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Experimental study of a sorption cold storage supporting the air conditioning system

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Abstract

Techniques related to elimination of environmental pollution are divided into two main trends. These are primary and secondary solutions. Primary solutions are based on the creation / selection of technologies that do not emit pollutants, secondary solutions are used in the situation that pollutants are already generated. Elimination is made by selected technological processes. When using residential, office or industrial buildings, emissions are primarily associated with the use of energy carriers such as electricity, heat or cold. During electricity production, pollution is related mostly to the atmosphere degradation. Thus, any solution that reduces energy consumption or improves the energy efficiency of buildings is the primary method of environment protection. This article proposes and investigates an idea of cold storage system based on an adsorbent bed (silica gel), which aims to reduce the energy consumption of the domestic air conditioning system. As a result of experimental research, it was shown that for a building with a volume of 1000m^3 and multiples of air exchanges at 0.5 level, a silica gel bed with a volume of 1.63 m^3 is required in order to continuously unload the air conditioning system for 8 hours (while outside air temperature exceeding 25^oC).

Keywords: adsorption, energy efficiency, cold storage

1 Introduction

An increase in the standard of living in Europe, causes the energy consumption for air conditioning is growing all the time [9]. While in commercial or office buildings air conditioning is a standard, in residential buildings, it is estimated market saturation at 10% (in Europe) and in Poland it is 8% [7]. In the United States, market saturation is 87%, and in Japan almost 100%. It is estimated that within a few years, air-conditioning systems will be the main energy consumers in buildings next to heating systems. For office buildings it is already a fact - the Figure 1 presents the energy demand for an office building located in Warsaw [5].

Therefore, at this point it is worth considering the technologies that enable the reduction of energy consumption by compressor type domestic air conditioning systems. One of the solution is using of district cooling [6]. Another is magentocaloric system [11]. The other one of such solutions is the use of cold storage [10]. It is known that the efficiency of cooling generation depends on the temperature of the outside air. Therefore, it seems advisable to generate the cold at the lowest temperature and to use it when there is a demand. Cooling storage systems can be divided into several types [1, 2, 13]:

- cold storage as a cold water tank;
- cold storage using change of phase:
  - ice type;
  - binary ice type;
  - dry ice type;
  - other PCMs (phase change materials);
- cold storage using sorption phenomena.

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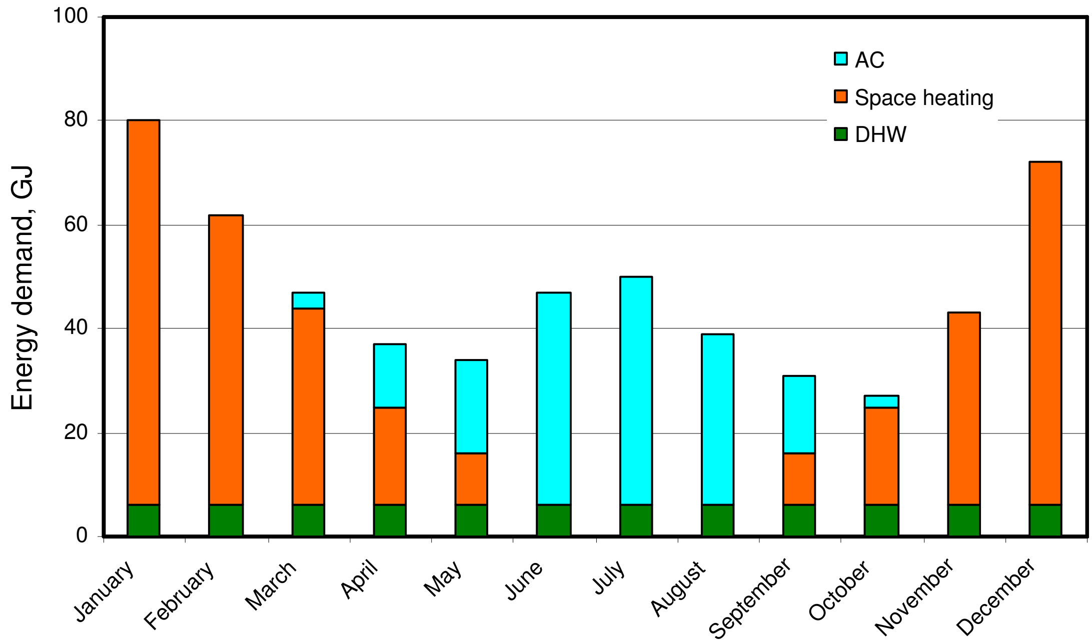

Figure 1. Demand for cold and heat in office buildings (AC – air conditioning, DHW – domestic hot water)

In all types of storage, a working fluid has to be used to storage energy. The cool storage medium, like the heat storage medium, should meet several conditions [1, 8, 14]. The working fluid should be:

- commonly available;
- cheap;
- environmentally friendly;
- non-flammable;
- non-explosive;
- non-toxic;
- compatible with materials used in popular HVACR systems;
- does not cause corrosion;
- chemically neutral;
- well-documented thermo-physical properties;
- high density;
- low viscosity;
- high specific heat (for non phase change storage systems);
- high thermal conductivity;
- works at low pressure;
- stable (the properties of the fluid should not change during long term usage);

Unfortunately, none of the real working fluids meet all the requirements at the same time. In cold storage systems, the most frequent are used: water, water-glycols solutions and water- salt solutions [2].

This work focuses on cold storage systems based on the sorption process. Figure 2 presents currently available sorption techniques used to store heat and cold [3, 4, 12, 15]

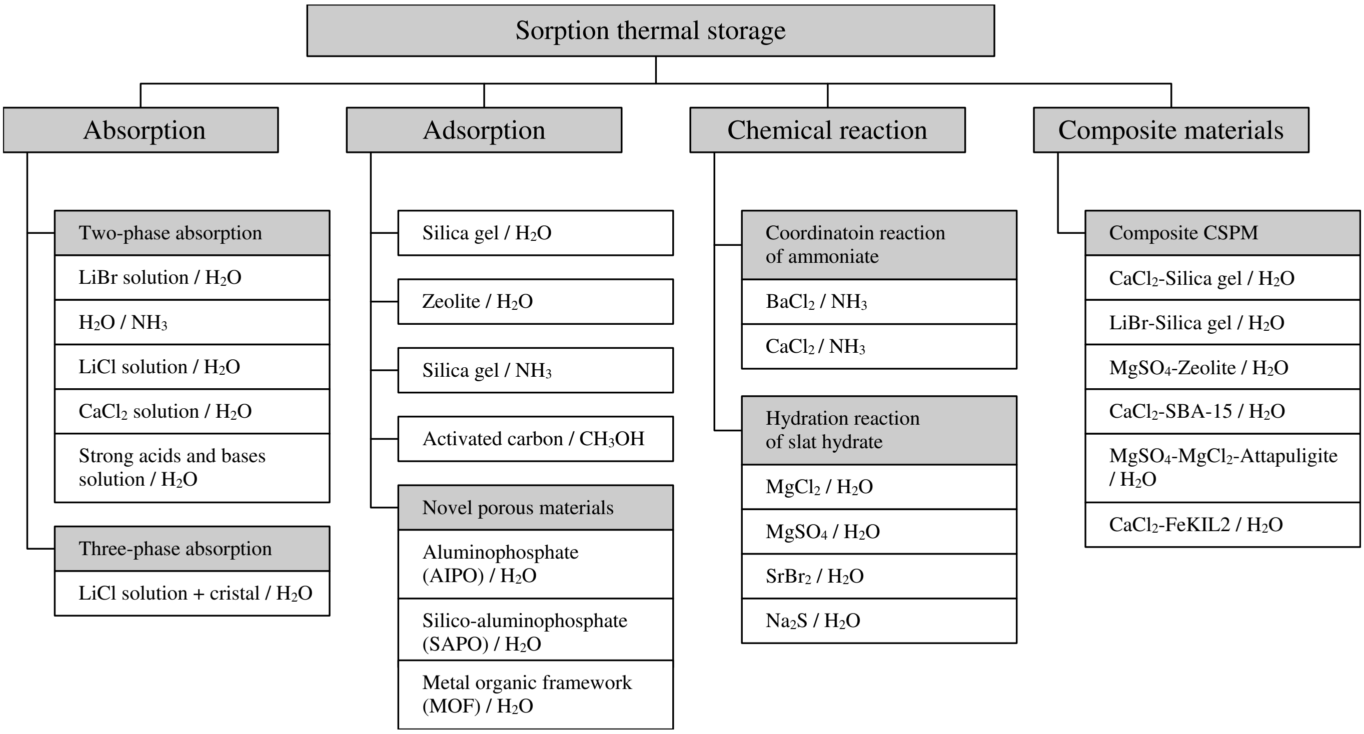

Figure 2. Sorption techniques for heat and cold storage (CSPM – Composite "Salt in Porous Matrix")

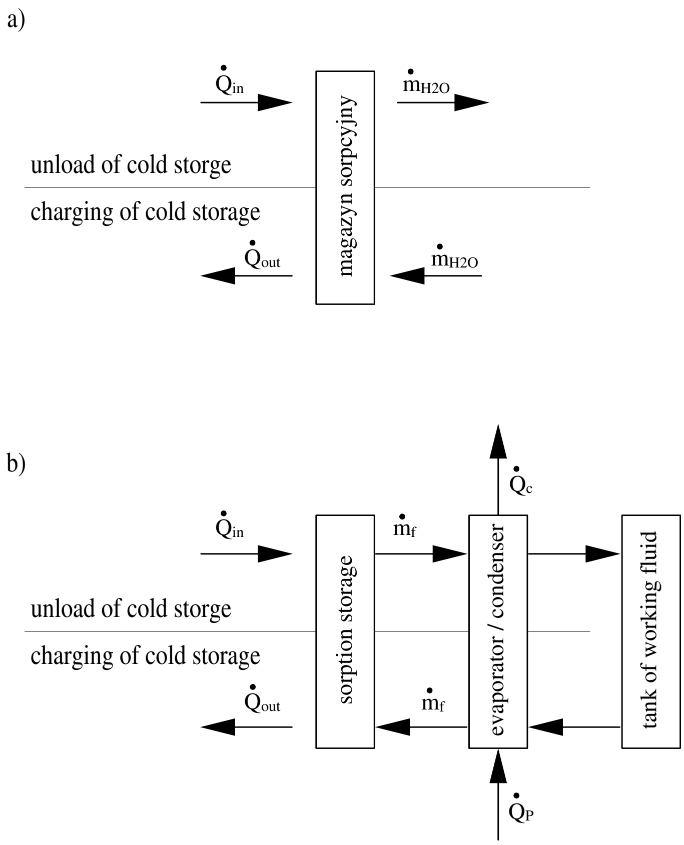

Figure 3. Cold storage sorption systems: a) open type, b) closed type

Adsorption cold storage systems can be divided into open and closed type (Figure 3). Working fluids used in closed adsorption bed storage systems are water, ammonia or methanol. In open systems, the working medium, for safety reasons is water (dissolved in the air – so it is humidity). Water goes directly to the environment at the time of desorption, and is absorbed from the environment during the adsorption period. In the case of devices in a closed system, the desorbed working medium goes to the tank, and then in the period of cold demand it returns from the reservoir to the bed. In the case of all sorption cold storage systems, the following parameters should be taken under consideration:

- storage density (kWh/m^3),
- load temperature,
- unload temperature,
- auxiliary energy needed for the transport of working fluid between heat exchangers.

2 Materials and methods

In order to analyze the possibility of using adsorbent beds for air conditioning purposes, a measurement stand was constructed as shown in Fig. 4. The stand consists of a fan, an air heater, a humidifier, a test adsorbent bed.

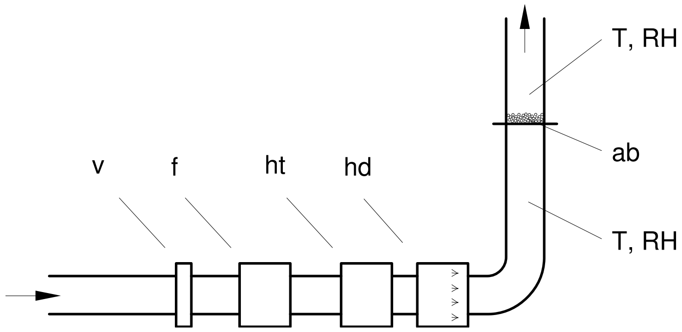

Figure 4. Measuring stand (v – measuring orifice, f - fan, ht - heater) hd - humidifier, T - temperature sensor, RH - humidity sensor, ad - adsorbent bed)

During the measurement, the temperature and humidity before and after the bed were measured. Silica gel was used as an adsorption bed (CAS No. 121226-00-8). The following items were used for measurements:

- temperature sensors in the form of K type thermocouple (accuracy class A);
- relative humidity sensors: HONEYWELL HIH-4000;
- Measuring orifice: Lenticular throttle IRIS 100.

The measuring device allows to change the inlet air temperature in the range of 10 to 40^{o}C and relative humidity in the range of 20 to 80%.

3 Results

Figure 5 presents the results of measurements for a 7.7 cm high bed in a 100 mm diameter pipe. The measured air velocity is 1.18 m / s, according to the equation:

$$q_v = A \cdot v = \frac{\pi \cdot d^2}{4} v \tag{1}$$

the volumetric air flow is 33.36 m^3/h.

The measurements show that the V_0=0.60 liter adsorption bed was able to decrease the outside air temperature for t_0=160 seconds. The results of the measurements were generalized to the air temperature in August 2018 in

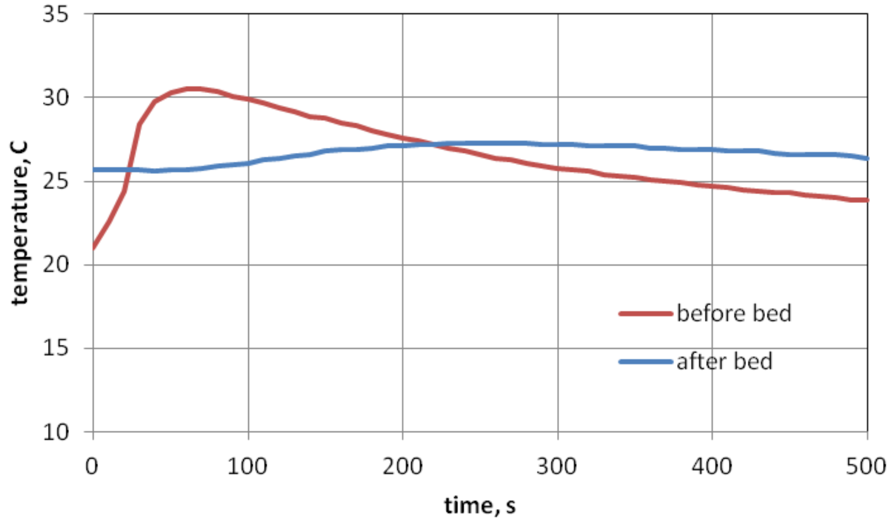

Figure 5. Change in air temperature before and after storage

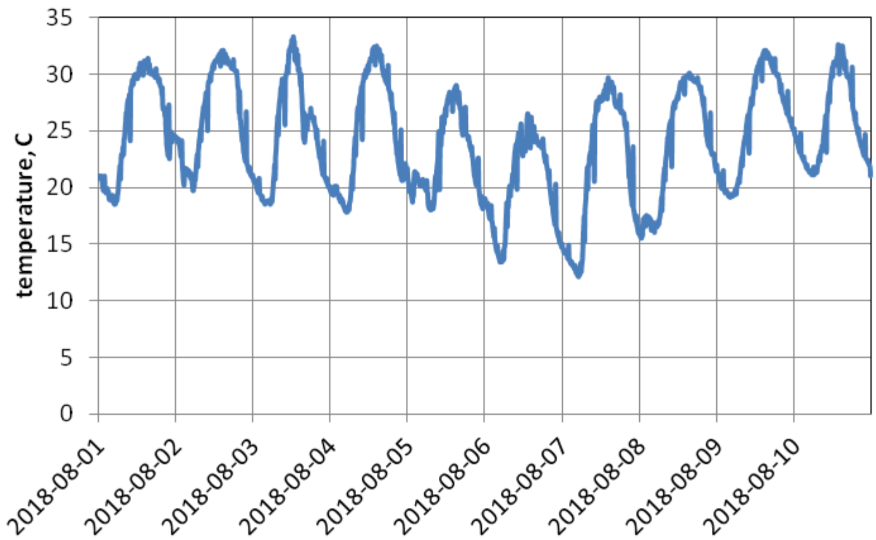

Figure 6. Air temperature from 1-10 August 2018

Warsaw (Figure 6). In the selected month during the day the temperature reached thirty-several degrees and at night it dropped to below 20^{o}C.

The aim of the generalization was to determine how large the adsorbent bed must be to allow the temperature to fall below 25^{o}C of the inflow air. Assuming that the air will flow through the bed all the time in one direction and that the building volume is 1000 m^3 (and the required air exchange rate is 0.5), to maintain the airflow temperature over 25^{o}C in Polish climatic conditions the bed must have V$_1$=1.63 m$_3$ volume. Generalization was made according to equation:

$$V_1 = V_0 \frac{t_1}{t_0} \frac{q_{v,1}}{q_{v,0}} \tag{2}$$

4 Conclusions

The adsorbent bed consisting of silica gel was tested for improving air conditioning system efficiency. The study involved a one-direction open type flow system. During the day, the system is designed to cool the air by regenerating moisture from the bed, during the night cold air transports moisture into the bed, and at the same time raising the air temperature. Experiment has confirmed that it is able to maintain the temperature below 25^{o}C in the air blown into the house throughout the summer period in Poland. For a building with a volume of 1000 m^3 and a air volume rate of 0.5, the bed must have a volume of 1.63m ^{3}. Regeneration of the bed of cold storage system occurs at night because in Polish climatic conditions in summer the temperature drops significantly compared to the day. For such large volume of the bed, the problem is the air flow pressure drop - the amount of energy needed to force the air through a bed of this size of bed can be greater than the energy needed for the production of cold in traditional way. It is possible to reduce the pressure drop through the appropriate construction of the bed - but it requires a large surface area of inflow. Experiment also shows that the solution is perfectly suited for heat storage system - however, in one-directional operation in the winter it is not possible to regenerate the bed during the day.

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