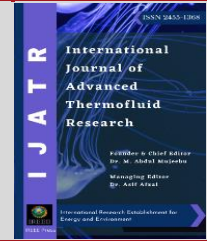




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## A Review of Solar Energy Exploration and Utilization in Saudi Buildings

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### Abstract

The building construction sector in the Kingdom of Saudi Arabia is the largest and fastest in the Middle East. It is estimated that 2.32 million new homes are to be built by 2020 in order to meet the demand of growing population. Despite possessing ample potential, the realization of solar energy technology in Saudi Buildings has a long way to go. This article sheds light into the progress in exploring the utilization of solar energy in the Saudi Arabian building sector. Starting with a background of energy scenario, the article covers the policy-level measures and research and development activities reported so far. This review reveals the Kingdom has wide scope for further developments to ensure that all the viable state-of-the-art solar technologies are implemented in buildings.

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### 1. Introduction

The rapid growth of global energy use has raised concerns over problems of energy supply, energy sustainability and exhaustion of energy resources (Iwaro & Mwashia 2010). It also contributes to pollution, environmental deterioration and global greenhouse emissions (Dincer 1998). Renewable energy (RE) options, including solar power are becoming increasingly viable alternatives to conventional sources of energy such as oil, coal and natural gas (Taleb & Al-Saleh 2010). The Gulf Cooperative Council (GCC) countries are major oil and natural gas producing countries; they fall in the top 25 countries of CO<sub>2</sub> emissions per capita and act crucially in blocking international climate change negotiations. As the domestic electricity and hence the oil consumption in the Kingdom of Saudi Arabia (KSA) is increasing at a very alarming rate compared to the other countries in the world, it is important to resort to urgent energy conservation measures (ECMs) in various sectors in the Kingdom (Jomoah et al. 2013). In the past few years, the

contribution of buildings towards energy consumption has steadily increased, reaching up to 40%. Therefore, energy efficiency in buildings is a prime objective of energy policy in KSA (Al-Shaalan et al. 2014).

The present article reviews the solar energy options for the buildings in KSA and the initiatives taken so far. In the following section, the national energy scenario is outlined, which includes the generation and consumption pattern, national energy policies and initiatives, and detailed data of energy consumption in buildings. Subsequently, the researches on solar energy utilization in Saudi buildings are reviewed and presented. Many of the new and emerging research challenges are described, followed by conclusions and recommendations.

## **2. The Saudi Arabian Energy Scenario**

### ***2.1 Resources and Electricity Generation***

Oil and natural gas are the main energy sources in KSA. Currently more than half a million barrels of oil per day is used directly for power generation (Farnoosh et al. 2014). The total installed electricity generation capacity is 44,485 MW, all being supported by oil and natural gas. The respective share of oil and natural gas in the production of electricity is 57% and 43%. The Kingdom is yet to explore other energy resources to support the power sector. It has significant potential for RE resources, particularly solar and wind (Pazheri et al. 2012). The country annually receives around 3245 sunshine hours accounting for a solar radiation of over 2200 kWh/m<sup>2</sup>. The total installed capacity of solar photovoltaic (PV) is currently 4.4MW and another 10 MW is under construction (Alrashed & Asif 2012). In July 2011, the world's largest solar thermal system was commissioned in Riyadh. The solar thermal plant, with a total capacity of 25 MWth (36.305 m<sup>2</sup>), is connected to a district heating network for the supply of space heating and domestic hot water of the Princess Noura Bint Abdulrahman University campus (Weiss & Mauthner 2012). A comprehensive review of the developments in solar energy exploration and exploitation in KSA has been provided in (Hepbasli & Alsuhaibani 2011).

### ***2.2 Energy Consumption Pattern***

The electricity consumption in KSA has increased and should continue to increase at a very fast rate. Since 1990, the demand has increased at an annual rate of 6%. In 2010, Saudi Arabia has consumed about 212,263 GWh of electricity, and the residential sector consumes 108,627 GWh or 67% of the total consumption. Therefore, KSA is experiencing a rapid growth in the electric energy demand, which is estimated to be at the rate of 2015.7 GWh per annum. It has been forecasted that the electricity consumption is expected to increase from 193,474 GWh in 2009 to about 280,757 GWh in 2015 (Al-ghamdi & Al-feridah 2011). Peak loads reached nearly 24GW in 2001 (25 times their 1975 level) and are expected to approach 60GW by 2023 (Al-Ajlan et al. 2006).

### ***2.3 Policies and Solar Energy Initiatives***

The Ministry of Water and Electricity (MoWE) and Ministry of Petroleum and Mineral Resources (MoPM) are the prime governmental bodies for the energy sector while Saudi Aramco and the Saudi Electricity Company (SEC) serve as the leading parastatal bodies. The MoWE is responsible for setting policies for the electricity sector and for overseeing private investment in the sector. Saudi Aramco controls the oil and gas

production and export. The National Energy Efficiency Program (NEEP) was established in 2005, to address energy and environmental issues (Alrashed & Asif 2012). Its activities include energy audits, equipment standards, energy service companies, technical training and energy efficiency awareness (Alyousef & Varnham 2010). The policies and initiatives on implementing solar energy technologies in KSA have been detailed by Hepbasli and Alsuhaibani (Hepbasli & Alsuhaibani 2011).

As one of the formalized projects under the United States-Saudi Arabian Joint Commission on Economic Cooperation (established on June 8, 1974), an agreement (SOLERAS) was signed on October 30 1977, between the US Department of Energy (DOE) and the Saudi Arabian National Center for Science and Technology (SANCST) for cooperation in the field of solar energy. The main focus of this agreement was on active and passive solar cooling, solar desalination, solar-electricity generation and thermal processes (Anon 1979). A second program was begun in 1989 with the DOE to address, in addition to solar energy, other RE technologies (Alawaji & Hasnain 1999). KSA is working with the DOE's National Renewable Energy Laboratory (NREL) on measuring its solar energy resources (Anon 2014). Another initiative was the Solar Village project located near the villages of Al-Jubailah, Al Uyaynah, and Al- Higera, which are about 50 km northwest of Riyadh. The objective of this project was to use solar energy to provide power to remote villages not served by an electric power grid (Alnaser & Alnaser 2009). A collaboration with Germany — Saudi-German Joint Commission on Economic and Technical Co-operation was also signed in March 1980, to address several solar energy related issues (Alawaji & Hasnain 1999). An updated overview of the developments in solar energy technology and its future in the Kingdom has been provided by Almasoud and Gandayh (Almasoud & Gandayh 2014).

### 3. Solar Energy Utilization in Saudi Buildings

#### *3.1 Building Integrated Photovoltaics*

The PV technology has recently received substantial attention as a clean power source for buildings (Al-Saleh 2009). Historically, no energy technology has changed more dramatically than PV, the cost of which has declined by a factor of nearly 100 since the 1950s (Nemet 2006). The KSA being endowed with high intensity of solar radiation, is a prospective candidate for deployment of PV systems (Shaahid & El-Amin 2009). Building integrated photovoltaics (BIPV) which refers to the integration of photovoltaic cells into one or more of the exterior surfaces of the building envelope, is a growing PV application. A recent techno-economic assessment (Sharples & Radhi 2013) has highlighted three key benefits of BIPV technology for residential buildings in the GCC countries: savings in capital cost due to central power plants and transmission and distribution processes; increase in the exported oil and natural gas used for electricity generation; and reduction in the CO<sub>2</sub> emissions from conventional power plants. This is consistent with the conclusions drawn from similar appraisals (Taleb & Al-Saleh 2010) (Taleb & Pitts 2009). Almasoud and Gandayh (Almasoud & Gandayh 2014) have proved that the cost of solar energy would be less than the cost of fossil fuel energy if the cost of the environmental and health damages is taken into account.

Few researches have been reported for exploiting PV technology for buildings in KSA. Shaahid and Elhadidy (2003) studied the feasibility of hybrid (PV + diesel) power systems for a typical residential building in Dhahran, KSA. The systems comprised different combinations of PV panels/modules supplemented with battery storage unit and diesel back-up. It was shown that with 225 m<sup>2</sup> PV together with 12 h of battery storage, the diesel back-up system had to provide 9% of the load demand. In their extended study (Shaahid

& Elhadidy 2004) a commercial building with an annual electrical energy demand of 620,000 kWh was considered. Subsequently (Shaahid & Elhadidy 2005), they focused on the optimal sizing of battery storage for the system. This system was recently tested (Shaahid et al. 2014) for residential buildings (with annual electrical energy demand of 35,120 kWh) in five different provinces of KSA. It was predicted that for a hybrid system composed of 4 kWp PV system together with 10 kW diesel system and a battery storage of 3 h of autonomy (equivalent to 3 hours of average load), the PV penetrations were 22%, 21%, 22%, 20%, and 20% at Abha (Southern Province), Hofuf (Eastern Province), Qurayat (Northern Province), Taif (Western Province), and Riyadh (Central Province) respectively. Study on integration of PV into the envelop of a hospital building in Riyadh was reported by Osman (Osman 2012).

Moving beyond just a PV panel-roofed housing, the modern trend is to realize the concept of “Solar House” where the electricity is produced by the grid-connected PV roofing while employing energy-efficient materials and structures for the other building components such as walls, glazing, windows, shading, etc. To the best of authors’ knowledge, this idea was introduced in KSA in 1975 (Sayigh & Abdul-Salam 1975), but was not pursued further. Recently, an interesting work on such a building design which was proposed for the Saudi Arabian environment has been reported from a Swedish university (Maerten & Tan 2011).

### ***3.2 Solar Cooling/Air-Conditioning***

The electricity consumption for air-conditioning (A/C) in KSA which is dominated by hot desert climate exceeds 70% of the total electricity consumption during the summer months. Therefore, there is a strong demand to implement cooling solutions with minimal electricity consumption. While evaporative cooling is highly effective in arid climates, the scarcity of fresh water supplies in the Kingdom prohibits excessive use of water for cooling. As an alternative, solar A/C provides a means to utilize the high solar irradiance in KSA to mitigate electrical loads associated with peak cooling demand (Al-mogbel et al. 2013; Sofrata & Abdul-Fattah 1982). Solar electrical and solar thermal are the basic modes of solar cooling; the former uses solar energy to power conventional vapor compression system while in the latter, the A/C system works directly on solar energy (e.g, absorption/adsorption, liquid/solid desiccant and hybrid). The former system was found (El-Shaarawi et al. 2013) to be uneconomical in KSA without government subsidy. A performance comparison of various techniques (such as Rankine engine-powered, flat-plate solar collector-powered thermochemical absorption, lithium-bromine (LiBr) absorption and passive convection tower) was reported (Sayigh 1981) for hot and arid climate as that of Riyadh.

Liquid desiccant cooling and hybrid absorption-desiccant systems have been studied by few researchers. An open-cycle solar space-cooling system, which operates on the ventilation mode using a liquid desiccant has been proposed by Gandhidasan (1994) for places like Dhahran where temperature and humidity are high during the summer months. The ambient air was dehumidified using a liquid desiccant followed by adiabatic evaporative cooling, and the weak desiccant was regenerated by solar energy. This study was extended (Ahmed et al. 1997) to simulate a hybrid open-cycle vapor absorption and liquid desiccant system using LiBr for the process of absorption and dehumidification. The system was modeled with a partly closed-open solar regenerator for regenerating the weak desiccant and a packed tower dehumidifier for the dehumidification of ambient air. The air was first dehumidified in the dehumidifier and then sensibly cooled in the evaporator. The coefficient of performance (COP) of the hybrid model was about 50% higher than that of a conventional vapor absorption machine.

Later on, Al-Farayedhi et al. (2002) proposed another hybrid cooling system wherein liquid desiccant was used to remove the latent load and the conventional vapor-compression system was used to provide sensible cooling only. Calcium chloride ( $\text{CaCl}_2$ ) solution was used as the desiccant to dehumidify the air. Gauze-type structured packing towers were used for the dehumidification of air and also for regeneration of the weak desiccant. The dehumidifier and the regenerator were combined with a 5-ton capacity vapor compression system along with the heat recovery units. The hybrid system was found to provide higher COP compared with conventional system. In a recent development, Al-mogbel et al. (2013) proposed adsorption cooling which has the greatest potential benefit for electricity reduction due to the absence of internal moving parts, leading to a high electrical coefficient of performance ( $\text{COP}_{\text{el}}$ ). Also, compared to absorption cooling, adsorption chillers can be driven at relatively low temperatures, typically  $60^\circ\text{C}$  or above, and can therefore be combined with low-cost flat plate collectors. However, the low thermal coefficient of performance ( $\text{COP}_{\text{th}}$ ) of these systems leads to high re-cooling needs. Further, the performance in terms of  $\text{COP}_{\text{th}}$ ,  $\text{COP}_{\text{el}}$  and cooling power is highly dependent on the temperature level for heat rejection, which in KSA tends to be significantly higher than the nominal middle temperature of commercial adsorption chillers.

As part of the research program in the field of passive solar cooling strategies at the King Faisal University, sponsored by the Joint United States-Saudi Arabian Program for Cooperation in the field of Solar Energy (SOLERAS), Bajwa (1995) performed experiments to identify the comfort enhancement potential of an integrated landscape design in a full-scale prototype passive solar cooling test house. Conventional concrete-block load-bearing construction with external insulation and heavy internal thermal mass was used. The initial observations were claimed to be consistent with those of other researchers.

#### 4. Emerging Research and Commercial Options

Solar energy utilization needs enhanced research to realize its outstanding merits for the existing and future buildings in the Kingdom. Computer aided simulation and optimization techniques need to be applied to perform technical and thermo-economic analyses on various solar cooling options such as absorption/adsorption, liquid/solid desiccant system (Panaras et al. 2010), ejector system (Nguyen et al. 2001) and hybrid systems (Fieber 2005). The works done on solar absorption system (Aly 1988; El-Shaarawi et al. 2014; Izquierdo et al. 2014; Anon 1981) and novel solar-assisted A/C systems (Wrobel et al. 2013) should be pursued further. While studying the viability of PV technology in buildings, the economic assessment should incorporate the monetary share of human health and other environmental benefits (with respect to fossil fuel utilization), in order to justify the cost. The reviews of Hepbasli & Alsuhaibani (2011), Almasoud & Gandayh (2014) and others (Chow 2010; Grossman & Johannsen 1981; Sumathy et al. 2003; Ward 1979; Geetha & Velraj 2012; Hasan & Sumathy 2010; Ibrahim et al. 2011; Moldovan et al. 2014; Thirugnanasambandam et al. 2010; Tyagi et al. 2012; Parida et al. 2011) provide insight into the research and commercial opportunities for various solar cooling technologies. Various methods of solar energy modeling have been reviewed in (Khatib et al. 2012).

Latent heat thermal energy storage (LHTES) is becoming attractive for space heating and cooling of buildings, which has good potential for peak load management, solar energy utilization, and storing the natural cooling at night and to release during the day (Zhang et al. 2007; Khudhair & Farid 2004). Use of phase change materials (PCM) (Ascione et al. 2014; Farid et al. 2004; Kenisarin & Mahkamov 2007; Sharma et al. 2009; Tay et al. 2012; Tyagi & Buddhi 2007) in the building envelope is involved in this technology. With suitable PCMs and a suitable incorporation method with building material, LHTES can be economically



efficient for heating and cooling of buildings (Zhang et al. 2007). Few more reviews include those of Sores et al. (2013) and Pasupathy et al. (2008).

The commercial future in the domain of building energy management would be highly attractive in KSA. Recent studies by King Abdulaziz City for Science and Technology has suggested that Silicon raw material for photovoltaic production should be considered for further investigation towards solar cells manufacturing in KSA (Elani & Bagazi 1998). The new heatproof solar panel developed by BP (British Petroleum) and being tested at the King Abdullah University of Science and Technology (KAUST) is expected to enhance energy output in extreme temperatures. BP Solar — the solar wing of BP has installed 60 new PV modules at KAUST's New Energy Oasis (NEO). The panel incorporated 'Thermocool' technology, which is claimed to be designed to cool the solar cells and improve energy conversion.

## 5. Conclusion

A review of the various initiatives in solar energy utilization in buildings in KSA has been made. Many works might be left uncited but not intentionally. While analyzing the energy utilization and its major environmental impacts from the standpoint of sustainable development in Saudi Arabia, renewable energy technologies have been identified as one of the most viable solutions to the current environmental issues. Hence it is obvious that there is a wide scope for research in this direction, especially solar energy. With the growing enthusiasm towards technical education and scientific research, and the excellent infrastructure and resources available in KSA, it is expected that there would be enhanced research activities in this domain in the days to come. The authors believe that this document would definitely help the researchers in deciding the direction of further research and enable the designers, architects, engineers and policymakers to take constructive measures in promoting solar energy technology.

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