extensive amount of research has been conducted about solar air conditioning in the world especially in countries that have high summer temperatures and high solar energy availability. Unfortunately, a diminutive amount of research has been conducted on the renewable energy sources in Afghanistan, and also a few solar projects are implemented in the southern provinces of Afghanistan. But still, no investment is done neither by the government and private sector on the solar air conditioning system. This paper reviews the feasibility and the installation of solar-type air conditioners by considering Afghanistan's region Solar- geographical information systems (GIS) data and a short review of solar air conditioning systems for heating and cooling of buildings.

2. Current state of energy in Afghanistan

Afghanistan is a landlocked country located in central Asia, in the north and west of Pakistan, east of Iran and south of Uzbekistan and Tajikistan, and connected to China with a narrow Wakhan corridor from the northeast. Kabul is the capital city of Afghanistan. According to a report by the ministry of energy and water in 2013, Afghanistan imports about 73 % of its overall electricity demand from neighboring countries (Iran, Tajikistan, Turkmenistan, and Uzbekistan) [7]. Currently, about 29.7% of households are connected to city power in Afghanistan and most of the rural areas do not have access to the city power [8]. World bank reports that, in 2004 only 8% of households had access to the city power, but it has increased to 31% in 2019 [9]. The electricity generation capacity is estimated about 520 MW, 49% of this capacity is generated from the hydropower resources, 39% is generated from by the thermal sources, and 12% is generated from distributed generators [10]. Afghanistan has sufficient conventional and renewable energy sources, however, because of educational, technological, social, and other demographical problems, the country's potential in producing solar energy is not entirely employed. Heating and cooling are considerable issues to be mindful of. In Afghanistan heating is done with conventional heat pumps, radiant systems, coal, fuel, wood resources. The aforementioned techniques have immensely negative effects on climate and cause environmental pollutions. Cooling is done by conventional air conditioners and ceiling fans. The major part of the supplied energy is consumed by conventional air conditioning.

3. Climate data

Afghanistan has a semi-arid climate, with cold winters and hot summers. The highest temperature in the summer season is recorded at 49 °C while in winter it drops -15 °C in the northeastern regions [11]. Afghanistan has very few rainy days because of its geographical location during the spring, summer, and fall seasons; the rainiest days are in winter. Afghanistan has the sunniest days in a year, especially in southern provinces. Table 1 shows the average sunshine hours per month for three major cities in Afghanistan. Kabul is located almost in the center of Afghanistan. Mazar city is located in the northern part of the country and Kandahar is located in the southern part of the country. Kandahar province has the most sunshine hours per month. and Mazar has less hours of sunshine than Kandahar and Kabul. Generally, the southern provinces have more sunshine hours than the other parts of the country.

Table-1.
Average sunshine hours of Kabul, Mazar, and Kandahar provinces [12].

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kabul	294.3	278.6	346.1	374.8	421.3	446.6	449.3	401	372.6	352.3	284.4	294.9
Mazar	265	256.4	337.1	363.4	436.1	446.3	455.4	410.1	379.8	340.2	282.2	256.5
Kandahar	299.2	298.3	360.2	381.9	412.6	419.9	433.9	407.3	382.7	339.2	323.1	316.7

4. Potential of Solar Energy

The sun is one of the primary natural energy sources for the earth, it produces an abundant amount of energy that is endless and higher than the required amount for the earth. The emitted energy from the sun is called solar radiation or solar energy. Compare to solar radiation, other energy sources on the earth are all relatively negligible [13]. Due to day-to-day variations in the spectrum by solar activity and sun-earth distance the solar radiation interception by the earth is not constant all the time [13]. The major portion of Afghanistan is located between the latitude of 60 – 72 degrees east and 30 – 38 degrees north. Solar energy forms the foremost part of renewable energy potential in Afghanistan [14] with 300 sunny days in a year, the solar radiation per square meter of horizontal surface on a clear day is on average about 5.3 kWh with a standard deviation of 0.42 kWh [15] [15]. Figure 1 shows the global horizontal irradiation for Afghanistan [6]. Higher potential values are recorded in the southern and western provinces Kandahar, Helmand, Farah, and Herat, besides some provinces in the north part of Afghanistan has an average global horizontal irradiance (GHI) of 4.5 kWh/m^2/day [16]. The total valence of solar power in Afghanistan is estimated at 222,000 MW [17]. This makes the country technically feasible for solar air conditioning systems. The average annual global horizontal irradiance is equivalent to 1935 kWh/m^2 [15]. The

maximum national average seasonal GHI accounts 7.84 kWh/m^2/day and the minimum is 2.38 kWh/m^2/day [15]. In general, solar radiation is higher in the south, southeast, and southwest of the country than the north parts of the country [18]. From the view point of the technology and efficiency annual solar radiation at the rate of 3.5 kWh/m^2/day is suitable for the photovoltaic electricity generation [18] for solar thermal collector systems the minimum annual irradiation of 1500-1600 kWh/m^2 is suitable, if the annual irradiation reduced to 1000-1200 kWh/m^2 , using from the solar energy for solar collector system is less favorable [19]. While in Afghanistan the potential of solar energy is considerably higher.

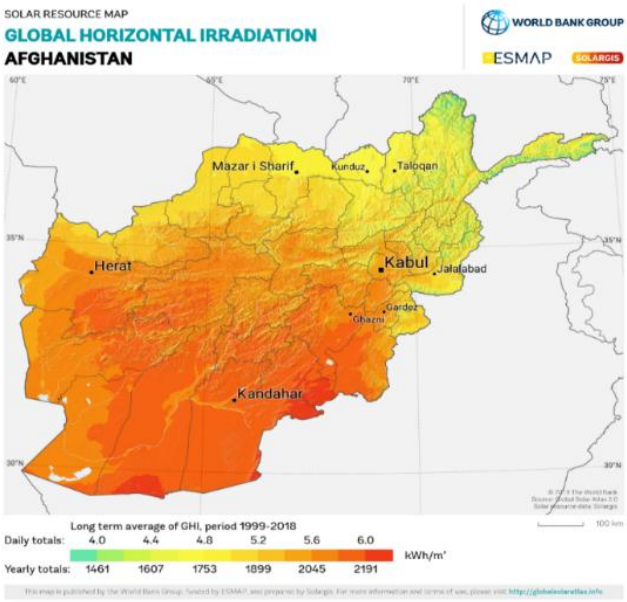

Figure-1.
Global horizontal irradiation map of Afghanistan [6].

5. Solar Air Conditioner Systems for Heating and Cooling of Buildings

The air conditioning system consists of a sequenced order of equipment and components that are used to provide heat, cool, humidification, ventilation, transfer, and circulation of air for conditioned space [20]. Solar energy for air conditioning is converted by solar thermal collectors and photovoltaic modules. Using different conversion techniques, both systems can be used for solar heating and cooling of buildings [21].

5.1. Solar thermal collector air conditioning system

Solar thermal collector system operates by thermal processes and it is divided into different subsystems:

1. Absorption cycle
2. Adsorption cycle
3. Desiccant cycle
4. Ejector cycle

Absorption solar air conditioner is the most common type and globally in use among the thermally driven machines [5]]. It works based on the absorption and refrigeration cycle. The best-selected refrigeration with the highest coefficient of performance (COP) is a mixture of water and lithium-bromide (H_2O-NH_3) for the absorption cycle. Figure 2 shows a schematic view of the solar sorption Refrigeration cycle [22].

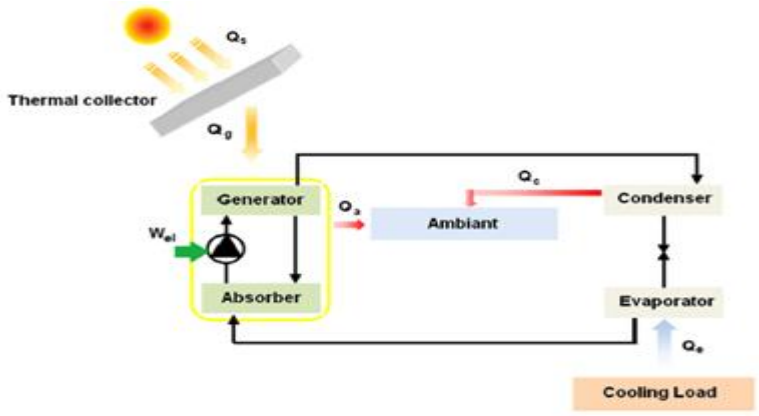

Figure-2.
Solar sorption refrigeration cycle [22].

5.2. Photovoltaic Module Air Conditioning System

In this system, the air conditioner works directly from a solar panel by converting sunlight through a charge controller into electricity. This system can be used for both solar-powered air conditioners and conventional air conditioners. The solar-powered air conditioner is directly connected to the solar panel and works on a direct current (DC) power supply system. Figure 3 shows a schematic diagram of the solar-powered air conditioner. If the need for air conditioning is only for the daytime, there is no need for backup batteries [23]. Conventional air conditioners work on alternating current (AC) and mechanical vapor compression cycle. For running a conventional air conditioner using the solar energy source, a solar inverter is required to change the direct current (DC) to alternating current (AC). In this case, the efficiency of the supplied power becomes low due to the conversion process [24].

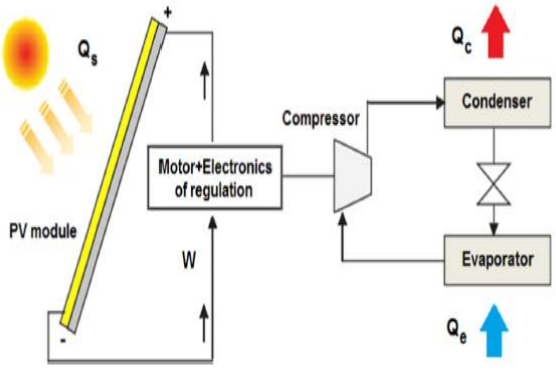

Figure-3.
Solar powered compression air conditioning system schematic diagram [22, 23].

5.3. Comparison of Vapor Compression and Absorption Refrigeration Systems

Both vapor compression and absorption refrigeration systems perform rejection of heat at the high pressure through to the refrigerant's condensation and removal of heat at the low pressure through to the refrigerant's evaporation [25]. The main differences between vapor compression and absorption refrigeration systems are at the circulation, creating the required pressure difference for the circulation of the refrigerant. The vapor compression refrigerant cycle engages a mechanical compressor to establish the required pressure difference for circulation of the refrigerant whereas the absorption refrigerant cycle uses a heat source with no work input. This difference causes the absorption system to become attractive and most in use in the regions that have resources of energy in form of heat, such as solar energy or other sources of heat [26].

6. Environmental Impacts

The most important factor to be considered for having a clean environment, free of pollution is reducing the usage of conventional energy sources. Due to global warming and high summer temperatures, the demand for air conditioning is increasing day by day in the world, as the amount of cooling consumption increases, the amount of energy production in the power plants also increases, and that causes CO_2 emission and air pollution. Recent research shows that, an air conditioner consumes about 96 KwH electrical energy for 8 hours of operation per day [27], produces about 384 grams of carbon dioxide [27].

7. Cost Analysis

The most important factor in the design and installation of solar energy systems is the economic analysis of the system. Because the main reason for using solar heating and cooling for buildings is reducing the energy cost. An economic analysis should be done to predict the payback period and lifetime benefit of the selected model. Generally the average lifespan of solar PV systems is estimated 25 years [28]. The payback period depends of different factors such as: energy consumption and spends, the amount of generated energy by PV system, initial cost of the system installation, and financing the initial installation cost [29]. On average the cost of a 1-ton cooling capacity single split inverter air-conditioner in Malaysia is estimated 497.71 $, this air conditioner with the maximum energy saving of 65% has a payback period of 3.42 years [30]. In Afghanistan, the rate of electricity consumption for commercial areas is about 14 AFN per kWh [31], by considering a 4-ton conventional air conditioner having seasonal energy efficiency ratio (SEER) 10 in a commercial space, consumes about 4.8 kW-h electricity, with 8 hours operating in a day from May to end of September, the overall electricity bill payment for 5 months cooling become; (4.8 kW)x(1200 Hours/year)x(14 AFN/kWh) = 80,640 AFN/year, by the same manner the heating payment for the winter season is about 48,000AFN. The total annual payment for the whole conventional air conditioner is about 128,640 AFN, which is a considerable amount. Comparing this much payment with the 25 years of solar system life span shows that a large amount of saving can be done by using from the solar energy source for the air conditioning. In a case study for an educational building in Kabul city, the amount of payment for a conventional cooling system is predicted by about 1,024,800 AFN per year and for a heating system, 1,332,240 AFN per year. The initial cost for replacing the conventional cooling system with a solar cooling system having 20-years lifetime estimated 679,883 AFN plus 6,798 AFN per year operation and maintenance cost, and for the heating

system it costs about 4,730,388.7 AFN. The payback period for the solar cooling system is calculated to be 3 months and for the solar heating system is 4.36 years [31].

8. Conclusion

Afghanistan needs more work in the renewable energy sectors to develop the capacity of government, people, and private sectors to invest in renewable energy technologies. There is an available solar energy source in Afghanistan to be used as energy for air conditioning systems, from viewpoint of technology and efficiency, the annual solar radiation for Afghanistan is acceptable for the generation of electricity. On average; Afghanistan's southern provinces have more than 6 kWh/m^2/day solar annual global irradiance and Northern provinces have about, 4.5 kWh/m^2/day solar annual global irradiance, which is feasible for solar air conditioning system. Different types of solar air conditioning systems are used worldwide, among which, the absorption refrigerant air conditioning system is a more attractive and economically viable option among the solar air conditioning systems. Its refrigeration cycle works by using heat energy that is produced by solar thermal collectors. The generated heat can be also stored and used at a time when there is no sunshine. Vapor compression refrigerant system also works by using solar energy with a different cyclic system from the absorption refrigeration system and needs more maintenance than the solar absorption refrigeration system. Using solar air conditioners instead of conventional air conditioners, energy-saving, and prevention from environmental pollution can be achieved. As solar air conditioners use solar energy, for long time operation it is cheaper than conventional air conditioning systems. Using solar energy supports the local economy and causes social development in the countries that are encountered with energy shortage.

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