Renewable and Sustainable Energy Reviews 50 (2015) 770–781

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Economic and environmental assessment of solar air-conditioning systems in Morocco

Amine Allouhi [a,*], Tarik Kousksou [b], Abdelmajid Jamil [a], Tarik El Rhafiki [c], Youssef Mourad [a], Youssef Zeraouli [b]

[a] École Supérieure de Technologie de Fès, Université Sidi Mohamed Ben Abdellah, Route d' Imouzzer, Fez BP 242, Morocco
[b] Laboratoire des Sciences de l'Ingénieur Appliquées à la Mécanique et au Génie Electrique (SIAME), Université de Pau et des Pays de l'Adour, IFR, A. Jules Ferry, Pau 64000, France
[c] Ecole Nationale Supérieure des Arts et Métiers, ENSAM Marjane II, Meknès Ismailia BP 4024, Morocco

ARTICLE INFO

Article history:
Received 21 November 2014
Received in revised form
9 April 2015
Accepted 12 May 2015

Keywords:
Solar
Air-conditioning
Climatic
Economic
Environment
Morocco

ABSTRACT

In addition to their harmful impact on the environment, air-conditioning applications account for a significant percentage of total energy utilization; thinking about clean resources becomes a world priority. Solar cooling systems using either adsorption or absorption technologies show a great potential since they can use a permanent energy and operate with environmentally safe working pairs. This paper investigates the potential of solar air-conditioning systems in Morocco (enjoying different climates) through a comparative study between conventional and solar closed cycle processes based on economic and environmental indicators. Accordingly, annual simulations in 6 climatic zones were performed to estimate cooling loads for a typical Modern Moroccan House. The major finding of this work is that solar air-conditioning systems in hot climates must be an attractive alternative to mitigate CO_2 emissions and increase energy savings. However, the high installation cost is a main obstacle facing their implementation.

Contents

* Corresponding author. Tel.: +212 670 42 49 28.
E-mail address: allouhiamine@gmail.com (A. Allouhi).

http://dx.doi.org/10.1016/j.rser.2015.05.044
1364-0321/

1. Introduction

In the recently published international energy projections, the world net electricity generation is expected to increase by 84%, from 19.1 trillion kilowatt hours in 2008 to 25.5 trillion kilowatt hours in 2020 and 35.2 trillion kilowatt hours in 2035 [1], keeping in mind that about one-third of the world's population still does not have access to electricity, and that underdeveloped and developing countries almost totally use fossil fuels as the major source of energy [2]. On the other hand, environmental issues resulting from climate change and global warming are becoming progressively more dangerous with a catastrophic impact affecting global ecosystems and human life [3]. Consequently, great efforts have been paid by many nations in order to increase their energy independence and to reduce their carbon dioxide emissions [4,5].

Morocco, despite its strategic position, is the largest energy importer in the region. Presently, around 96% of the Moroccan energy needs are sourced externally. Petroleum represents nearly 61% of the overall national energy consumption. The actual status together with the rapid growing of energy consumption has prompted the Moroccan policy makers to the implementation of the National Energy Strategy with Renewable Energy and Energy Efficiency Plan in 2008. Throughout its ambitious strategy, Morocco aims to promote renewable energy in order to achieve the fixed target: insuring 42% of the total electricity generation by 2020 from renewable alternatives.

Accordingly, a new project called "Moroccan Solar Plan (MSP)" was suggested in order to take advantage of the enormous Moroccan solar capabilities and fulfill its energy requirements. In fact, like almost of the North African countries, Morocco enjoys a huge solar potential with more than 3000 h per year of sunshine and an average daily radiation exceeding 5 kW h/m^2 [6].

Actually, the building sector accounts for 35% of energy consumption in Morocco, with an average increase of 41% during 8 years [7]. The summer peak demand of electricity due to the large use of vapor air-conditioning systems may cause major problems in the country's energy supply. Moreover, these systems have many impacts on the stratospheric ozone depletion and participate in the global warming. This is relevant in view of the fact that they use chlorofluorocarbons (CFC) and hydrofluorocarbon (HCFC) refrigerants.

The opportunity of using solar air-conditioning systems appears an attractive option in order to cope with high energy requirements during summer, since the availability of solar energy coincides most the time with the cooling needs. On the other hand, significant environmental benefits may be achieved thanks to the refrigerants with zero ozone depletion impact that can be used as working media in solar cooling systems.

It is well-known that solar radiation can be converted into electricity or heat. These two types of energy can be utilized to drive the refrigeration cycle [8,9]. Currently, solar cooling systems using sorption phenomena like absorption and adsorption cycles are the subject of numerous studies and are commercialized at different sizes [10]. In this paper, we will assess the economic feasibility and evaluate the energy and environmental benefits of using solar thermal air-conditioning technologies in Moroccan cities. This study can serve as a model for North African countries enjoying similar huge solar energy potential.

2. Background

2.1. Energy considerations in Morocco

Morocco is located in the north-west of the African continent between latitudes 21° and 36° and longitudes 2° and 18°, bordered by the Mediterranean Sea in the north, Mauritania in the south, Algeria in the east, and the Atlantic Ocean in the west. Morocco covers an area of 710 850 km^2. The total length of the Moroccan coast is 3500 km. According to recent projections of the Moroccan High Commission for Planning (HCP), based on previous years, the Moroccan population is estimated to be 32.95 million in 2013, equivalent to 46 inhabitants per km^2.

Morocco's climate varies greatly depending on the region; it is Mediterranean in the North West, subtropical in the south. In the

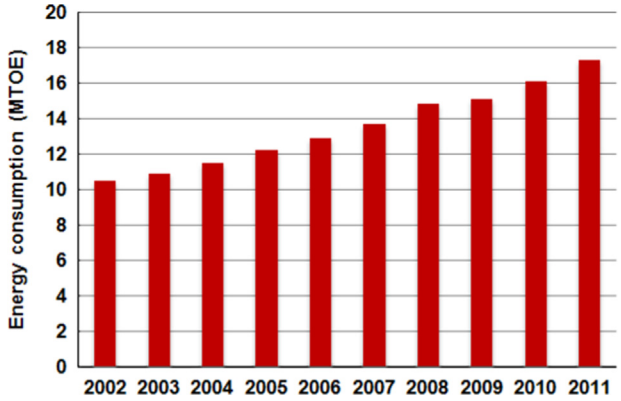

Fig. 1. Moroccan energy consumption.

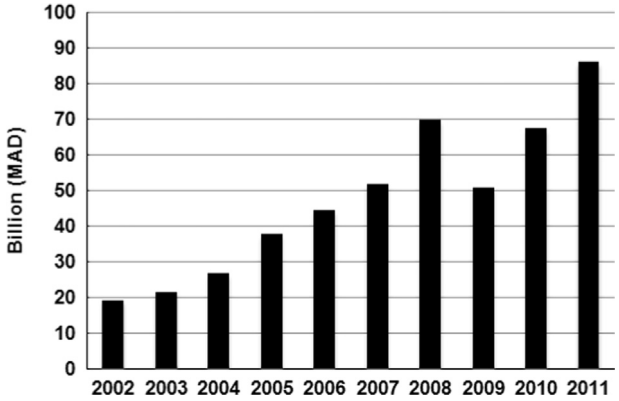

Fig. 2. Moroccan energy bill.