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Techno-economic analysis of solar-assisted air-conditioning systems for commercial buildings in Saudi Arabia

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ABSTRACT

Air-conditioning systems in Saudi Arabia consume approximately 65% of the electrical energy used in the building sector. Most air-conditioning systems in operation are of the vapor-compression variety. The use of solar energy to power such systems may save a large amount of electrical energy. Large-size commercial buildings in Saudi Arabia consume particularly high levels of electricity. This review compares three air-conditioning systems (conventional vapor-compression, solar LiBr–H_2O absorption, and solar photovoltaic (PV) vapor-compression) using a techno-economic analysis for a typical large-size building under a constant cooling load during daytime. The study utilizes the two economic methodologies, payback period (PBP) and the net present value (NPV), for a commercial building in Khobar City, located in the eastern province of Saudi Arabia. The purpose of this paper is to exploit the results achieved in the analysis to develop viable recommendations in mitigating the electrical peak power demand in Saudi Arabia by utilizing solar cooling technology in commercial buildings as well as to establish the tangible economic benefits from applying such technology. The results show that a solar absorption system ismoreeconomically feasible than a solar PV-vapor-compression system. Moreover, the feasibility of both solar-powered systems improves as the size of the commercial building and the electricity rate increase.

Contents

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1. Introduction

In Saudi Arabia, the high atmospheric temperatures directly affect the demand for artificial cooling and nearly all buildings are cooled by electrically powered conventional air-conditioning systems. The development of air-conditioning systems that run on alternative energy sources may save electrical energy, which is mainly produced by the burning of fossil fuels, for use in the production sector as opposed to the consumption sector. Such systems will significantly reduce carbon emissions, hence reduce environmental pollution and global warming effects of indoor climate control. Of the various renewable energy sources, solar energy has proven to be the best candidate for air-conditioning, because the maximum load on an air-conditioning system for cooling coincides with the period of greatest solar radiation input.

One of the main benefits of solar energy is its cleanliness and natural availability. The total solar radiation transmitted to the earth is approximately 1.74×1017 W [1]. Thus, solar energy can be used to power a refrigeration system in two ways. First, solar energy can be converted into electricity using photovoltaic (PV) cells and then electricity can operate a conventional vapor-compression refrigeration system.Second, solar energy can be used to heat the working fluid and create a refrigerant in the generator of a vapor sorption (absorption or adsorption) system. Many studies have been done in this field,and further research is ongoing, as described in Sections 1.1 and 1.2.

1.1. Techno-economic comparisons for different solar air-conditioning systems

Karagiorgas et al. [2] presented the project HOTRES describing the use of five renewable energy technologies (solar thermal, solar passive, solar PV, biomass, and geothermal energy) in parallel in five EU regions (East Attica, Sicily, Alpes-Maritimes, Andalusia, and Madeira). The project explored the future massive application of renewable energy in the tourism industry. The technical–economic results from data collected from 200 hotels showed that the shortest payback period (PBP) uniformly resulted from solar thermal energy systems. The PBP for solar thermal energy varies from 1.7 to 19 years in Greece and France, respectively. For solar PV, the PBP varies from 6 to 43 years in Spain versus Greece, respectively. Fong et al. [3] conducted a comparative study on the use of solar electric compression refrigeration, solar mechanical compression refrigeration, solar absorption refrigeration, solar adsorption refrigeration, and solar solid desiccant cooling in a subtropical city. Solar electric compression refrigeration and solar absorption refrigeration were found to have the highest potentials for saving energy in the subtropical city of Hong Kong.

Kim and Ferreira [4] conducted a comparative study between solar electric and solar thermal refrigeration systems from the perspectives of both energy efficiency and economic feasibility. Solar electric refrigeration systems using PV cells appeared to be more expensive than solar thermal systems. Mokhtar et al. [5] conducted an assessment of solar cooling technologies. The methodology is based on assessing the performance of each solar cooling technology as a system taking into account cost, performance parameters and weather and cooling demand. The assessment was applied to 25 solar cooling technologies based on the climatic conditions and cooling demand time series of Abu Dhabi, UAE. The results showed that large-scale cooling plant options are the most economical. On a smaller scale, Fresnel concentrators and thin film PV cells are the most economically viable. In terms of overall efficiency however multi-crystalline PV cells with vapor compression chillers were the most efficient option of all. Hartmann et al. [6] presented a comparison of solar thermal and solar electric cooling for a typical small office building exposed to two different European climates (Freiburg and Madrid). A parametric study on collector and storage size was carried out for the solar thermal system to reach achieve the minimal cost per unit of primary energy saved. The presumed macroeconomic advantages of the solar thermal system, due to the non-usage of energy during peak demand, can be confirmed for Madrid.

Kohlenbach and Dennis [7] presented an outlook on the current and future situation of solar cooling in Australia. The current potential savings in energy and greenhouse gas production by the use of alternative solar air-conditioning technologies were discussed. Solar thermal cooling systems were found to have a lower lifetime cost than PV-based systems. Pietruschka et al. [8] compared different solar thermal cooling systems to a PV driven and a net connected compression chiller in hot and dry southern climate for an office building project in Cairo Egypt. Four different systems are studied: single effect, double effect and triple effect absorption chillers and a PV driven compression chiller. The single effect reaches efficiency of 40% where double and triple effects reach to 31% and 27%. The COP is 0.7, 1.31 and 1.83 for single, double and triple effects. The triple effect has the highest primary energy ratio of 1.6 while the single effect has the lowest ratio of 1.43.

Chemisana et al. [9] presented a comparison between two cooling systems for a specific three-floor building, with and without solar concentration. The first is a conventional system which consists of evacuated tube collectors feeding a single-effect absorption chiller. On the other hand, a Fresnel reflective solar concentrating system is coupled to a double-effect absorption chiller. The results showed an important reduction of the solar collectors' absorber area in the concentrating system compared with the standard solar thermal installation. However, the solar concentrating system requires a large aperture area. In addition, the rejected heat in the double-effect chiller is lower, implying that the investment and operation costs of the solar concentrating cooling system can be reduced significantly. Otanicar et al. [10] described an economical comparison of existing solar cooling approaches, including both thermally and electrically driven. The comparison of the initial costs of each technology, including projections about future costs of solar electric and solar thermal systems was discussed. For solar electric cooling, the system cost is highly dependent on the system COP when photovoltaic (PV) prices remain at the current levels, but when prices are lowered the impact of COP becomes diminished. For solar thermal cooling, the cost of solar collection is much lower as a percentage of the overall cost, but the cost of the refrigeration system often represents a larger percentage of the cost. The cost for solar thermal cooling is not projected to decrease as much as PV cooling over the next 20 years due to the relatively stable cost of collection and storage.

1.2. Techno-economic analysis for solar thermal air-conditioning systems

Tsoutsos et al. [11] conducted economic evaluations of two types of solar thermal cooling systems using absorption versus adsorption. The study showed that the absorption systems were cheaper than the adsorption systems by 50% in terms of capital cost. The analysis demonstrated that solar cooling systems were well suited to replace conventional air-conditioners in remote areas, where no connection exists with the electricity grid and the conventional fuel used is gas. Younes et al. [12] studied a LiBr absorption machine and showed the capacity of the system to save a large amount of fuel. The study showed that the machine required 6.7 years to recoup the initial investment, with an annual payback of \$120,000. The absorption machine and accompanying equipment were shown to cost more than the centrifugal machine