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The use of phase change materials in domestic heat pump and air-conditioning systems for short term storage: A review

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A B S T R A C T

Heat pumps for space heating and cooling are a mature and highly efficient technology that can take advantage of renewable energies. They can also provide energy savings by load shifting when they operate together with thermal energy storage (TES). This paper presents a literature review of TES systems using phase change materials (PCM) potentially applicable to domestic heat pumps used in residential and administrative buildings. The paper describes the systems proposed by the different authors and presents the main conclusions of the studies. The TES systems presented are not only used as energy storage to shift the load demand but also for other applications such as heat recovery or defrosting in air-conditioners. The PCM have the suitable melting temperature to work together with standard heat pumps in each application. Moreover, some systems where the heat pump is coupled to latent heat thermal energy storage (LHTES) units and other energy sources or where the TES system is incorporated in a radiant floor or air distribution system have also been included.

Contents

1. Introduction

Buildings represent 40% of the European Union's final energy consumption [1]. In residential homes, two thirds of this consumption is for space heating, which means that a large energy saving potential remains untapped [2]. Heat pumps technology is presented as candidate technology to achieve high energy savings since it is included in the Directive on the promotion of the use of energy from renewable sources (2009/28/EC) as an environmentally friendly technology [3].

Heat pumps use renewable energy from their surroundings (ambient air, water or ground) and "high-grade" energy, e.g. electricity or gas, to raise the temperature for heating or to decrease it for cooling. If certain criteria are met, the European Union credits heat pumps as using renewable energy. They achieve point-of-use efficiencies greater than 100%, i.e. they provide more

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useful cold or heat (in energy terms) than the electricity input. The heat pump cycle can be used for space heating or cooling; reversible systems can alternate heating and cooling, while hybrid systems (for instance those that couple heat pumps with conventional boilers or solar thermal collectors) can provide heating and cooling simultaneously. Heat pumps for space and water heating are mature technologies, but their share of the global heating market is small [4]. In Europe, the heat pump sales underwent negative growth the last years, in part, due to the global financial crisis. However, the initial recovery of the market was observed since sales in 2011 finished on par with 2010 results (Fig. 1) [5].

The International Energy Agency (IEA) includes the heat pumps for space heating and cooling and hot water as one of the technologies which has the greatest long-term potential for reducing CO_2 emissions. According to the proposed BLUE Map scenario (a scenario in which energy-related CO_2 emissions are reduced by 50% in 2050 from 2007 levels), it is estimated that heat pumps will dramatically increase their share of space and water heating. The total number of installed units at global level in the residential sector for space heating and cooling and hot water is estimated to reach almost 3.5 billion by 2050, which involves a CO_2 emissions reduction of about 1.25 $GtCO_2$ [4].

In recent years, the number of air-conditioning systems in southern European countries has severally increased. This creates considerable problems at peak load times, increasing the cost of electricity and disrupting the energy balance in those countries. Therefore, priority should be given to strategies which enhance the thermal performance of buildings during the summer period [6].

The use of thermal energy storage (TES) systems for thermal applications such as space and water heating, cooling, or air-conditioning has received much interest since it is considered to be one of the most promising solutions to correct the mismatch between supply and demand of energy. TES systems give the opportunity to shift the load demand from high-cost energy period to off-peak period meeting the thermal loads that occur during high-demand. In addition, the purchase of additional equipment for heating, cooling, or air-conditioning applications can be deferred and the equipment sizing in new facilities can be reduced. The equipment can be operated when thermal loads are low to charge a TES systems and energy can be withdrawn from the storage to help meeting the maximum thermal loads that exceed the equipment capacity [7].

Moreover, TES systems provide environmental advantages by using electricity produced at night, when utilities are generally operating their most efficient plants. As a result, significant savings of primary energy sources (coal, natural gas, oil or nuclear fuel) accrue to electric utilities and reduce pollutant emissions [8]. In Europe, it has been estimated that around 1.4 million GWh per year could be saved and 400 million tonnes of CO_2 emissions avoided in the building and industrial sectors by more extensive use of heat and cold storage [9].

Latent heat thermal energy storage (LHTES) using phase change materials (PCM) present the advantage of operating within small temperature ranges and, at the same time, accumulating large amounts of heat or cold comparing to sensible storage. In fact, PCM can store about 3–4 times more heat per volume than is stored as sensible heat in solids or liquids in a temperature interval of 20 °C [10] Combining PCM LHTES with heat pumps is a promising technology which can lead to take advantage of both technologies for energy savings and environmental benefits.

This paper reviews the use of LHTES systems when coupled to domestic heat pumps for space heating and cooling. The described TES systems are not only used as energy storage to shift the load demand but also for other applications such as heat recovery or defrosting in air-conditioners. Moreover, some studies have incorporated the energy storage in a radiant floor or air distribution system. The paper presents first those systems studied for space heating and later those for space cooling.

2. PCM storage in heat pumps for space heating

2.1. Thermal energy storage within the heat pump cycle

Few studies are found in the literature about the use of PCM storage tanks included in heat pump systems for space heating. In these systems, the exhaust heat produced by the condenser of the heat pump is used to heat up a heat transfer fluid (HTF), such as water, which is used for heating applications. Hamada and Fukai [11] (Japan) analysed an experimental set-up where the condenser of a heat pump was connected to two different PCM storage tanks and the evaporator was connected to an ice storage tank so that the system provides heating and cooling. The study was focused on the heat transfer improvement of the TES tanks and the results were compared to a three dimensional heat transfer model evaluated in a previous study [12]. The flow diagram of the experimental set-up is shown in Fig. 2. During the night the heat pump supplies cold to the ice storage tank using night time power. Hot water, heated by the exhaust heat of the heat pump, is simultaneously pumped into tanks A and B. Paraffin wax with a melting temperature near 49 °C and 180 kJ/kg as latent heat is used in both tanks to store heat. The tanks (2.29 m width × 4.55 m length × 2.05 m height) are shell and tube

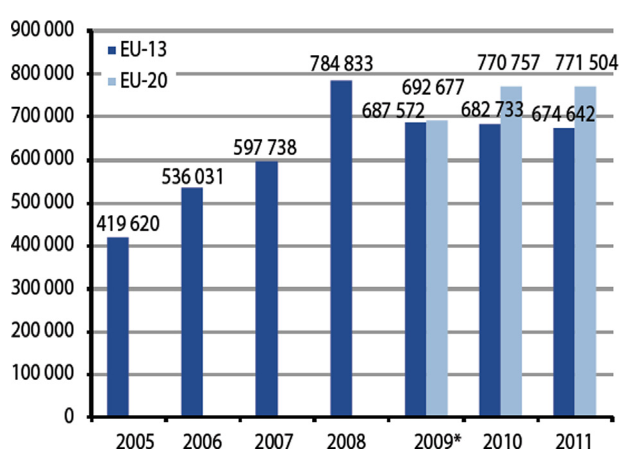

Fig. 1. Development of heat pumps sales from 2005 to 2011 in EU [5].