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Achieving better energy-efficient air conditioning – A review of technologies and strategies

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ABSTRACT

Air conditioning is essential for maintaining thermal comfort in indoor environments, particularly for hot and humid climates. Today, air conditioning, comprising cooling and dehumidification, has become a necessity in commercial and residential buildings and industrial processes. It accounts for a major share of the energy consumption of a building or facility. In tropical climates, the energy consumed by heating, ventilation and air-conditioning (HVAC) can exceed 50% of the total energy consumption of a building. This significant figure is primarily due to the heavy duty placed on cooling technologies to remove both sensible and latent heat loads. Therefore, there is tremendous potential to improve the overall efficiency of the air-conditioning systems in buildings.

Based on today's practical technology for cooling, the major components of a chiller plant are (1) compressors, (2) cooling towers, (3) pumps (chilled and cooling water) and (4) fans in air handling units. They all consume mainly electricity to operate. When specifying the kW/R ton of a plant, there are two levels of monitoring cooling efficiency: (1) at the efficiency of the chiller machines or the compressors which consume a major amount of electricity; and (2) at the overall efficiency of cooling plants which include the cooling towers, pumps for moving coolant (chilled and cooling water) to all air-handling units. Pragmatically, a holistic approach is necessary towards achieving a low energy input per cooling achieved such as 0.6 kW/R ton cooling or lower by considering all aspects of the cooling plant.

In this paper, we present a review of recent innovative cooling technology and strategies that could potentially lower the kW/R ton of cooling systems – from the existing mean of 0.9 kW/R ton towards 0.6 kW/R ton or lower. The paper, broadly divided into three key sections (see Fig. 2), begins with a review of the recent novel devices that enhances the energy efficiency of cooling systems at the component level. This is followed by a review of innovative cooling systems designs that reduces energy use for air conditioning. Lastly, the paper presents recent developments in intelligent air-control strategies and smart chiller sequencing methodologies that reduce the primary energy utilization for cooling.

The energy efficient cooling technology, innovative systems designs, and intelligent control strategies described in the paper have been recently researched or are on-going studies. Several have been implemented on a larger scale and, therefore, are examples of practical solutions that can be readily applied to suit specific needs.

Contents

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1. Introduction

The world energy use is rapidly growing at an alarming rate. This has already raised concerns over potential supply difficulties, depletion of energy resources and expediting environmental impacts (ozone layer depletion, global warming, climate change, etc.). The global raising pattern in buildings energy consumption, both residential and commercial, has climbed steadily; reaching figures between 20% and 40% in developed countries. In fact, it has exceeded the other major sectors, namely, industrial and transportation. Key reasons attributing to this increasing figure include: (1) growth in population; (2) greater demand for building services; (3) the need for better comfort levels; and (4) longer duration of occupants spent time inside buildings. Without a doubt, the upraising trend in energy demand will continue into the future. For this reason, improving energy efficiency in buildings is today a prime objective for global energy policy makers.

The growth in energy use for HVAC systems is particularly significant. For example, in the United States, it accounts for 50% of building consumption and approximately 20% of total consumption [1]. The ability to maintain desired heating HVAC is considered to be one of the most important accomplishments of modern technology. Today, air conditioning has become a necessity in building, dwellings and industrial processes. In fact, it has become the largest energy end use both in the residential and non-residential sector. Additionally, the relentless proliferation of energy consumption and CO_2 emissions in the built environment has made energy efficiency and savings strategies a key priority during energy policies formulation. An apparent example is the European Energy Performance of Buildings Directive [2] which has proposed higher standards for ventilation, air-conditioning systems energy efficiency. By and large, HVAC consumption in developed countries accounts for almost half the energy consumed in buildings and approximately one fifth of the total national energy use [9]. Future predictions have clearly indicated a colossal growth in energy consumption and areas to be thermally conditioned in the next 15 years [3]. The predicted number is an astounding 50% increment. Fig. 1 shows the typical electricity consumption by end-use in Singapore and the building sector which has 31% shares, of which 60% of the electricity usage in this sector is for cooling [4]. Within the household sector, approximately a quarter of the electricity consumption is associated with air conditioning. About 9650 GW h or almost a quarter of the total electricity consumption in Singapore is attributed directly or indirectly to cooling applications. Such statistics are not surprising for countries with tropical climates because cooling plants need to perform substantial sensible and latent cooling.

It is the intent of this paper to review the most recent developments concerning innovative cooling technologies and strategies found in literature that could potentially lower the kW/R ton of cooling systems. As the literature on this subject is now voluminous and rapidly expanding, it is difficult to produce a completely comprehensive review of the subject. However, we intend to examine a large number of articles, particularly recent ones, to present a useful overview of research interests and directions in this growing, multidisciplinary field. We start this review article by documenting the recent findings of the impact of climate change on cooling energy in different parts of the world. This review is broadly divided into three key categories (see Fig. 2) and will be systematically organized. It begins with a review of the recent novel devices that enhances the energy efficiency of cooling systems at the component level. This is followed by a review of

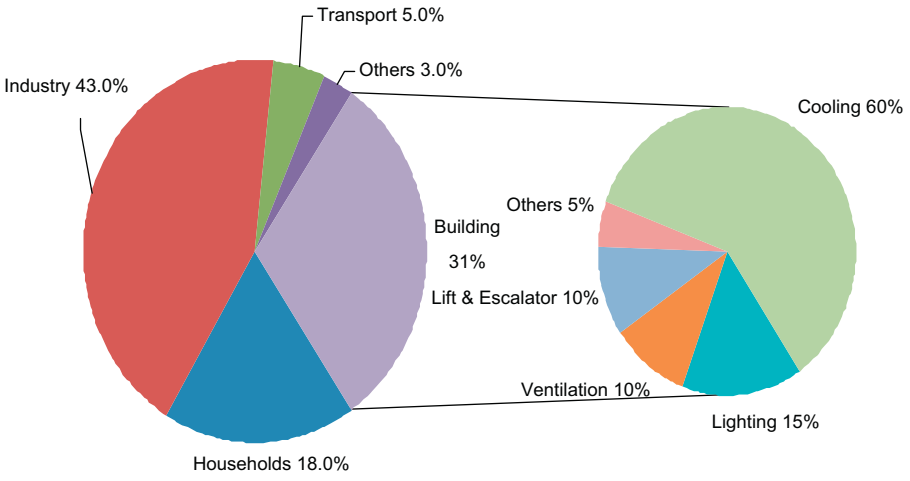

Fig. 1. Typical electricity consumption by end-use in Singapore and in the building sector.