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A case study of an educational building transformation to renewable energy

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ABSTRACT

This is an economic and technical feasibility analysis of a pilot project on transitioning energy usage to renewable and sustainable sources of energy for the Engineering School at Kabul University from economic, security, and academic considerations. The objectives of this research are improving energy security and sustainability, achieving economic benefits, and reflecting the advantages of renewable energy for Afghanistan's sustainable development. Energy demand for the Engineering School is calculated before and after transitioning to adaptable renewable energy resources. The total initial cost of a new system is about 14,237,771AFN with an operation and maintenance (O&M) cost of 341,862.74 AFN/year with the payback time of investment of fewer than 4.5 years. Based on this investigation, we found that, it is economical and technically feasible to switch to renewable and sustainable sources of energy, especially in commercial and governmental buildings.

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1. Introduction

Global greenhouse gas emissions and renewable energy resources are at the forefront of worldwide trends [1]. Renewable energy has been playing a significant role in the current and future global energy supply since the energy revolution in 1970 (oil crisis). Due to environmental contribution of fossil fuels to global climate change, high fuel costs, and depleting reservoirs, we must consider alternatives to fill future energy gaps, save the environment, reduce GHGs, and improve energy security. Energy agencies and higher education institutions are highly responsible for developing renewable energy and applying its advantages. Governments should establish renewable energy policies and tariffs to encourage energy investment in renewable energy sectors. To this end, construction of the Energy School at Kabul University is selected as a pilot project to find out how economically and technically feasible a transition from conventional sources of energy to more sustainable and renewable sources of energy could be.

Solar and wind power started a sea change by incorporating intermittent renewable energy resources into the electric grid. This has changed the planning and operation of grid power, which became attractive to utility managers interested in smart and optimum practices in engineering [2].

Renewable energy comes from natural processes and is replenished in short periods after use. Energy sustainability focuses on the delivery of energy services in a sustainable way for all customers now and in the future. Those services should be affordable, environment-friendly, available to all, and acceptable to suppliers and consumers [3].

In this era, the entire world highly desires renewable energy because it is sustainable, secure, green, environmentally friendly, and locally available. Several renewable energy technologies have been developed in global markets and compete with conventional energies. Many international organizations are dedicated to enhancing renewable energy; the International Energy Agency (IEA) focuses its support for renewable energies: "The transition to a sustainable energy future will be complex and will take time. We need to change not only the structure of the energy sector but also the behavior in our societies and economies..." and "The challenge is to find worldwide economic growth with a secure and

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reliable energy supply without spoiling our environment. It is possible. The energy supply needs to be further de-carbonized, diversified …” [4,5].

Interest in the integration of renewable energy into power systems has risen significantly among researchers. As renewable energy technology becomes more reliable and economically feasible, interest in connecting renewable energy resources into the existing power system offers more practicality to end-users, such as [6]:

- reliability improvement and access to electricity;
- peak load shaving;
- selling electricity back to utilities or other consumers;
- power quality improvement

National development goals must include conversion to more solar energy usage. Many studies looked at changing from conventional energies to solar [7]; one was a feasibility study of energy-techno economics analysis of a 20,000 m^2 area in Aksaray, Turkey. Tarigan simulates a rooftop photovoltaic (PV) system on a roof at the University of Surabaya, Indonesia [8]. Razmjoo et al. presented a feasibility study on energy sustainability in southern cities of Iran using PV-DG hybrid systems [9]. Jo et al. proposed a solar PV rooftop system at Illinois State University [10]. Stina et al. presented a case study on a commercial office building with integrated PV systems in Norway. Kumar et al. [11] suggested replacing high power consumers (ACs) to DC water blower coolers that operate with the solar PV systems for villages, schools, and offices [12].

Fahmy et al. focused on a Thermal Collector for Water and Space Heating System in a hospital building in a remote site of Sante Catherine in Egypt [13]. Ahmadi et al. considered a novel optimization methodology to allocate multiple renewable energy resources, including rooftop PV, in a real power system in Afghanistan [14]. Based on their study, the proposed method can not only significantly improve technical parameters but also make a positive impact on the environment by reducing carbon emissions. This was done with significant cost savings, an encouraging statement for future investment on renewable energy resources.

The Energy Engineering Department at Kabul University highly encourages sustainable, green, and renewable energies. This study performs an economic and technical feasibility analysis on transitioning energy usage to renewable energy to achieve energy sustainability, security, and economic benefits. Afghanistan is one of the least developed countries in different sectors, including the energy sector. It routinely faces energy outages and insecurity, especially in the winter. The electricity cost is also high at about 14 AFN/kWh in governmental and commercial buildings. There are several causes: first, the domestic energy supply does not meet demand; second, as a result, more than half of Afghanistan’s energy is imported and transmitted from neighboring countries; finally, there is a lack of a strong utility management system. Because importing electricity from neighboring countries is expensive and insecure, Afghanistan has set a target to increase renewable energy usage by 95% in 2032 to improve energy accessibility and sustainability [15].

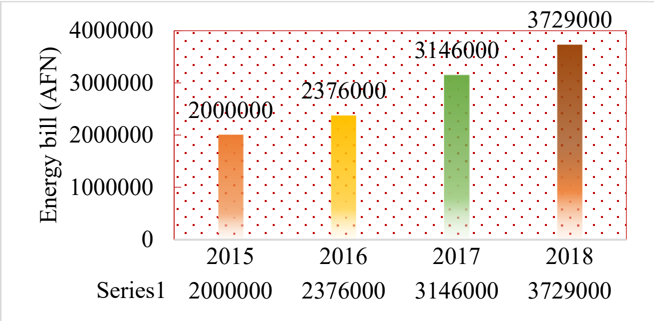
2. Case study

2.1. Site information

The Engineering Faculty Building at Kabul University is located at the latitude of 34.51566° N and longitude of 69.139376° E at an altitude of 1800m above sea level in the third district of Kabul. It has six active departments, including Civil Engineering, Energy Engineering, Mechanical Engineering, Electrical and Electronic Engineering, Architecture Engineering, and Urban Design and Planning Engineering. The structure of the building is J-shaped, and its total roof area is about 4505 m^2. Approximately 2300 m^2 of their roofs are inclined about 30 degrees south-facing (Figure 1). It has 14 classrooms, 15 professors’ offices, three architectural studios, eight large rooms, seven laboratories, one mechanical shop, a library, and an auditorium.

Figure 1. Engineering faculty image.

The energy consumption bills of the engineering building are shown in Figure 2, showing anticipated increases of 25%.



Energy consumption bills in the four previous years (in AFN).

2.2. Power demand

The power demand of the selected case is expressed in three categories: rest electrical equipment, cooling, and heating. The power demand comes for rest electrical equipment is about 81.5 kW with a 25% future load becomes 101.8 kW. With a 10-kW installed PV system, the proposed energy demand for rest electrical equipment is about 91.8 kW (Table 1).

Table 1: Proposed photovoltaic system for rest electrical appliance.

Appliance	Quantity	Power(W)	kW
PC	127	220	27.94
Light LED	128	24	3.072
Printer	21	120	2.52
Printer large	5	1200	6
Light FLC	389	72	28.008
Projector	19	240	4.56
Vacuum cleaner	2	700	1.4
Labs instrument	1	8000	8
Total			81.5
Total with 25% future load demand			101.875
existing PV system			10
Proposed/Required PV system			91.875

For the battery backup sizing, the following points are considered:

- This system is used only during the day hours, so it does not require more energy at night. Only the energy for outdoor lighting, the security guards room, and corridor lighting will be considered.
- New programs will be scheduled for the evenings (4:00-8:00 PM local time), so a battery backup should be considered for the PC-laboratory and the three special classrooms.
- During the day, a backup system is not necessary because generation and consumption are occurring. The solar system generates power, depending on the strength of the sunlight. Therefore, we plan for a half-hour back battery system for some sensitive equipment during the day that provides stable or constant power.

Total energy demand for a battery backup size anticipating a 25% future load is about 96.282 kWh, and the installed battery storage potential is 3*6.743kWh. Therefore, the proposed energy demand for battery backup sizing is about 76.053 kWh (Table 2).

Table 2: Proposed energy demand for battery backup sizing.

Appliance	Power (kW)	Quantity	Working hour/ day	Consumption/day (kWh)
Night energy demand				
Outdoor lighting (LED)	0.1	6	6	3.6
Corridor lighting (LED)	0.024	58	6	8.352
Four special classrooms	0.072	110	4	31.68
PC	0.22	40	2	17.6
Guards room	0.024	2	10	0.48
	0.22	1	4	0.88
Projectors	0.24	4	4	3.84
Total				66.432
Day energy demand				
Lab instrument	8	1	0.5	4
Printer (small)	0.12	21	0.25	0.63
Printer (large)	1.2	5	0.5	3
PC	0.22	127	0.5	13.97
Projectors	0.24	19	0.5	2.28
Energy demand with 25% future load				29.85
Total energy demand				96.282
Existing battery capacity (3*6.743kWh)				20.229
Proposed energy demand				76.053

According to the Ministry of Urban and Development; the heat required per square meter floor area in Kabul City is about 100-150 W, depending on the insulation system of buildings [16]. Therefore, in this study, 120 W/sq. m is considered (Table 3).

Table 3: Proposed heat power demand for heating system.

Room type	Quantity	Floor area (sq. meter)	W/(sq. meter)	The heat required (kW)
Office type 1	11	16	120	21.12
Office type 2	20	22	120	52.8
Conference room	1	144	120	17.28

PC lab	1	238	120	28.56
En & E labs	2	119	120	28.56
Library	1	293	120	35.16
Total heat demand				183.48

The current cooling system consists of high electrical power consumption devices (ACs). Therefore, DC coolers suggested for the cooling system because they consume less power and operate with PV panels, a charge controller, and a battery [13]. Two types of DC coolers are selected; the first type for office rooms and a second type for large rooms. In Table 4, the quantities and power requirements are specified.

Table 4: Proposed energy demand for cooling system.

Appliance	Power (W)	Quantity	Working hour(h)/day	kW
DC cooler instead of large AC	100	15	6	1.5
DC cooler instead of small AC	48	31	6	1.488
Total				3
For battery sizing (2h)				– kWh

2.3. Renewable energy potential

Renewable energy resource availability depends on geological, geochemical, geophysical, weather, climate, time and several other factors. In this specified area, two types of renewable energy resources are available: solar and wind energy. A monthly average wind speed of less than 5 m/s (Figure 3) is not appropriate to operate the proposed model. In addition, wind turbines have negative environmental impacts like visual impact and noise. These negative impacts are not acceptable for a critical educational area. Solar energy, however, is a proper choice with an average monthly potential of more than 4.2 kWh/m^2 per day [15]. In addition, electricity generation and consumption match during daily hours, which reduces the need for a battery storage system. Moreover, the rooftops are suitable for PV module installation as more than half of the rooftops area are approximately 30^o south facing. The area also has 300 sunny days available for solar energy exploitation. Monthly wind and solar potential for Kabul city are shown in Figures 3 and 4.

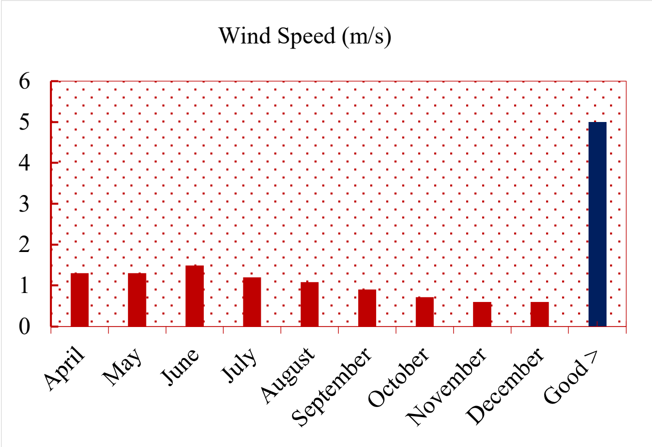


Figure 2. Average monthly wind speed of Kabul University.

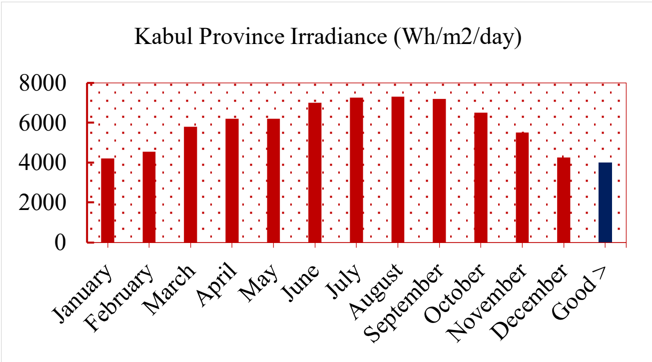


Figure 3. Monthly irradiance of Kabul city [15].

3. Proposed system design

3.1. PV system sizing for electric system

Solar PV systems are generally designed as standalone, hybrid, and on-grid. For this study, we chose a hybrid system. During the PV system design process, all main elements should be sized appropriately: PV modules, charge controllers, battery storage, and inverters. The PV system should provide the total electric power of about 91.8 kW with 76.053 kWh battery storage capacity (Table 1 and 2). The AC system voltage and frequency are 220 V and 50 Hz, respectively. Refer to Annex A for the PV system equipment catalogs, the inverter efficiency is 93% and cable efficiency should be 98%; therefore, the total power is:

$$Total\ Power = \frac{Proposed\ power\ demand}{(Inverter\ efficiency) * (Cable\ efficiency)} = \frac{91.8\ \text{kW}}{0.93 * 0.98} = 100.72\ \text{kW}$$

The number of panels is calculated as follows:

$$Number\ of\ modules = \frac{Total\ power}{Module\ power} = \frac{100720\ W}{260\ W} = 386 \text{ modules}$$

The string voltage system, according to the selected inverter capability, should be 90 V DC. Therefore, the arrangement of the panels in series and parallel is calculated as follows:

$$Number\ of\ modules\ in\ series = \frac{System\ voltage}{Module\ voltage} = \frac{90\ V}{36\ V} = 2\ (Round\ down)$$

$$Number\ of\ \text{strings} = \frac{Number\ of\ modules}{Number\ of\ modules\ in\ series} = \frac{386}{2} = 193$$

The inverter converts direct current (DC) to alternating current (AC) and should provide a safe operation with high efficiency. The efficiency of an inverter varies with input power and voltage and is sized by maximum power and stirring voltage. The inverter power is calculated as follows:

$$P_{inverter} = \frac{(Proposed\ demand\ power) * (safety\ factor)}{(Inverter\ efficiency)} = \frac{(91.8\ kW) * (1.2)}{(0.93)} = 118.45 \text{ kW}$$

The selected inverter in this pilot project is a cost-effective inverter with an intelligent solar built-in; this means the inverter and charge controller are in one device. The number of inverters is calculated as follows:

$$Number\ of\ inverter = \frac{P_{inverter}}{Inverter\ power} = \frac{118.45\ kW}{5\ kW} = 23.69 = 24\ unit$$

Battery sizing determines the capacity of the battery (Ampere-hour), the voltage of the battery (Volt), and the type of battery. In battery sizing, the battery should be large enough to store sufficient energy to operate appliances for a specific time.

Assumptions:

- Battery efficiency assumed 90%
- DOD is assumed to be 84%
- Days of autonomy is considered as one day
- System voltage should be 48 V, according to inverter capability

The amount of energy provided by batteries, as found in Section 3.2, is 76.053 kWh per day.

$$\text{Battery system capacity (Ah)} = \frac{\text{Energy needed}}{\text{Efficiency} * \text{DOD} * \text{Batt. Syst. Volt}} = \frac{76053 \text{ Wh}}{0.9 * 0.84 * 48 \text{ V}} = 2095.82 \text{ Ah}$$

$$\text{Number of batteries in parallel} = \frac{\text{Battery system capacity (Ah)}}{\text{Battery Capacity (Ah)}} = \frac{2095.82 \text{ Ah}}{250 \text{ Ah}} \approx 9$$

$$\text{Number of batteries in series} = \frac{\text{Battery system voltage}}{\text{Battery voltage}} = \frac{48 \text{ V}}{12 \text{ V}} = 4$$

$$\text{Number of batteries} = 9 * 4 = 36 \text{ unit}$$

4. PVs system design for cooling system

From section 3.2, the cooling system needs 3 kW DC power and a 6 kWh battery backup system to operate DC coolers. The main components of the DC system are PV modules, a charge controller, and a battery backup. The charge controller efficiency is 93%, and cable efficiency should be 95%; therefore, the total power is:

$$Total\ Power = \frac{Needed\ power\ for\ DC\ coolers}{(Charge\ controler\ efficiency) * (Cable\ efficiency)} = \frac{3 \text{ kW}}{0.93 * 0.95} = 3.39 \text{ kW}$$

The number of modules is calculated as follows:

$$Number\ of\ modules = \frac{Total\ power}{module\ power} = \frac{3390\ W}{160\ W} = 21.1 = 21 \text{ modules}$$

Charge controllers are sized by current and voltage; the system voltage is 12 VDC, and current is calculated as follows:

$$Total\ current = (SC_{current}) * (Number\ of\ Modules) * (Safety\ factor) = (9.5\ A) * (21\ unit) * (1.2) = 239.4\ A$$

The selected charge controller is 12 V and 25 A.

$$Number\ of\ charge\ controllers = \frac{Total\ current}{Charge\ controller\ current} = \frac{239.4\ A}{25\ A} = 10\ \text{unit}$$

$$\text{Battery system capacity (Ah)} = \frac{\text{Energy Required}}{\text{efficiency} * \text{DOD} * \text{Batt. Volt}} = \frac{6000\ \text{Wh}}{0.9 * 0.84 * 12\ \text{V}} = 661.4\ Ah$$

$$Number\ of\ batteries = \frac{Battery\ system\ capacity}{battery\ capacity} = \frac{661.4\ Ah}{250\ Ah} \approx 3\ \text{unit}$$

5. Solar thermal design for heating system

Solar thermal energy is a different application of solar energy that relies on the laws of thermodynamics. Because space heating and water heating represent 59% of the total energy consumption in buildings [17], there are many advantages to replace conventional heating systems to solar thermal heating systems for their economic and environmental benefits.

There are two types of solar thermal heating: active and passive. A passive solar thermal system is not applicable in this study as it is used mainly in new construction. A solution for space heating is central solar thermal heating, which depends on an active heating system. The main components of the central solar thermal heating system include: a solar collector, thermal storage tank, piping system, forced circulating electric pump, and heat exchangers or radiators. First, a thermal storage tank heated by thermal collectors. Next, hot water from the thermal storage tank distributes with the piping circulation system into the entire space; then, heat exchangers (radiators) transfer heat from the hot water piping system into heating space by temperature difference. Finally, the working fluid is pressurized by the electric circulating pump and rises to collectors for reheating [18].

Radiators send the heat energy from hot water through tubes into the room space. For this study, the Turkish PKKP-22 radiators were selected. (For more details on the radiators sizing details refer to Annex B.) Pipes are the hot water transitional components in the HVAC system and selected according to materials, insulation, and strength. The selected pipe material is black steel pipes, and for the sizing details, refer to Annex B.

The circulating pump circulates gases or liquids in a closed circulating system and is designed to overcome piping friction. The circulating pump is sized based on head and flow rate. Head is evaluated as below [19]:

$$Head = (0.075) * (Critical\ Path)$$

The critical path is the most extended length in the piping system, and it is equal to 140 m.

$$Head = (0.075) * (140m) = 10.5m \approx 11m$$

Flow rate is calculated as below (184 kW = 628254 Btu/h):

$$Flow\ Rate = \frac{Heat\ Load\ (\frac{Btu}{h})}{10000} = \frac{628254\ Btu/h}{10000} = 62.8\ GPM = 14.3\ {m^3}/{h} = 3.96\ L/s$$

Because there is an 11 m head and 14.3 m^3/h flow rate, the selected circulating pump to handle the system is BPH 150/280.50T [15], See Annex **F** for pump specifications.

Two types of solar thermal collectors in low temperatures are flat-plate collectors (FPC) and evacuated tube collectors (ETC); both provide temperature levels up to 120°C. FPC use copper tubes carrying a heat transfer fluid running through an insulated, weatherproof box with a dark absorbing material and thermal insulation material on the backside that prevent heat loss. ETC use rows of glass tubes, each with a heat pipe collector containing a heat transfer fluid surrounded by a vacuum which significantly reduces heat losses. This pilot project selected an FPC, and its specification indicated in Annex B. The total collector area is calculated as the following formula:

$$A_R = \frac{Energy\ Demand}{\left(\frac{Insulation}{day}\right) * (Collector\ Efficiency)}$$

- Solar insolation in winter days is about 4.5 kWh/sq. m per day (Figure 5).
- Collector efficiency is about 60%.

$$Energy\ Demand = (Heat\ power\ demand) * \left(\frac{Working\ hour}{day}\right) = (184kW) * \left(\frac{6h}{day}\right) = 1104\frac{kWh}{day}$$

The total collector area is:

$$A_R = \frac{(1104\ kWh/day)}{\left(4.5 \frac{kWh}{m^2 * day}\right) * (0.6)} = 409\ m^2$$

The number of flat plate collectors evaluated as follows:

$$Number\ of\ collector = \frac{A_R}{collector\ obsorbtion\ area} = \frac{409\ m^2}{1.82\ m^2} = 225\ unit$$

A backup system is necessary for rainy and cloudy days. Therefore, we consider a gas boiler to maintain the system during uncertain situations. The gas boilers are sized by water input, output temperature, and power. The system temperature range is 90-70 ^{o}C, and rated power is 184 kW. The selected gas boiler is WNS0.35-0.7/95/70-Y (Q) (Alibaba, 2019). It is not necessary to use the thermal storage tank because thermal energy consumption occurs during the day hours; the hot water comes from collectors into the boiler tank and distributes to the entire space for heating.

6. Economic analysis

In this section, we determine whether this transition is economically feasible. The parameters we considered are investment cost, annual saving, operation, and maintenance (O&M) cost and payback time of investment. The price of equipment is collected based on available local and international resources.

7. PV system economic analysis

The initial cost of the PV system is about 8,827500 AFN (Annex C). To find the annual benefit of the PV system, we should evaluate the amount of energy the system can generate. Kabul city experiences about 300 sunny days annually, and the average peak sun hours (PSH) is about 5.73 h/day.

$$Energy\ generation = (PVs\ \ power\ capacity) * \left(\frac{Generation\ days}{year}\right) * (PSH) = (91.8\ kW) * \left(300 \frac{day}{year}\right) * \left(5.73 \frac{h}{day}\right) = 157804.2\ kWh/year$$

Electricity Price at 14 AFN/kWh and yearly benefits of PV system becomes:

$$Yearly\ benefits = \left(\frac{Energy\ generation}{year}\right) * \left(Energy\ price \frac{AFN}{kWh}\right)$$

$$= \left(157804.2 \frac{kWh}{year}\right) * \left(14 \frac{\text{AFN}}{\text{kWh}}\right) = 2{,}209{,}258.8\ \text{AFN/year}$$

The O&M cost of PVs systems is about 1% of investment cost [20], about 88,275 AFN/year. In addition, the lifetime of the PV system is about 25 years, so the total lifetime benefit of the whole life is about 53,024,595 AFN. The payback time of investment is calculated as follows:

$$Payback\ time = \frac{(Investment\ cost)}{(Annual\ benefit) - (O\&M)}$$

$$= \frac{8{,}827{,}500\ AFN}{2209258.8 \frac{AFN}{year} - 88{,}275\ AFN/year} = 4.2\ year$$

8. Cooling system economic analysis

To find the replacement benefits of the conventional cooling system with a new cooling system (DC coolers), we should calculate the energy cost for the conventional cooling system. Second, we estimate the implementation cost for the new cooling system for comparison.

Assumptions are as follows:

- The cooling system operates for four months at 6 h/day.
- The power demand for the conventional cooling system should be 122 kW, which 62 kW in 31 small ACs and 60 kW in 15 large ACs.

$Energy\ cost\ for\ conventional\ cooling\ system\ per\ year$:

$$= (\ ACs\ power\ demand) * (energy\ cost) * (autonomy\ days) * \left(\frac{hours}{day}\right)$$

$$= (122\ \text{kW}) * \left(14 \frac{\text{AFN}}{\text{kWh}}\right) * \left(100 \frac{\text{day}}{\text{year}}\right) * \left(6 \frac{\text{h}}{\text{day}}\right) = 1{,}024{,}800.00\ \text{AFN/year}$$

The initial cost of a cooling system is about 679,883 AFN (Annex C), and O&M cost is about 6798 AFN/year (IRENA, 2013).

$$Payback\ time = \frac{New\ system\ investment\ cost}{Energy\ cost\ pay\ for\ conventional\ system - O\&M} = \frac{679{,}883\ AFN}{1{,}024{,}800\,\frac{AFN}{year} - 6{,}798\ AFN/year} = 0.67\text{ year}$$

$$= \text{about, 3 month}$$

The lifetime of a new cooling system is about 20 years, and the total lifetime benefits are about 19,471,200.00 AFN.

9. Heating system economic analysis

The initial cost of the heating system is 4730,388.7 AFN (see Annex C) and O&M cost is about 50,000 AFN/year. To find the annual benefits of the new heating system, we should calculate the energy cost for the conventional heating system. Second, we estimate the implementation and running costs of a new heating system for comparison.

Assumptions:

- The heating season lasts about five months, or about 130 days without 20 holidays and operates 6 h/day.
- The power demand for a conventional heating system should be 122 kW; which 62 kW in 31 small ACs and 60 kW in 15 large ACs.

$$Energy\ cost\ for\ conventional\ heating\ system\ per\ year: = (\ ACs\ power\ demand) * (Energy\ cost) * (Autonomy\ days) * \left(\frac{hours}{day}\right)$$
$$= (122\text{ kW}) * \left(14\,\frac{\text{AFN}}{\text{kWh}}\right) * \left(130\,\frac{\text{day}}{\text{year}}\right) * \left(6\,\frac{\text{h}}{\text{day}}\right) = 1{,}332{,}240\text{ AFN/year}$$

Kabul experiences 42 cloudy or rainy days within its 130 heating days (Weather and climate, 2018). Liquefied Petroleum Gas (LPG) fuel costs per year are calculated as follows:

The heat content (HC) of LPG is about 46.1 MJ/kg, and the LPG price assumed at 50 AFN/kg.

$$Energy\ demand = (Power\ demand) * \left(\frac{hour}{day}\right) = (184\ kW) * (6\ h) = 1104\ kWh/day$$

$$LPG\ demand = (Energy\ demand\ \left(\frac{kWh}{day}\right)) \div (HC\ \left(\frac{kWh}{kg}\right) * (Boiler\ efficiency))$$

$$LPG\ demand = \left(\left(1104\,\frac{kWh}{day}\right)\right) \div (\left(46.1\,\frac{MJ}{kg} * \frac{1000\ kJ}{1MJ} * \frac{1\ kWh}{3600\ kJ}\right) * (0.92)) = 93.7094\ kg/day$$

$$Annual\ LPG\ fuel\ cost = \left(LPG\,\frac{kg}{day}\right) * \left(LPG\ price\,\frac{AFN}{kg}\right) * (Rainy\ and\ cloudy\ days)$$
$$= \left(93.7094\,\frac{kg}{day}\right) * \left(50\,\frac{AFN}{kg}\right) * \left(42\,\frac{day}{year}\right) = 196789.74\ AFN/year$$

$$Annual\ saving\ cost = Energy\ cost\ will\ pay\ for\ ACs - Annual\ LPG\ fuel\ cost = 1332240\,\frac{\text{AFN}}{\text{year}} - 196789.74\ \frac{AFN}{year} = 1135450.26\ AFN/year$$

Payback time is calculated as follows:

$$Payback\ time = \frac{New\ system\ investment\ cost}{Energy\ cost\ of\ conventional\ heating - O\&M\ cost} = \frac{4730388.7\text{ AFN}}{1332240\,\frac{AFN}{year} - (196789.74\,\frac{AFN}{year} + 50000\,\frac{AFN}{year})} = 4.36\ year$$

The lifetime of the new heating system is about 20 years and total lifetime benefits are about 21,990,133.4 AFN.

10. Results and conclusion

More than half of Afghanistan's electric energy is imported from neighboring countries with long transmission lines. Due to regional, geological, and political situations, the stability and security of the supplier grid are feeble resulting in a high electricity price for commercial and governmental sectors at about 14 AFN/kWh. A case study is considered to determine the economic and technical feasibility to meet the energy usage of the Engineering Faculty Building at Kabul University from renewable energy sources. Three solar energy technologies were suggested for the proposed area of study: PV system with battery backup for rest electrical equipment, the central solar thermal system for space heating, and DC coolers for space cooling with DC PVs system. The proposed energy demand is about 91.975 kW with 76.053 kWh battery capacity for rest electrical equipment, about 183.48 kW heat energy for space heating system, and 3 kW with 6 kWh battery backup for space cooling system. After analysis of these new system designs, the results are as follows:

- The initial cost of the PVs system is about 8,827,500 AFN, and annual saving is 2,209,258 AFN/year with a payback time of 4.2 years. A whole lifetime it will recover about 53,024,595.00 AFN.
- In cooling system implementation cost is 679,883 AFN, and annual saving is 1,024,800 AFN/year with a payback time of 3 months. A whole lifetime will save about 19,471,200 AFN.
- The investment cost for the heating system is about 4,730,388 AFN, and yearly saving is about 1,135,450 AFN/year with a payback time of 4.4 years. A whole lifetime will save about 21,990,133.00 AFN.

The rooftop area is 4,504 m^2 with about 2,300 m^2 of this area inclined approximately 30^{o} facing south. There is enough area to install solar systems: about 729.47 m^2 for PVs panels and 500 m^2 for thermal collectors. Despite the conventional energy system's low initial cost, the solar power system is much useful in the long-term. There are significant savings over the 20-25 year lifetime of the system compared to the conventional system. Furthermore, solar energy is sustainable, secure, and free of charge during its operation. The results show that it is economically and technically feasible to invest in renewable and sustainable energy. From this analysis, similar designs with educational buildings throughout Afghanistan can be proposed. Future studies will consider more novel sustainable energy technologies for renewable energy implementation.

Appendix

A. PV system equipment

Table 5: PV panel specifications.

Model	CNCB260W
Maximum Power at STC (Pmax)	260W
Optimum Operating Voltage (Vmp)	30.92V
Optimum Operating Current (Imp)	8.409A
Open-Circuit Voltage (Voc)	37.36V
Short-Circuit Current (Isc)	9.27A
Solar Cell Efficiency (%)	18.13
Solar Module Efficiency (%)	15.98
Operating Temperature	-40 to85℃
Maximum System Voltage	DC1000
Maximum Series Fuse Rating	15A
Dimensions	1640mm*992mm*40mm
Power Tolerance	+/-3%
Price/module	14500 AFN
STC: Irradiance 1000W/m2, Modules Temperature 25℃, AM=1.5	

Table 6: Inverter specifications.

Model	Model
CAPACITY	CAPACITY
INPUT (From Grid)	INPUT (From Grid)
Acceptable Voltage Range	Acceptable Voltage Range
Frequency	Frequency
AC Voltage Regulation (Batt. Mode)	AC Voltage Regulation (Batt. Mode)
Surge Power	Surge Power
Efficiency (Peak)	Efficiency (Peak)
Waveform	Waveform
Battery	Battery
Battery Voltage	Battery Voltage
Floating Charge Voltage	Floating Charge Voltage
Overcharge Protection	Overcharge Protection
MPPT Solar Charge Controller	MPPT Solar Charge Controller
MPPT Range Operating Voltage	MPPT Range Operating Voltage
Maximum Solar Charge Current	Maximum Solar Charge Current
Maximum AC Charge Current	Maximum AC Charge Current
Price/unit	Price/unit

Table 7: Battery specifications.

Model	JPC12-250
Nominal Voltage	12V
Nominal Capacity	250Ah
Design life	15 years
Terminal	M8
Approx. Weight	Approx. 70.5kg (155lbs)
Container Material	ABS
Max. Discharge Current	3000A(5S)

Table 8: 160 W panel specifications.

Model	SF-M636XXX 160W
Maximum Power at STC (Pmax)	160
Optimum Operating Voltage (Vmp)	18.89

Optimum Operating Current (Imp)	8.47
Open-Circuit Voltage (Voc)	22.67
Short-Circuit Current (Isc)	9.85
Solar Cell Efficiency (%)	19.16
Solar Module Efficiency (%)	15.87

STC: Irradiance 1000W/㎡,Modules Temperature 25°C,AM=1.5

B. *Heating system equipment specifications*

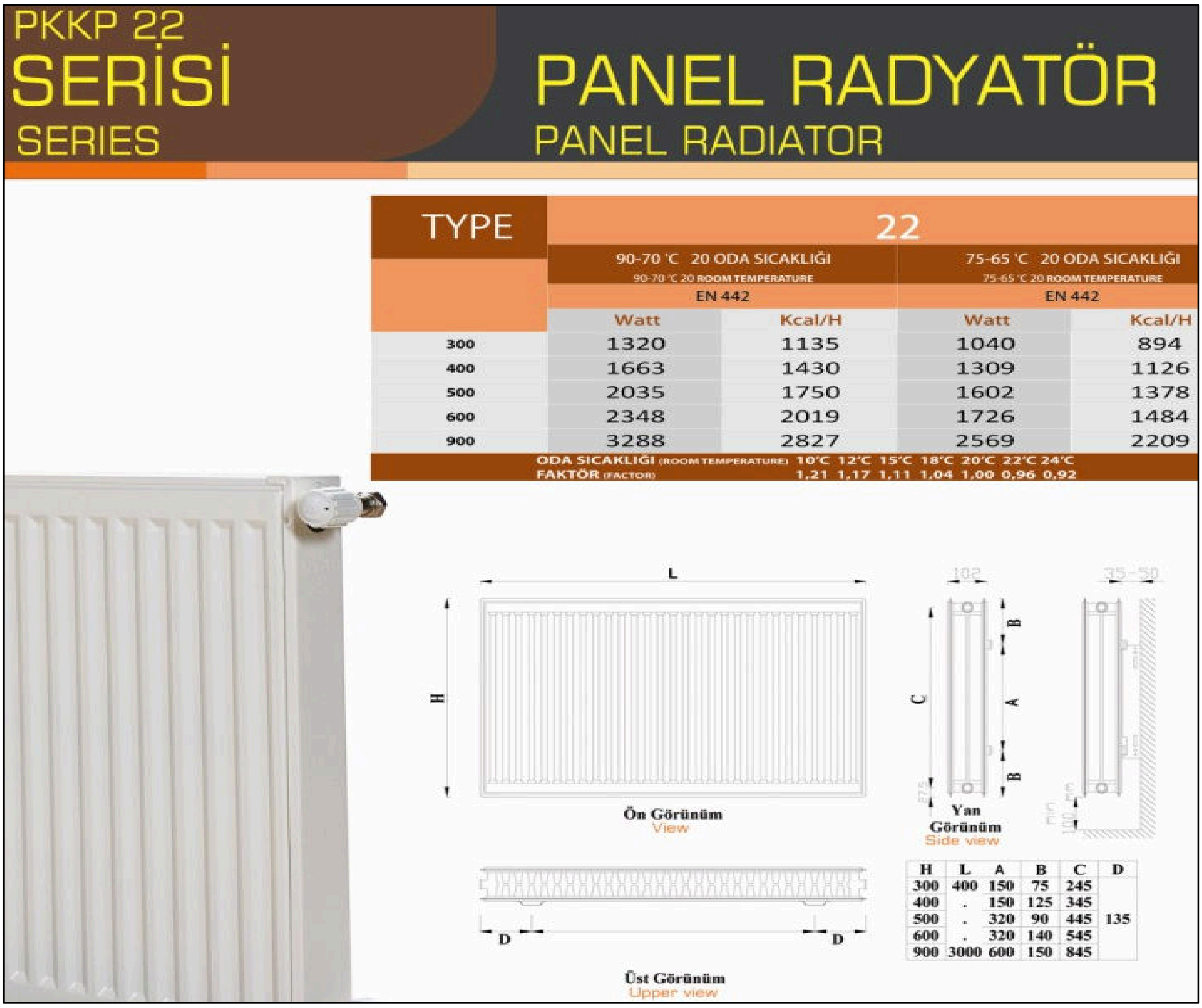


Figure 4. Radiator catalogue.

Table 9: Radiator sizing.

	Quantity	Heat Required(kW)	Rad Type	No Rad	Dimension(cm)
Office type1	11	21.12	PKKP 22	11	80x60
Office type2	20	52.8	PKKP 22	20	110x60
Conference room	1	17.28	PKKP 22	5	150x60
PC lab	1	28.56	PKKP 22	8	150x60
Energy and Electric Labs	2	28.56	PKKP 22	8	150x60
Library	1	35.16	PKKP 22	10	150x60

Table 10: Circulating pipe sizing.

Head pipe		East to north of building		East to west of building	
Diameter	Length	Diameter	length	Diameter	length

80 mm	20 m	20 mm	10 m	20 mm	10 m
End pipe		25 mm	10 m	25 mm	50 m
Diameter	Length	32 mm	15 m	32 mm	70 m
15 mm	93 m(62X1.5m)	40 mm	15 m		
		50 mm	20 m		

* Pipe sizes in Kabul market: 15mm, 20mm, 25mm, 32mm, 40mm, 50mm, 65mm, 80mm

Table 11: Circulating pump specifications.

MODEL	CODE	PUMP COUPLINGS	VOLTAGE 50 Hz	P1 MAX W	In A	V (m3/h)	Head
BPH 150/280.50T	5.06E+08	DN 50	3 x 230 V ~	1130	3,22	14.4	11.8

Table 12: Flat plate solar thermal collector specification.

Model	overall size(mm)	Stagnation Temperature	Gross Area(m2)	absorption area(m2)	Efficiency	Flow rate (L/h*m2)
FP-GV 2.00	2000x1000x80	180 oC	2	1.82	81%	70-80

Table 13: Gas boiler specifications .

Model	Capacity (kW)	Pressure (MPa)	Hot Water Temperature (°C)	Return Water Temperature (°C)	Efficiency	Fuel
WNS0.35-0.7/95/70-Y (Q)	350	0.7	95	70	92%	Natural gas, LPG and diesel oil

C. Implementation costs details

Table 14: PVs system initial cost including installation cost

Component	Quantity	Cost/unit (AFN)	Total cost (AFN)
Component	Quantity	Cost/unit (AFN)	Total cost (AFN)
Modules	387	14500	5611500
inverter with MPPT	24	80000	1920000
Battery	36	36000	1296000
Total			8827500

Table 15: Cooling system initial cost

Component	Quantity	Cost/unit (AFN)	Total cost (AFN)
Small DC cooler	31	4500	139500
Large DC cooler	15	10000	150000
Module	21	8923	187383
Charge controller	10	9500	95000
Battery	3	36000	108000
Total			679883

Table 16: Heating system initial cost

Circulating pump (AFN)	42900	Pipes			
Thermal Collector (AFN)/Panel	15600	Type	Price/m (AFN)	Length (m)	Total cost
Total (225 Unit)	3510000	15 mm	100	93	9300
Gas Boiler (AFN)	537488.9	20 mm	120	20	2400
Radiator With valves (AFN) /m	4446	25 mm	150	60	9000
Total (77.3 m)	343675.8	32 mm	180	95	17100
Installation cost 156 AFN/sq. m	238524	40 mm	200	15	3000
		50 mm	250	20	5000
		80 mm	600	20	12000
		Total			57800
Total cost					4730388.7

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