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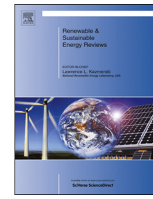

A review on the coupling of cooling, desalination and solar photovoltaic systems

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Single cooling and desalination technologies require a high amount of energy to produce cooling and fresh water, respectively. Coupling these systems seems to be attractive not only to reduce their energy consumption rates and to gain more flexibility in operation but also for environmental considerations. Besides, using solar energy to drive these coupled systems appears also interesting. The major increases in cooling and desalination demands occur in locations where solar energy is abundant. This article reviews the latest research works on systems able to carry out cooling and/or desalination using solar energy. The ability of coupling desalination technologies to cooling systems is investigated. A heat pump can produce cooling energy at the evaporator and heat at the condenser for a membrane distillation unit. An ice slurry process can operate with sea water. It freezes only pure water that can be separated from the liquid. A comparison of these systems is made. Membrane distillation (MD) and ice slurry systems must improve to be as efficient as standard technologies. An intelligent energy and water production management will have to be developed to control the operation of a system coupling ice slurry, MD and solar photovoltaic energy.

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1. Introduction

This article first describes the global context of cooling energy demand and fresh water scarcity and the relationship with the available solar resource. A path for energy savings is the coupling of technologies. The possibility of coupling cooling, water desalination and solar power systems is then discussed by means of a review of systems. Some desalination techniques are identified as adaptable to cooling systems. Finally, a short study is carried out to assess the different chosen coupled solutions.

1.1. Climate change

Following the latest report from the International Energy Agency (IEA) [1], the global primary energy supply has increased by approximately 3000 Mtoe (million tons of oil equivalent) since the year 2000 to reach nearly 13,000 Mtoe in 2011. The outlook to 2035 shows two trends of total primary energy consumption that constitute two boundaries. The trend based on policies under consideration in the concerned countries forecasts a global growth of 4000 Mtoe. The second scenario is based on policies needed to limit global average temperature increase to 2 °C. This scenario would lead to a stabilization of primary energy supply. In both scenarios, energy supply in countries from the Organisation for Economic Co-operation and Development (OECD) will decrease whereas in other countries, it will increase, especially in China and other Asian countries. Global warming is one of the most significant causes of the increase of cooling energy consumption [2,3]. Indeed if the climate is warmer the cooling demand will rise.

1.2. Population growth

Beyond the climatic issue, the first reason for the cooling demand increase is the growth of the world population expected to pass from 7 billion in 2011 to 9.3 billion in 2050 [4]. Rural exodus even emphasizes the growth of big cities. Another factor is the urban heat island effect [5]. The proximity of buildings and their cooling equipment creates hot outdoor environment because of the hot air flowing out of the condensers. It provokes higher cooling needs and lower performance of the air-conditioners. The use of condenser heat for desalination would help address this issue. In addition, economic growth of emerging countries where the climate is quite hot in some seasons lead to higher air conditioning consumption. Architectural choices are often not so well adapted to the climate and to the increase of internal gains due to more and more household electrical equipment and ICT (Internet Connected Technologies) devices like computers, smartphones, etc.

1.3. Buildings

The building sector accounts for 40% of the world's energy consumption and one third of total greenhouse gas emissions [6]. Following the Intergovernmental Panel on Climate Change (IPCC) [7], energy saving measures in this sector would be among the most efficient in terms of benefit-cost ratios. Cooling applications already account for an important part of energy consumption. Ren et al. [6] predict that cooling represents 28.3% of the electricity consumption of a dwelling in Townsville, Australia's largest tropical city. For Sadineni and Boehm [8], the US electricity consumption is devoted at 22% and 7% to air-conditioning and refrigeration, respectively. In 2011, 23% of electric energy in French houses is consumed for cooling [9]. The proportion has decreased since 1990 but the amount of energy is just stable even when considering the significant effort of manufacturers to produce more efficient cooling systems. The reason is due to the fact that the global sales of air-conditioners have grown from 44 to 94 million units from 2002 to 2012 [10]. There is obviously an important desire of people from developed and developing countries to access higher level of comfort [11]. Cooling demands participate to power outages in regions where the electrical grid shows weaknesses. An IEA document on energy in emerging countries reports the number of power outages per month, their duration and the equivalent lost value estimated as a percentage of sales [12]. In the Middle East and North Africa regions and in the Sub-Saharan Africa, the number of power outages is respectively 10.45 and 14.3 per month. The higher value, 42.18 power outages per month, occurs in South Asia, representing a lost value up to 10.68% of sales. In these regions, the electricity supply network needs a strong support. The other goal of shifting the peak load is to pay less for energy subscription [13]. According to the IEA, a peak load reduction of 5% could have reduced the highest wholesale prices by 50% during California's power crisis in 2000 [14]. Some solutions enable to shift the peak demand using storage systems (ice slurries, cold water, building mass, PCM…) [13,15–21]. Solar energy can also be an interesting way [22]. It can reduce the energy consumption of the cooling technologies as well as the related environmental impacts.

1.4. Solar energy

Solar cooling is an interesting way of saving energy. An IEA programme is dedicated to solar heating and cooling systems [23] and