Renewable and Sustainable Energy Reviews 65 (2016) 57–80

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Hybrid cooling systems: A review and an optimized selection scheme

Farah Kojok [a], Farouk Fardoun [b], Rafic Younes [c,*], Rachid Outbib [a]

[a] LSIS, Aix-Marseille University–Domaine Universitaire de Saint-Jérôme, Av. Escadrille Normandie-Niemen, 13397 Marseille Cedex 20, France
[b] University Institute of Technology, Department GIM, Lebanese University Campus, P.O. Box 813, Saida, Lebanon
[c] Department of Mechanical Engineering, Lebanese University, Beirut, Lebanon

ARTICLE INFO

Article history:
Received 9 June 2015
Received in revised form
25 May 2016
Accepted 29 June 2016

Keywords:
Hybrid cooling systems
Energy saving
COP improvement
Environmental impact
Selection scheme

ABSTRACT

The hybrid cooling system has proved to be an energy saving technology for building air conditioning. Numerous systems combining different cooling processes or cooling machines have been proposed and investigated in the literature. A properly selected hybrid cooling system offers a great reduction in energy consumption and a coefficient of performance improvement varying according to different climates and system designs. This paper provides a detailed review of existing hybrid cooling systems with their corresponding individual cooling machines. A brief state of the art of the most common individual cooling systems in hybrid cooling for building use is firstly presented. Then, the hybrid cooling systems are classified into five main categories according to the combination of cooling processes or machines: Vapor compression based cooling, absorption based cooling, adsorption based cooling, desiccant-evaporative and multi-evaporator cooling. In each category, the studied configurations and the benefits of each hybridization method are presented. It is found that each hybrid system combines the advantages of the different cooling processes used. However, a hybrid system could have a negative repercussion if it does not match the climatic zone where it will be used. Consequently, a selection scheme to recommend the best hybrid cooling system for minimum energy consumption and pollution emissions in buildings according to different parameters is proposed.

Contents

* Corresponding author.
E-mail address: rafic.younes@lsis.org (R. Younes).

http://dx.doi.org/10.1016/j.rser.2016.06.092

1. Introduction

The rapid growth of the world's population and the raised comfort level has imposed a significant increase in energy demand. According to the International Agency of Energy (IEA), the energy consumption increased at a rate of 15.7% during the 30 years from 1973 to 2004 [1]. Consequently, the CO_2 emissions augmented at a rate of 5% during that period. Therefore, governments are focusing on the search for alternative sources of free and renewable energy. Despite the advantages of these sources, the renewable energy contributed only to about 1.5% of world energy demand in 2006 and is estimated to rise up to 1.8% in 2030 [2].

Among building services, the energy use of HVAC systems is significant. It consists of 50% of the total energy consumption in buildings in developed countries, and around 10–20% of the total energy consumption in developed countries [1]. In order to reduce the amount of non-renewable energy consumed by HVAC systems, the development of cooling and heating efficient energy systems using free energy sources is accelerating rapidly. Accordingly, cooling loads in buildings could be covered, either by hybridization of different cooling systems or using various energy sources (e.g., solar, biomass, waste, geothermal, etc.). Solar cooling systems have attracted the attention of many researchers, and a lot of review studies were carried out. Thanks to pollution-free working fluids, solar thermal cooling is found more suitable than solar electric cooling, notably in areas where solar energy is always available. In addition, higher capacity and better COP could be achieved using solar hybrid cooling systems which are mostly based on absorption chiller and mainly LiBr/water machine [3]. It is recommended that the auxiliary heat required for solar absorption cooling systems to be other type of renewable or clean energy. Furthermore, at high cooling load, it is better to use an electric chiller as auxiliary cooling system when the solar absorption system is not sufficient. In order to reduce the operational cost of a solar absorption system, methods are suggested such as placing the hot storage tank above the solar collector, integrating the generator inside the insulated storage tank and increasing the vacuum pressure in the cooling circuit [4].

Adsorption cooling is one of the energy saving cooling methods which can cover waste heat at low temperatures. However, the COP and cooling capacities of adsorption systems are still low compared to absorption. This is due to poor mass and heat transfer, leakage, adsorbent deterioration, high vacuum in water required (methanol likely systems), etc. ([5–8]). Numerous efforts have been devoted to the improvement of system performance and cooling capacities of adsorption systems. In [8], the progress in silica gel-water adsorption cooling systems is reviewed. They suggested using mixed refrigerant in order to reduce the high vacuum requirement determined by water vapor. The authors in [7] noted that the development of hybrid systems is an efficient method that makes adsorption technology cost competitive compared with other cooling systems. The authors in [9] showed that the highest COP was reached in a hybrid adsorption-vapor compression cooling system where the adsorption bed used activated carbon/CO2.

In addition of absorption and adsorption cooling, a desiccant system is also a thermally-driven sorption system which allows humidity control. A hybrid desiccant cooling system is suitable for hot and humid climates where the latent load is much larger than the sensible load [10]. A desiccant system is rarely used as a standalone system. It is usually hybridized with another cooling machine such as vapor compression, absorption, adsorption or evaporative cooling systems. Yin et al. [11] reported the recent developments in the field of liquid desiccant dehumidification and the utilization of solar energy in such systems. Mohammad et al. [12] pointed out the importance of sizing and operating temperatures of vapor compression chiller in hybrid liquid desiccant combined with vapor compression machine. Compared to standing alone evaporative coolers, the hybrid liquid desiccant systems combined with direct or indirect evaporative achieved a COP increase greater than 20% [13].

The aim of this work is to present a detailed study of hybrid cooling systems and the benefits attained by combining different cooling technologies. Therefore, an updated state of the art for the individual cooling systems with their advantages and disadvantages is carried out. Then, the hybrid cooling systems are classified into five main categories according to the combination of cooling processes or machines: vapor compression base cooling, absorption base cooling, adsorption base cooling, desiccant-evaporative and multi-evaporator cooling system. Based on this review, a selection scheme to find the best hybrid cooling system for minimum energy consumption and pollution emissions according to each climatic zone is suggested. As a result, a hybrid cooling system could be chosen properly according to the meteorological data of the studied climatic zone. The data required are for temperature and relative humidity to estimate the sensible and the latent load, respectively. In addition, the availability of solar energy must be studied in order to investigate the possibility of using thermal driven cooling machine.

2. Individual cooling systems

In this section, a brief recent state of the art of the most common systems in hybrid cooling for building use is described.

2.1. Vapor Compression cooling system (VCC)

VCC is the most commonly used cooling system due to the high COP obtained [14], the application over a large temperature range (from −40 °C to 7° [15]) and the wide variety of refrigerant types [16]. However, the great dependence of VCC on electrical energy and the high power consumption are the major drawbacks that make the use of such a system undesirable, especially in countries that suffer a shortage in the electricity generation. Therefore, different methods were investigated in order to mitigate these