Cost Benefit Analysis of a Net-Zero Energy Housing in Qatar

Samer Gowid, Farayi Musharavati, and Abdelmajid Hamouda

***Abstract*—In response to local and global energy and health challenges, this paper presents the design and cost benefit of the implementation of Net-Zero Energy Housing (NZEH) to the existing villas in Qatar. Thus, this work determines whether the benefits outweigh the cost of the implementation of NZEH. There is uncertainty over the reliability of the presented cost benefit data in other countries as cost benefits differ from one place to another. A lack of empirical evidence has increased this uncertainty; particularly, a lack of evidence on the costs and benefits of a net zero and low emission housing option to private households. These costs include the cost of renewable energy technologies. This paper aims to bridge the research gap by applying cost benefit methods. Thermal insulation, solar power generation and solar water heating systems were modelled and lifecycle costing was applied to explore the costs and benefits across 25 years for net zero emission new house scenarios in Qatar. The average typical residential villa energy use establishes a baseline for determining energy and cost savings. A cost-benefit analysis was first performed at the subsystem level, house level and then at the country level and the results were in favour of the implementation of NZEH. Solar photovoltaic and solar water heating subsystems are designed in order to meet the hot water and electricity requirements of a typical villa. Thermal insulation was found to be non-beneficial due to the low electricity tariff in Qatar. Annual savings of 299 Qatari Riyals (QAR) per villa and 21 million QAR at the country level could be achieved if NZE housing is implemented. This is in addition to the numerous benefits of the utilization of clean and sustainable energy. If the initiative of NZEH is implemented to all types of residential and commercial units, Qatar would save a multiple of this amount with a significant reduction in related health problems.**

***Index Terms*—Renewable energy, net-zero energy housing, solar energy, cost benefit analysis, electricity production in Qatar.**

I. Introduction

The demand for electricity rises worldwide and the populations' consumption of electricity has been increasing constantly over years. People always have the willingness and ability to add more electrically powered devices that are often used in their daily activities. Electricity consumption among Qatar households has been growing significantly in the past few years, and hence the future consumption will be difficult to manage if no effective sustainable measures are undertaken. The increasing consumption of fossil fuels associated with the increasing demand for electricity results in a higher energy cost, increasing risks of global climate change, in addition to negative environmental, safety and health effects. The direct cost of fossil fuels in addition to the indirect costs caused by global climate change and environmental pollution are high and represent a burden on Qatar Gross Domestic Product (GDP). The government expenditure on health increases annually as a direct result of the pollution caused by the generation of electricity using fossil fuels [1]. Currently, Qatar spends 5.8 billion on healthcare programs and this amount is expected to grow to 6.6 billion in 2020 [2].

Furthermore, from the aspect of sustainability, fossil fuels are unstainable energy resources and they will run out over time [3]. Therefore, there is an emerging need to reduce energy consumption as well as move towards renewable energy with a clean, safe, cheap and more sustainable energy resource. The renewable energy is collected from renewable resources that are naturally replenished on a human timescale, such as sunlight, wind and rain. This energy cannot be exhausted as it is constantly renewed.

In 2009, the residential sector in Qatar consumed 47% of the total power generated for all sectors (see Fig. 1). The average household electricity consumption is estimated to be 34,000 kWh/year and per-capita household water consumption is over 300 liters/day, both of which are the highest in the world [3]. Thus, this study will introduce Net Zero Energy House (NZEH) with a view to reduce the household electricity consumption, air pollution and the dependency on fossil fuels. "NZE-houses are regular grid-tied homes that are so air-tight, well insulated, and energy efficient that they produce as much renewable energy as they consume over the course of a year leaving the occupants with a net zero energy bill, and a carbon-free home" [4].

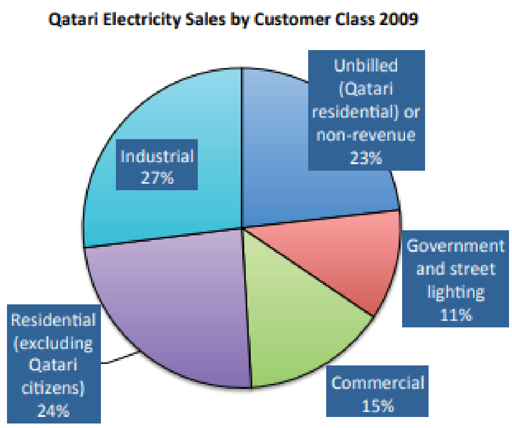


Fig. 1. Electricity consumptions by sector.

To date in Qatar, there has been is a lack of clear cost benefits research into the development of energy economic and low emission housing, in terms of both higher energy

Manuscript received February 22, 2019; revised April 28, 2019.
The authors are with Qatar University, Qatar (e-mail: samer@qu.edu.qa, farayi@qu.edu.qa, hamouda@qu.edu.qa).

doi: 10.18178/jocet.2019.7.3.507

efficiency and renewable energy technologies. There are a number of published papers on the subject of residential energy efficiency [5]-[7] however, a research gap remains in the investigation of lifecycle cost implications of increased energy efficiency and renewable energy systems at the household and country level in Qatar. Therefore, this paper will investigate the cost benefits of the utilization of NZE-housing option in Qatar as they have the potential to improve health by reducing pollution, reduce bills for residents as well as to improve the economic growth at the country level by alleviating the rising consumption of energy and health issues. A number of basic subsystems are employed in order to achieve the target set for these type of houses; namely thermal insulation, solar power generation and water heating.

II. Literature Review

In this paper, three major subsystems will be reviewed with a view of studying the introduction of a NZEH in Qatar. These subsystems are thermal insulation, solar power generation, and solar water heating.

The *first subsystem* is thermal insulation. Thermal insulation plays an essential role in minimizing heat transfer and hence achieves the goals set for Net Zero Energy buildings. When insulation is efficient, it minimizes the consumption of energy utilized to either warm up or cool down structures. Table I compares the major types of insulator materials in terms of both thermal conductivity and cost (source of information: Alibaba website).

Table I shows Rockwool and EPS are the best insulation materials in terms of both thermal conductivity and cost. However, these materials have a low long-term moisture resistance and hence they are unfavorable to be utilized for insulation in the humid weather in Qatar. Unlike Rockwool and EPS, XPS demonstrated a better long-term moisture resistance and its cost comes next to these poor moisture resistance materials. Therefore, this paper will consider XPS for the insulation of buildings in Qatar. The thermal conductivity of the commercial grade insulators ranges from 0.02 w/m*K to 0.057 w/m*K and hence this paper will utilize an average thermal conductivity of 0.03 w/m*K.

The *second subsystem* is the solar power generation system. The three major solar photovoltaic (PV) panel types are Monocrystalline, Polycrystalline and Thin-Film. These panels are discussed in terms of material, efficiency, space-efficiency and cost. The major types of PV power management systems are Grid-Tied (On-Grid), Off-Grid and Hybrid. The equipment needed for each solar power management system are shown in Fig. 2. It obvious that the On-Grid system has the lowest cost as it includes costly battery banks. Also, this system will allow the lowest possible maintenance cost as it utilizes any batteries that should be replaced after certain charging and discharging cycles. Monocrystalline is made of monocrystalline silicon (Mono-Si) and its efficiency typically ranges from 15% to 20%. The second type is Polycrystalline and it is made of multi-crystalline silicon. Its efficiency typically ranges from 13% to 16%. The third type is Thin-Film. It has three different types; namely Amorphous Silicon, Cadmium telluride and Copper indium gallium selenide. The efficiency of Thin-film panels is relatively low compared to Monocrystalline and Polycrystalline panels. The efficiency of the solar panels is affected by the quantity of sun heat falling perpendicularly on panels. The efficiency drops as the surface temperature increases by approximately 0.45% for each degree above 25 ℃. Therefore, this study will consider the Monocrystalline PV panel type along with an on-grid PV power management system that will help minimize the cost of NZEH.

TABLE I: Summary Table for All Materials Compared in This Paper

Material	Thermal conductivity (w/m*k)	Dimension of the sheet	Cost
Extruded Polystyrene (XPS)	0.02-0.034 w/m*K	Length:250 cm Width:60 cm Thickness: 8 cm	$20/piece [10] – 166.6 USD/m3
Expanded Polystyrene (EPS)	0.033-0.057	Length: 360 cm Width:120 cm Thickness: 8 cm	$8/piece [11] – 23 USD/m3
Rigid Polyurethane (PUR)	0.025	Length: 300 cm Width: 122 cm Thickness: 2.5 cm	$50/piece [12] – 546 USD/m3
Rock wool	0.035-0.038	Length: 120 cm Width: 60 cm Thickness: 15 cm	$5.86 / Piece [14] – 54 USD/m3

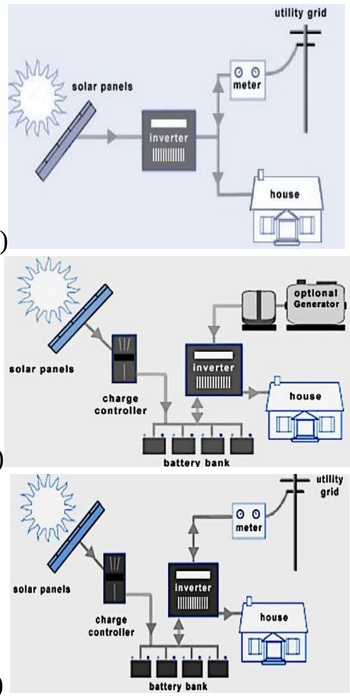
a)
b)
c)


Fig. 2. Major PV power management are (a) On-Grid system, (b) Off-Grid system and (c) Hybrid system.

TABLE II: Comparision between Evacuated Tube and Flat Plate

Criterion	Evacuated-tube collector (ETC)	Flat plate collector (FPC)
Average Efficiency	75.9%	60.04%
Cost (Alibaba website)	It is more expensive than flat plate collector. It ranges from 400 to 1250 US dollars	It is much cheaper. It ranges from 50 to 350 US dollars

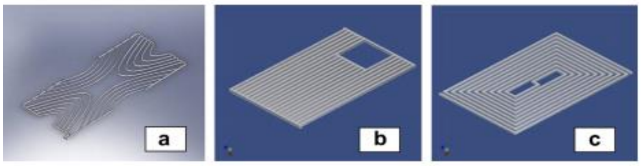


Fig. 3. (a) web-flow collector, (b) direct flow collecter and (c) direct flow collector [22].

The *third subsystem* is the solar water heating. The goal of this modality is to use cost-effective, eco-friendly, renewable energy to heat domestic water. Generally, Qatar residents use electricity to heat water which is not an eco-friendly source of power. Table II compares major solar thermal collector technologies; namely Flat Plate Collector (FPC) and Evacuated Tube Collector (ETC). As indicated, the cost to efficiency ratio suggests that the ETC is not cost-effective and that the FPC can provide efficiency at a lower cost. The pattern design of solar collectors also affects the efficiency of solar water heating systems at higher flow rates [7]. Therefore, an absorber collector pattern can help to get a higher efficiency when water mass flow rate increases. Experimentally, the efficiencies of web-flow, flat/direct-flow and spiral-flow solar collectors shown in Fig. 3 were 41.11%, 46.43% and 58.01%, respectively, at a mass flow rate of 0.011 kg/s. When the water mass flow rate was increased from 0.011 kg/s to 0.041 kg/s, the web-flow, direct-flow and spiral-flow solar collectors resulted in an increase in the thermal efficiency of 6.96%, 7.7% and 10.41%, respectively [7]. It is obvious that spiral-flow pattern has the highest efficiency among the patterns addressed.

In 2016, a study in Colombia compared the performance of stainless steel and copper collectors. The research indicated that copper collectors provide a better and more efficient way to carry the heat transfer fluid than stainless steel. However, aluminum is a good substance in the construction of fins that pick up the solar heat and conduct it to the tubes. The performances of stainless steel and copper collectors were 71.5% and 76.3%, respectively. It can be concluded that the utilization of copper tubes is best in comparison to the other materials considered.

Regarding the arrangement of the water tank and solar collectors, it is better that inlet and outlet are located on the very top and very bottom of the water tank as this results in minimal losses and stratification. It is also recommended to utilize a passive water heating system due to its cost-effectiveness and good performance [8].

Other energy generation subsystems such as micro hydroelectric power generation are not considered in this study since the majority of buildings in Qatar are either low-rise buildings or villas. This adversely affects the cost-effectiveness of hydropower systems.

In summary, three subsystems should be employed to develop NZE-Houses in Qatar; namely, thermal insulation, solar power generation, and solar water heating. All of these three subsystems should be cost-effective and are best suited to Qatar's hot and humid climate. XPS thermal insulation demonstrated a high moisture resistance along with a low thermal conductivity and cost. For solar power generation, PV Monocrystalline panels showed a superior performance over the other PV types (15% to 20%). The review of solar water heating technologies revealed that, although ETC has the highest efficiency, the spiral pattern is best in terms of cost effectiveness.

III. Cost Benefit Analysis

NZEH can be applied to both existing and new buildings. The majority of buildings in Qatar are of villa type (standalone villa or a villa complex). They have an average area of 400 square meter per floor with a total number of two floors and roof. Thus, this study will focus on existing villa type residential buildings. However, the same concept can still be applied to all building types in Qatar. In this section, the major systems relating to energy supply and consumptions will be studied and then compared with a view identifying the cost benefit of the implementation of each system.

A. Thermally Insulated Versus Non-insulated Insulated Houses

The temperature in Qatar is high throughout the year which leads to a significant increase in the consumption of electricity due to the heavy utilization of air conditioners. A typical house in Qatar is built from "double block" brick with no thermal insulation and with single glazed windows. Thus, this section aims to investigate the cost benefit of introducing thermal insulation to villas. This will be carried out by calculating the difference between the electricity consumption before and after the introduction of a thermal insulation system. This section shows the cooling load calculations for a typical villa before and after the implementation of thermal insulation based on a comfortable indoor temperature of 22 degrees Celsius. The calculations were based on the average monthly temperature in Qatar and the dimensions depicted in Table III.

TABLE III: Dimensions of Simultaneously Utilized Rooms in a Typical Vlla in Qatar (Based on a Survery Conducted by Qatar University Students

	Number	Walls dimensions (L*W*H)	ceiling dimensions (L*W)	Average number of hours (hr)
First floor and roof				
Room	4	5mx5mx3m	5mx5m	8
Living room	2	5mx5mx3m	5mx5m	16
Kitchen	1	5mx5mx3m	5mx5m	8

Cooling load calculation assumptions:

The comfortable temperature inside the house should not exceed 22 degrees Celsius.

1) One standard shaded double-glazed window per room with a thermal conductivity equal to an insulated wall.
2) AC Energy Efficient Ratio (EER) is assumed to be 10.
3) 8 persons are living in villa.
4) A total electrical equipment power of 48 KWhr/day was calculated based on average daily usage.
5) An average of 46 bulbs; 12 watts each, working for 8 hours a day.

In the calculation of cooling loads, four types of heat transfer were simplified and taken into consideration (Equation (1)) [9]. These equations are explained in sections a, b, c and d.

$$Q_{CL} = Q_{people} + Q_{equipment} + Q_{light} + q_{heat\ transfer} \quad (1)$$

where

Q_{CL}: Total cooling load (W)

Q_{people}: Heat released by people (W)

Q_{people}: Heat released by equipment (W)

$q_{heat\ transfer}$: Heat transfer through the walls, roofs and windows (W)

Table IV displays and summarizes the monthly electrical consumptions of a typical non-insulated house versus a thermally insulated house. The results were in favor of the thermal insulation option with an average monthly saving of 1190.75 QAR and an annual saving of 14,289 QAR per house.

TABLE IV. SUMMARY OF THE IMPROVED MONTHLY COOLING LOADS AND COSTS

Month	**Non-insulated rooms**		**Insulated rooms**		**Monthly saving**
	KWh/month	Cost (QAR)	KWh/month	Cost (QAR)	(QAR)
Jan	0	0	0	0	0
Feb	0	0	0	0	0
March	1332	199.8	840	126	73.8
April	2226	333.9	947	142.05	191.85
May	3567	535.05	1107	166.05	369
June	5917	887.55	1388	208.2	679.35
July	5917	887.55	1388	208.2	679.35
August	4238	635.7	1187	178.05	457.65
Sept	3791	568.65	1134	170.1	398.55
Oct	2785	417.75	1014	152.1	265.65
Nov	1891	283.65	907	136.05	147.6
Dec	997	149.55	800	120	29.55
	32,661		***10,712***		
Annual bill(QR)		***4899.2***		***1606.8***	***3292.35***

TABLE V: SUMMARY OF IRRADIANCE AND POWER GENERATION USING PV PANELS OVER A YEAR [9]

Month	**Irradiance (W/m2/day)**	**PV daily power generation (W/ panel)**	**PV Monthly power generation (W/month/panel)**
Jan	3749	544.8	16342.6
Feb	4366	634.4	19032.2
Mar	4893	711.0	21329.5
Apr	5699	828.1	24843.0
May	6204	901.5	27044.4
Jun	6463	939.1	28173.4
Jul	6051	879.2	26377.4
Aug	5847	849.6	25488.2
Sep	5458	793.1	23792.4
Oct	4817	699.9	20998.2
Nov	4149	602.9	18086.3
Dec	3498	508.3	15248.4
	Total per year:	***266,756***	

The total cost of the insulation of a typical existing house is 50,278 QR. The cost was calculated based on the costs of Gypsum boards (15 QR/m2), Aluminum sections (5 QR/m2), XPS insulation (48.7 QR/m2) and installation cost (7,000 QR/house) in Qatar. A cost-benefit analysis was conducted considering that house owners will request local banks to fund their thermal insulation with an annual interest rate of 4% over a time period of 15 years. House owners should pay 4,522 QR/year over a time period of 15 years. Unfortunately, these results show that the insulation of villas has no cost benefits for homeowners in Qatar. This can be referred to the low electricity tariff in (0.15 QAR/KWhr) as well as the high cost of insulating existing villas. This figure might significantly change if the insulation was planned before the construction of a building (high star rate building) as the insulation costs will be significantly lower and the insulation performance will be higher.

B. Solar PV Electricity vs Grid Electricity

This section will investigate the cost benefit of the utilization of a Solar PV System. Based on power consumption, the number of panels was calculated for both the existing and proposed houses (without insulation and with insulation). The following equation is used for the calculations of energy over a year.

$$E = A * r * H * PR \quad (2)$$

where

E = Energy (kWh)

A = Solar panel(s) Area ($1.623\ m^2$ per panel)

r = solar panel yield or efficiency (ranges from 12% to 20%, lowest 12 %)

H = Average solar radiation/Irradiance on tilted panels (kWh/m^2)

PR = Performance ratio (ranges from 0.5 to 0.9, default value = 0.75)

The annual power consumption of a non-insulated house is 32,661 KWh/year. The number of PV panels was calculated based on the monthly power generated by monocrystalline panels. Table V shows the power generation of PV panels in month of the year [10]. The number of panels needed to supply the house with the electricity required was determined by dividing the total annual power consumption of the villa by the power generation of a single solar panel in a year (266,756 kWhr). The total numbers of PV panels required is depicted in Table VI.

TABLE VI: NUMBER OF PV PANELS REQUIRED FOR A TYPICAL VILLA IN QATAR

	Non-insulated villa
Power Consumption (kW/year)	32,661
Number of PV Panels	$\frac{32661}{266.756} = 123$

The number of panels is 123 PV panels. The total cost of a standard grid-tied solar system is 64,000 QR (0.4 USD per PV-panel Watt). A cost-benefit analysis was conducted considering that house owners will request local banks to fund their PC solar system with an annual interest rate of 4%

over a time period of 20 years (standard life time of a PV solar system). House owners should pay 4,709 QR/year over a time period of 20 years, allowing them to save about 190 QAR a year (=4899-4709 QAR), with a total saving of 3,800 QAR over a time period of 20 years.

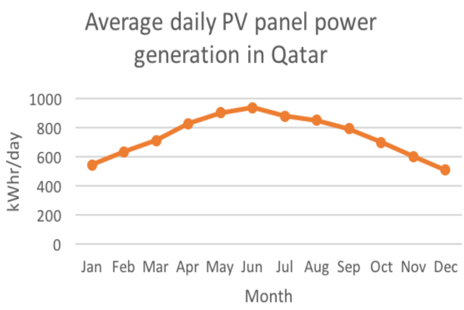


Fig. 4. Average daily standard PV panel power generation in Qatar.

TABLE VII: ANNUAL POWER CONSUMPTIONS OF ELECTRIC AND SOLAR WATER HEATERS

	Electric Water heater (100 L / 85 min)	Solar water heater (300 L /day)	Saving/year (QR)
Price (QR)	1550	4000	
Average Life time (years)	10	10	
Power consumption	2 kWhr	0 (passive system)	
Power consumption cost per year (300 L/day) (QR)	492	0	492
Power consumption cost over the life time of the devive (QR)	4920	0	4920

TABLE VIII: COST SAVING COMPARISON BETWEEN A TYPICAL, THERMALLY INSULATED AND NET ZERO ENERGY HOUSE (VILLA) IN QATAR

Improvement	Annual Installment (QR)	Saving per Annum (QR)	System Lifetime (year)	Total Saving over Lifetime (QR)
Insulation of existing villas	4,522	NA	15	NA
Solar Power generation for non-insulated villas	4,704	109	20	3800
Solar water heating	302	190	10	1900
NZEH (all systems)		299		

C. Solar Water Heater vs Electric Heater:

This section will investigate the cost benefit of utilizing a commercial solar water heater. However, the literature suggests the utilization of a spiral solar water heater manufactured from copper tubes in order to minimize loses. As this paper focuses on the utilization of existing commercial systems, flat solar collectors will be considered in this study.

The price and running/operation cost of commercial electrical and solar water heaters are compared in Table VII. An electric solar water heater from HAIER , model AS2712, costs about 4000 QAR , can last for 10 years, and can provide up to 300 L/day of hot water. A platinum electric water heater, costs about 1550 QR, has a power consumption of 2kWhr and heats 100 Liters of water in 85 minutes on average.

A cost-benefit analysis was conducted considering that house owners will request local banks to fund their solar water heating systems with an interest rate of 4% over a time period of 10 years (life time of a standard solar water heater system). For a loan of 2450 QR (4000 QR- 1550 QR), house owners will be requested to pay 302 QR per year for 10 years. The total saving will be about 190 QR per year if both heaters do not require maintenance over their lifetime.

D. Cost Saving Comparison between a Typical, Improved and Net Zero Energy House in Qatar

Table VIII shows that the construction of NZEH will yield an annual saving of 299 QR per each residential villa. Doha's existing housing stock in 2014 was approximately 129,000 units comprised of apartments being 76%, with the remaining 24% being villas. In 2018, the number of residential units is expected to reach 293,000 units. If the same apartment to villa ratio is maintained, there will be 70,320 residential villas in Qatar. Hence, the total saving at the country level will reach approximately 21 million QAR. Fig.5. graphically presents the contribution of each of subsystems in the total saving of a typical NZEH in Qatar.

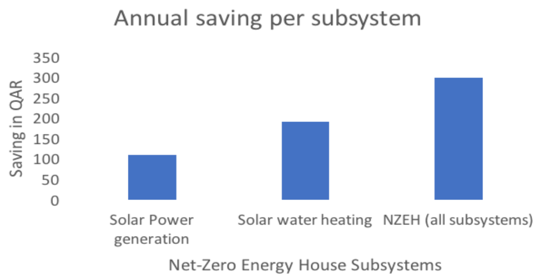


Fig. 5. Annual saving per NEZH subsystem.

IV. CONCLUSION

Fossil fuel is a high cost and non-sustainable source of energy. Fossil fuels cause global warming, which in turn causes health risks and environmental challenges. Thus, this paper investigated the introduction of Net Zero Energy Housing (NZEH) in Qatar in order to overcome the drawbacks of fossil fuel as well as to determine whether the benefits outweigh the implementation cost. Based on the results of the cost benefit analysis study of a typical, improved net zero energy villa in Qatar, the impelemtation of NZEH on existing villas will yield an annual saving of 299 QAR. A total amount of 21 million QAR could be saved if NZE housing is implemented in all villas in Qatar (70,320 units).

If solar power generation and solar water heating in current housing and future builds is implemented, Qatar will reduce its annual fossil energy consumption. This will help reduce both pollution and the budget share spent on energy generation and healthcare. Villas are of the smallest building types in Qatar and if the initiative of NZEH is implemented to all types of residential and commercial units, Qatar would save a multiple of this amount with a significant reduction in related health problems as the air would be cleaner and health risks, in the form of asthma and upper respiratory diseases, would decrease drastically. This study limits itself to typical villas in Qatar and the costs of energy and materials in 2018. This work can be extended to study the cost benefits of implementing NZEH to all residential and commercial buildings in Qatar as well as to calculate the indirect saving from the implementation of such a system.

REFERENCES

[1] W. Organization, *Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease*, 2016.

[2] Qatar's healthcare expenditure may rise to $6.6bn in 2022: Alpen Capital. *GULF TIME*. [Online]. Available: http://www.gulf-times.com/story/586743/Qatar-s-healthcare-expenditure-may-rise-to-6-6bn-i

[3] A. Meier, M. Darwish, and S. Sabeeh, "Complexities of saving energy in Qatar," *ECEEE 2013 SUMMER STUDY*, pp. 41-46, 2013.

[4] Zero Energy Homes. [Online]. Available: https://zeroenergyproject.org/buy/zero-energy-homes/

[5] Thermal insulation materials technical characteristics and selection criteria, Fisheries and Aquaculture Department.

[6] T. Pakkala and J. Lahdensivu, "Long-term water absorption tests for frost insulation materials taking into account frost attack," *Case Studies in Construction Materials*, vol. 1, pp. 40-45, 2004.

[7] Y. Boles, Thermodynamics: An Engineering Approach 8th Edition, *McGraw Hill Comp*, P F 1989 Heat Exchanger Design, 2nd ed., New York, 2014.

[8] Passive solar water heater advanatages and benefits. [Online]. Available: https://www.hot-water-heaters-reviews.com/passive-solar-water-heater.html

[9] Activair William Tombling. (2002). [Online]. Available: http://www.tombling.com/cooling/heat-load-calculations.htm

[10] P. Rao and M. Al-Kuwari, "Assessment of solar and wind energy potential in Qatar," in *Proc. Qatar-Japan Environment Symposium (QP-JCCP)*, 2013.

Samer Gowid is a teacher assistant at the Mechanical and Industrial Engineering Department, Qatar University. His research focuses on automation, control, condition based maintenance, fault diagnosis, artificial intelligence, reliability and renewable energy.

Farayi Musharavati is an associate professor at the Mechanical and Industrial Engineering Department, Qatar University. His research focuses on advanced manufacturing systems & optimization, genetic algorithms, neural networks, simulated annealing, supply chain management and renewable energy.

Abdelmajid Hamouda is a professor and the acting dean of the College of Engineering at Qatar University. He is an active member of a number of international scientific committees and professional societies. He has several Malaysian and US patents, and has edited several conference proceedings. He set in the editorial board of a number of international journals. His research focuses on advanced materials, lean management, artificial intelligence and process optimization as well as engineering education.