The Economics of Using Solar Energy: School Buildings in Saudi Arabia as a Case Study

Faris A. Alfaraidy, Hassan A. Sulieman

Department of Civil Engineering, Northern Border University, P.O. Box 1321, Arar 91431, Northern Border – KSA

***Abstract—As* a result of increasing population and building of new schools in Saudi Arabia, the demand for electricity is growing rapidly. In this context, the utilization of renewable energy resources such as solar energy appears to goal since it is abundant and holds huge ecological and economic promise. This study aims to provide a new entrance in school buildings' design and construction by studying the current situation of energy consumption, the possibility of using solar cells, and the economics of its exploitation in school buildings. Interviews were conducted in school buildings at different levels in Arar city as a case study to collect data on energy consumption. Furthermore, a base case school building was selected for studying detailed energy consumption, and then, photovoltaic (PV) energy was proposed to use the on-grid system in accordance with governmental regulations. The study concluded that the use of PV energy in school buildings is economically feasible in addition to that more incentive from the government is needed for wide penetration use in Kingdom Saudi Arabia.**

***Index* Terms—Arar, photovoltaic energy, Renewable energy, School building design.**

I. Introduction

School buildings are one of the most important public facilities in our daily social life; it is the main source of education and culture. The growing population in Saudi Arabia leads to the growing demand for new schools. However, it is a rise in the country's school buildings and electricity demands. Therefore, Arar city has the same stress demands. High-energy consumption is one of the most serious problems in the world today. Recently, this topic has encompassed not only economic but also ecological and social importance. School buildings are typical structures, and their optimal energy consumption is a matter of public interest. Renewable energy can be a cost-effective and environmentally friendly in the way to generate energy. Installing a renewable energy project should be carried out in conjunction with energy saving and efficiency measures around buildings. The aim of this study is to assess the current situation of energy consumption in school buildings, to study the possibility of using solar cells in the school buildings, and to study the economics of energy exploitation within school buildings in Arar city, KSA.

ARO-The Scientific Journal of Koya University
Volume VII, No.1(2019), Article ID: ARO.10461, 6 pages
DOI: 10.14500/aro.10461
Received 15 October 2018; Accepted 13 March 2019
Regular research paper: Published 01 May 2019
Corresponding author's e-mail: hassan.abdualrahman@nbu.edu.sa

II. Literature Review

Vast secondary data as a literature review from different sources pertaining to solar energy system were investigated. Brief summary for utilizing solar photovoltaic (PV) as a source of energy is also presented in this study.

Rising energy demand in school buildings can be reduced by improving the efficiency of energy use. There are various methods used in benchmarking energy efficiency in buildings (Mukwaya and Lating, 2014; Harputlugil, 2017). The electric energy consumption may be reduced up to 35.3% and also air condition unit efficiency can also be increased by 31% using some energy-efficient methods which will be beneficial for schools in the management of electric usage and reduce the electric bill by the considerable amount of money (Hani, 2013). Furthermore, 43% reductions in peak cooling load can be achieved by improving envelope insulation, space ventilation, shading, glazing, artificial lighting variation, and evaporative cooling of the structure (Zurigat et al., 2003). In school buildings' microclimate conditions of the city, the location should be considered, for example, in hot regions a need for natural ventilation technique to obtain the thermal comfort conditions. However, in moderate climate regions, the application of the cross natural ventilation technique is necessary to obtain thermal comfort conditions which lead to an efficient energy-saving procedure (Nazhatulzalkis et al., 2017; van Hoof et al., 2010; de Dear and Bragerb, 2002; Givoni, 1992). Saudi Arabia aims to reduce carbon dioxide (CO_2) emissions from 28 to 26 billion standard cubic feet per day by the end of the year 2020 (Saudi

 http://dx.doi.org/10.14500/aro.10461

National Transformation Program, 2020). It is clear that climate change is a threat that can only be tackled through the combined efforts of the international community, so the solution must be based on diverse clean, renewable, and environmentally sound sources of energy. Furthermore, Gregory Kats (2006) reported that green schools are less 2% costs than of conventional schools. Besides that, solar water heating can play an economically viable role toward energy security and greenhouse gas emission mitigation (Hafiz and Fahad, 2016).

Renewable energy most importantly, the solar energy source is not depleted, and it is distributed over a wide geographical area. At the end of 2012, the global renewable power capacity was exceeded 1500 GW, and it is expected that renewable energy can cover almost 13% of global energy demand by the year 2020 (Pazheri et al., 2014).

The application of solar energy in Saudi Arabia has been growing since 1960. Systematic major research and development of solar energy technologies were started by King Abdul-Aziz City for Science and Technology (KACST) in 1977. The Saudi Solar Radiation Atlas project was initiated in 1994 as a joint research and development project between the KACST Energy Research Institute and the US National Renewable Energy Laboratory (Said et al., 2008; Pazheri, 2014). Saudi Arabia started a "solar village" program to supply energy for three rural villages using solar power (Pazheri et al., 2011). Saudi Arabia sets a target to install about 54 GW of renewable power capacity by the year 2032, which represents 20% of total electricity production in Saudi Arabia sets a target to install about 54 GW of renewable power capacity by the year 2032, which represents 20% of total electricity production in KSA, and almost 41 GW of the targeted renewable power capacities may be met by solar power (REN21, 2013). The average annual rate of solar radiation is between 100 to 200 W/m2 in Europe, North America, Latin American, and Western Asia, whereas in the Arab countries, including the Gulf Cooperation Council countries, it reaches to about 250 W/m2, so Saudi Arabia is one of the most potentially productive regions and PV technologies may perform well at any Saudi location (Pazheri, 2012, Zell et al., 2015).

III. The Case Study

Arar city is located in the north side of Saudi Arabia, in the heart of a vast rocky limestone plain. It lies about 1100 km northwest of Riyadh, about 60 km from the Iraqi border, and 1451.3 km away from Jeddah town. The climate of Arar is described as a hot desert with annual average temperature varies from 13.75°C to 7.375°C as shown in Table I. Winds generally blow from the east or west, rarely from the south. It is noteworthy that the rainfall in the region has declined gradually over recent years. It is also noted that snow is not uncommon, falling on average every 2–3 years. A PV system is proposed to be connected to operate in parallel with the National Electric Grid.

IV. Materials and Methods

A literature review was cited for PV as a source of energy in different areas and, especially, in school buildings. Previous studies in solar energy and its economy were also cited as explained above. A total of 12 interviews were conducted at the Arar city schools, six schools were girls' schools, whereas the other six schools were boys' schools. On the girls' and boys' schools' side, two schools were elementary schools, two schools were intermediate schools, and two schools were secondary schools. The main reason for this kind of selection was to get a picture and understand the use and need of energy in different school levels in Arar city. In this study, qualitative and quantitative methods were applied to generate valid and reliable data. In particular, an in-depth structured interview sheet was applied in the whole process and the Arabic language was used throughout to generate the data. The data were collected through the interview and direct observation. These data were focused on the historical background of the school buildings aiming energy consumption. A typical school building was selected in Arar city. All the building details were used as an input for later examinations of software and simulation. The details include building drawings as plans, elevations, and perspectives. In addition, it includes the building structure details alongside with most common external walls and thermal insulations. The building case study is representative of a major school building style in the city. It is considered a low rise building which comprises mainly from three floors, with 1200 m^2 each floor area. The roof has a skylight gross area of 200 m^2. All elements which affect heat flow in the space are described including walls, windows, doors, roofs, skylights, floors, occupants, lighting, electrical equipment, miscellaneous heat sources, infiltration, and partitions as shown in school plan in Fig. 1. The government regulates

TABLE I
Annual average temperature

Parameter	Annual average temperature, °C
Mean dry bulb temperature	13.75
Mean coincident wet bulb temperature	7.375

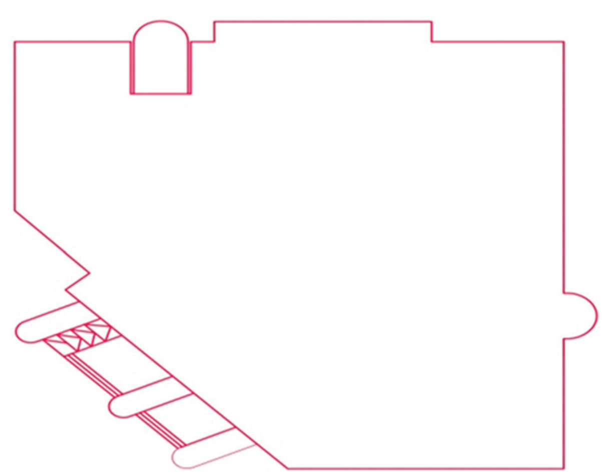

Fig. 1. School building layout.

that the use of PV system in the grid should be in the zone of 15% of the transformer capacity, and hence, the use of 150 kW is proposed to be used in the base case school building.

V. Results and Discussion

A. Conventional School Interview

The interview sheet was designed to explore the existing data of energy consumption of different conventional school types in Arar city. The sheet consists of two parts, the first part concentrated on general data such as school name, location, number of students, number of administration, number of teachers, and volume of school, and hence, the second part concentrated in various type sources of energy consumption such as lighting and air condition systems. This sheet gave results that the main source of energy consumption is air condition, lighting, and other appliances such as computers. Furthermore, the main type of air conditioning type used is window type of two-tone (24000 British Thermal Unit, BTU) and the main lighting type is fluorescent, whereas the window materials are the aluminum type with single glass layer and the material of the door is a steel type. Furthermore, Al interviewed school buildings are heat insulated but not well insulated. Then, the energy consumption varies from 36,000 kWh in small school buildings to 155,000 kWh in large school buildings and, in average, varies from 6,250 kWh, 81,500 kWh, and 116,500 kWh in intermediate, secondary, and primary schools, respectively, as presented in Table II.

B. Base Case School Building

The base case school building is an intermediate school located in Arar city 30.90 N and 43.48 W; it is front elevation facing southwest and has a rectangular shape with one corner cut a triangle. The building has three floors each of 3.5 m height of overall height 10.5 m. The building floor dimension is 41 × 37 m and the whole building is occupied by 500 students in addition to teaching and administrative staff. The external wall area of each floor is approximately 1625 m^2 structured as 25-mm thickness external marble particle plaster, hollow concrete blocks with 50-mm extruded polystyrene, and 25-mm thickness internal cement sand plaster. The floor structure is 100-mm thickness slab on grade and roof structure is composed of 10-mm ceramic tiles, 20-mm thickness cement sand mortar, 50-mm thickness aggregate sand, 50-mm extruded polystyrene, 200-mm thickness horde slab, and 25-mm thickness internal roof plaster. The type of windows is aluminum frame with 6-mm thickness unclear glass, 12-mm air gap, and 6-mm thickness glass and without thermal breaks with no curtains. The general characteristics of power density in the building are described in Table III.

Applying Hourly Analysis Program version 4.99 (HAP 4.99) software for the above characteristics, it is found that the absorptivity and overall U-Value for wall and roof are listed in Table IV.

The base case building is characterized as a low-rise building which falls in zone 2 (SBC601), The base case building is characterized as a low-rise building which falls in zone 2 (SBC601), and hence its heat transfer coefficient is listed in Table V.

Using ASHRAE standards for the above characteristics, it is found that the heat transfer coefficient for wall, skylight, windows, doors, and roof were listed in Table VI.

The actual heat transfer coefficients compared with the SBC601 code are illustrated in Table VII.

To predict the school energy consumption, some assumptions were drawn as illustrated in Table VIII.

Using the HVAC assumption that illustrated in Table VIII, the consumption of energy in the school building was set in Table IX.

C. Design of Solar PV Plant

A solar PV system was planned to be installed at intermediate school. The technical specifications of the PV system planned to be installed are included in Table X.

TABLE II
School buildings' average energy consumption

Energy consumption	School type		
Average	Primary	Intermediate	Secondary
Energy (kWh)	116,500	61,250	81,500

TABLE III
Summary of power density in base case

Characteristic	Description of base case school building
Solar absorbance	0.55 external walls, MC 0.35 for the roof, LC
Lighting power density	3 W/m^2 ground floor 2 W/m^2 1st floor 2 W/m^2 2nd floor
Equipment power density	2.0 kW ground floor 1.0 kW 1st floor 1.0 kW 2nd floor
Infiltration	0.5 ACH
HVAC System type	2 tons in classrooms and 25 tons central system
Thermostat setting	24°C for cooling 20°C for heating
Coefficient of performance	2.87
Weather file	IWEC2

MC: Medium color, LC: Light color, ACH: Air volume change per hour, IWEC2: Internal weather for energy calculations, V2.0.

TABLE IV
Overall u-value and absorptivity

Wall	The wall outside surface color	Medium external color
	Absorptivity	0.675
	Overall U-value	1.21 W/(m^2.°C)
Roof	The wall outside surface color	Light external color
	Absorptivity	0.675
	Overall U-value	0.764

TABLE V
The base case building heat transfer coefficient

Component	Area, m^2	Heat transfer coefficient (W/m^2.°C)
Wall	1625	1.21
Roof	1000	0.764
Skylight	196	6.975
Windows	158	4.082
Doors (metal)	10	5.93

 http://dx.doi.org/10.14500/aro.10461

TABLE VI
The base case building energy tefficient requirement

Wall and roof: Overall heat transfer coefficient (W/m².°C)	Wall: 0.387 For zone 2 Roof: 0.238 For zone 2
Door overall heat transfer coefficient (W/m². °C)	2.839
Window overall heat transfer coefficient (W/m². °C)	2.668 for all zones
Solar heat gain coefficient, SHGC	For all zones≥0.25
SRI for envelope color	SRI≥50
Water absorption for insulation materials	≤0.3%
Continuous insulation	Insulation shall be continuous across all structural members without thermal bridges other than fasteners and service openings.
Ventilation	qv=0.05*A+3.5*Noc Where, qv=Ventilation required flow rate, L/s, A=Conditioned floor area m² and, Noc=Number of occupants
Infiltration in fenestration	Fenestration and skylights should not exceed 1.5 L/s/m²
Infiltration in doors	a. Air leakage for sliding doors should not exceed 1.5 L/s/m² b. Air leakage for swinging doors should not exceed 2.5 L/s/m²
Vertical fenestration area	≤25% of the air-conditioned area for all zones
Skylight fenestration area	≤3% of the gross roof area for all zones
Interior lighting power allowance	≤10 W/m² for all zones
Energy efficiency ratio, EER	EER ≥11, for cooling capacities 12,000–240,000BTU/h, and EER≥10 for cooling capacities ≥240000 BTU/h.

SRI: Surface reflectance index

TABLE VII
Annual heat transfer coefficient compared to SBC601 requirement

Component	Area, (m²)	Building heat transfer coefficient (W/m².°C)	SBC601 heat transfer coefficient (W/m².°C)
Wall	1625	1.21	0.387
Roof	1004	0.764	0.238
Skylight	196	6.975	2.668
Windows	158	4.082	2.668
Doors	10	5.93	2.839

TABLE VIII
Assumptions of HVAC consumption (kWh)

Assumptions	Parameters
Energy efficiency ratio, EER (BTU/h)/kW	10
Number of months per semester	4
Number of semesters	2
Weekends	Friday and Saturday
HVAC running hours per day	3–7

HVAC

D. Economic Evaluation of PV System

The economics of PV are related to their efficiency as well as to their optics. The cost of PV materials is often expressed on a per-unit-area basis, but the modules are often sold based on cost per watt that potentially generated under peak solar illumination conditions. A 150 kW solar PV system is installed of 607,666.50 SAR total cost, that is, 4.051 SAR/watt. The electricity bill is decreased by the solar-generated energy as illustrated in Table XI.

TABLE IX
The school energy average monthly consumption

Item	Power, kW	Consumption, kWh/month
HVAC	217	8,554
Lighting and other appliances	65.2	3,459
Average predicted electrical consumption	282.7	12,013

HVAC

TABLE X
Technical specifications of PV system

Description	Measurement
Present connected load	282.70 kW
Installed PV system	151.20 kW
Number. of panels	577
Peak power capacity per panel	260 Watt
Solar PV module capital cost	607,666.50 SAR
Module efficiency	17%
Lifetime	25 years

PV: Present value

Assumptions:

1. Price of electricity from grid 0.32 SAR/kWh.
2. The electric load of the building (282.7 kW) exceeds the system size (150 kW).

The prospective owner of a solar system may have many reasons for purchase. They may wish to do their part for the investment or to lead others by example. However, one criterion that is likely to be high on the list of most individuals is the financial benefit of the investment. Several economic criteria have been proposed to do this job. Some useful criteria used for economic analysis of PV projects are reviewed: Payback period and net present value (NPV) methods.

E. Payback Period

Payback period is simply the number of years it takes to recoup an investment, and it can be calculated using equation (1) as shown below:

Payback period = investment/income or savings (1)

From the table, the investment is calculated as 720,000 SAR and the income or savings annually is 73,584 SAR, then

Payback period = 607,666.50/73,584 = 8.26 years.

F. NPV

The most broadly used economic evaluation tool for capital projects, for example, a solar system is the NPV, since it provides the actual value of completing a project. This is, however, more detail and complex than the payback strategy; in addition, it gives the best results since it considers the time value of money. NPV can be calculated using the formula in equation (2).

$$NPV = \sum_{t=0}^{n} \frac{C_i}{(1+r)^t} \quad (2)$$

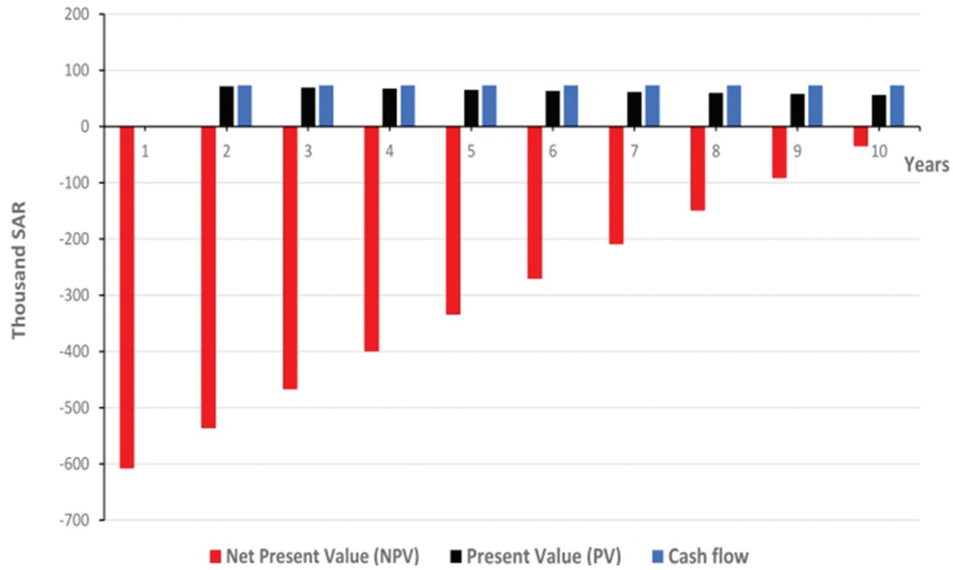

Fig. 2: Net present value calculations.

TABLE XI
Monthly savings after PV installation

Parameter	Amount/Year in SAR
Annual electricity bill before PV	138,681.3
Annual electricity bill after PV	39,480.3
Net savings	99,201

PV: Present value

TABLE XII
Net present value calculation

Year	Cash flow	Discount rate	PV	NPV
0		1.000000000		(607,666.50)
1	73584	0.970873786	71440.7767	(536,225.70)
2	73584	0.942595909	69359.9774	(466,865.70)
3	73584	0.915141659	67339.7839	(399,525.90)
4	73584	0.888487048	65378.4309	(334,147.51)
5	73584	0.862608784	63474.2048	(270,673.30)
6	73584	0.837484257	61625.4415	(209,047.86)
7	73584	0.813091511	59830.5258	(149,217.34)
8	73584	0.789409234	58087.8891	(091,129.45)
9	73584	0.766416732	56396.0088	(034,733.44)
10	73584	0.744093915	54753.4066	020,109.97

PV: Present value, NPV: Net present value

Where,
S = Initial cost of the system,
t = Time for cash flow,
N = The total time of the project,
R = The discount rate, and C_i = the net cash flow at time t.

Then, S = 607,666.50 SAR and the NPV are calculated in Table XII and Fig. 2, assuming that the constant cash flow with a fixed tariff of power during the coming years in addition to the constant discount rate of 3%.

VI. Conclusion

The objective of this paper is to understand the economic impact of increasing deployment of PV energy at significant scale in the KSA. The economics of solar PV can be a challenging problem to get a handle on; however, the costs of solar cells are expected to continue to decline. The value of solar PV installation is expected to be beneficial when solar PV may become economically feasible. This analysis was carried out for Arar city school buildings when PV system proposed to be on grid connection. The expected value of solar will continue to be dominated by radiation and the cost of electricity in the KSA. This type of quantification of financial value for solar cells and related technologies should play a vital role in the decisions made by the system user. The regions where solar PV shows economic feasibility are expanding and this analysis predicts that there is an ability to host a profitable PV installation. Finally, it is recommended that, for this system to be widely used toward sustainable energy systems, innovation and more government incentives should be made so as to increase the system economic feasibility.

Acknowledgment

The authors gratefully acknowledge the approval and the support of this research study by the grant No. ENG-20171-7-F-7150 from the Deanship of Scientific Research at Northern Border University, Arar, K.S.A.

References

de Dear, R.J. and Bragerb, G.S., 2002. Thermal comfort in naturally ventilated buildings: Revisions to ASHRAE standard 55. *Energy and Building*, 34(6), pp.549-561.

Givoni, B., 1992. Comfort climate analysis and building design guidelines. *Energy and Building*, 11(1), pp.11-23.

Hafiz, M.A. and Fahad, A.A.,2016. Optimum selection of solar water heating (SWH) systems based on their comparative techno-economic feasibility study for the domestic sector of Saudi Arabia. *Renewable and Sustainable Energy Reviews*, 62, pp.336-349.

http://dx.doi.org/10.14500/aro.10461

Hani, H.S., 2013. Auditing and analysis of energy consumption of an educational building in a hot and humid area. *Energy Conversion and Management*, 66, pp.143-152.

Harputlugil, T., 2017. *Energy Efficient Building Design Development: A Retrospective Approach*. International Symposium on Energy Efficiency in Buildings, Ankara, Turkey, pp.296-303.

Kats, G., 2006. *Greening America's Schools: Costs and benefits*. A Capital E Report. Available from: https://www.usgbc.org/drupal/legacy/usgbc/docs/Archive/General/Docs2908.pdf.

Mukwaya, N.I. and Lating, P.O., 2014. *Benchmarking Energy Efficiency of Commercial Office Buildings in Kampala*. 2nd. International Conference on Advances in Engineering Sciences and Applied Mathematics, Istanbul, Turkey.

Nazhatulzalkis, J., Nurul, I.M., Mohd, F.K. and Suriani, N.A.W., 2015. Thermal comfort of a residential building in Malaysia at different micro-climates. *Procedia Social and Behavioral Sciences*, 170, pp.613-623.

Pazheri, F.R., 2014. Solar power potential in Saudi Arabia. *International Journal of Engineering Research and Applications*, 4(9), pp.171-174.

Pazheri, F.R., Malik, N.H., Al-Arainy, A.A., Essam, A.A., Ahmed, I. and Safoora, O.K., 2011. *Smart Grid Can make Saudi Arabia Megawatt Exporter*. IEEE Asia-Pacific Power and Energy Engineering Conference (APPEEC), Wuhan, China, pp.1-4.

Pazheri, F.R., Malik, N.H., Othman, M.F. and Babar, M., 2012. Optimum power dispatch problems: An overview. *International Journal of Engineering Inventions*, 1(6), pp.49-54.

Pazheri, F.R., Othman, M.F., Malik, N.H., Al-Arainy, A.A. and Khan, Y., 2014. *Optimum Power Dispatch Management in Presence of Renewable Energy and Energy Storage*. Energy and Power, Science and Technology Publishing Inc., Available from: https://www.researchgate.net/publication/264971511.

REN21, 2013. *MENA Renewables Status Report*. Renewable Energy Policy Network for the 21st Century.

Said, S.A.M., El-Amin, I.M. and Al-Shehri, A.M., 2008. Renewable Energy Potentials in Saudi Arabia (Lecture). Workshop. American university of Beirut, Faculty of Engineering and Architecture, Beirut.

van Hoof, J., Mazej, M. and Hensen, J.L.M., 2010. Thermal comfort: Research and practice. *Frontiers in Bioscience*, 15, pp.765-788.

Zell, E., Gasim, S., Wilcox, S., Katamoura, S., Stoffel, T., Engel-Coxa, J. and AlSubie, M., 2015. Assessment of solar radiation resources in Saudi Arabia. *Energy and Building*, 119(1), pp.422-438.

Zurigat, Y.H., Al-Hinai, H., Jubran, B.A. and Al-Masoudi, Y.S., 2003. Energy efficient building strategies for school buildings in Oman. *International Journal of Energy Research*, 27(3), pp.241-253.