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EXPERIMENTAL STAND FOR IMPROVING THE ENERGY EFFICIENCY OF AIR SOURCE HEAT PUMPS

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Abstract: *The current climatic, political and economic situation, the constantly increasing price of electricity, requires the intensification of research in order to develop new methods of increasing the efficiency of heat pumps is an immediate desideratum. Because every percentage of efficiency has a major impact on the final operating costs, it is very important to design and make the most efficient system for heating and cooling installations. The paper presents the development of an experimental stand with air source heat pumps, which offers the possibility to control and determine the influence of the functional parameters so that the increase in efficiency is possible. The proposed solution increases the efficiency of the heat pump in the same climatic conditions, by heating or cooling the air taken by the evaporator's fan, but in the presented configuration it also eliminates the disadvantages of using the climatic well to ventilate the rooms.*

Keywords: *Heat pump, climatic well, energy saving, COP increase*

1. Introduction

In recent years, climate changes are felt more and more acutely through the occurrence of extreme weather phenomena with an increasing frequency, extreme heat waves are no longer isolated cases and with low frequency, but become periods of time with records in overcoming the most high temperatures, torrential rains with unusually high wind speeds, but also a continuous warming of the oceans, which implicitly leads to the melting of glaciers and the rise of sea levels, at a much faster rate than that observed in the last 50 years. The European average temperature for August 2022 was by far the warmest ever recorded for August, 1.72°C above the 1991-2020 average and 2.24°C above the 1981-2010 average. [1]

The "Fit 55" package includes a proposal to revise the Renewable Energy Directive. The proposal is to increase the current EU target of at least 32% of energy from renewable sources in the global energy mix to at least 40% by 2030, with a net greenhouse gas emissions by at least 55% by 2030. [2]

In order to decarbonize the economy but also to strengthen Europe's geopolitical energy independence, the solution with the highest energy efficiency in the use of electricity obtained with the help of renewable sources in applications for heating and / or cooling is the one with compressor heat pumps.

Despite the negative consequences of the coronavirus pandemic as well as challenges in global supply chains, demand for green air conditioning solutions continued to grow by around 30%. [3]

In the last two years, demand has exploded with the increase in energy prices, the war in Ukraine and the Russian gas crisis, and the upward trend is valid for the whole of Europe.

In these conditions where the price of electricity has a constantly increasing trend, the intensification of research in order to develop new methods of increasing the efficiency of heat pumps is an immediate desideratum. Each percentage of the efficiency has a major impact on the final operating costs and therefore the importance of designing and making a system as efficient as possible of heating and/or cooling installations with heat pumps is very high.

A solution for improving the energy efficiency in case of residential buildings is represented by heat pump systems (HPS), which are modern heating installations composed of the actual heat pump, the heat supply and distribution installation and the indoor central heating installation.

There are three main types of heat pumps used in residential HPS (figure 1):

- heat pumps with the outside air source
- heat pumps with the ground source,

- heat pumps with underground water source.

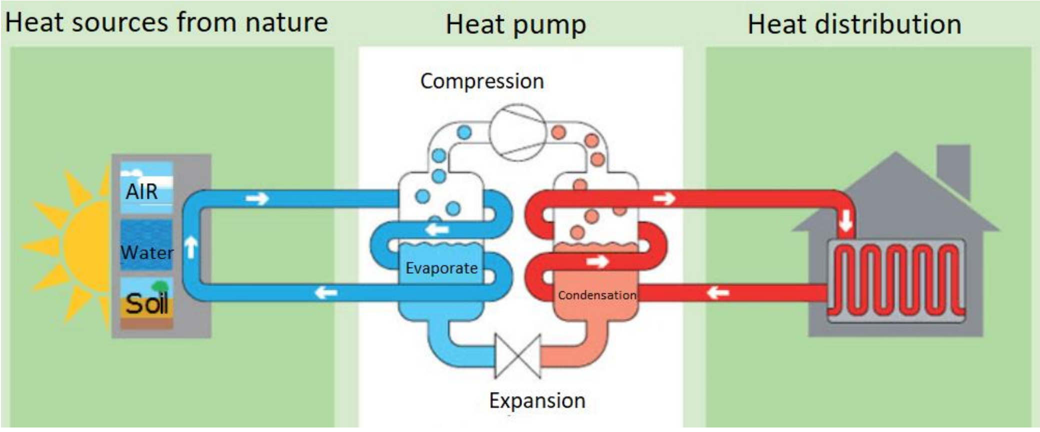

Fig. 1. Heat pump systems classification [www.ct1.ro]

The most affordable heat pumps, whose installation does not require drilling or complicated construction work, represent the first category, figure 2.

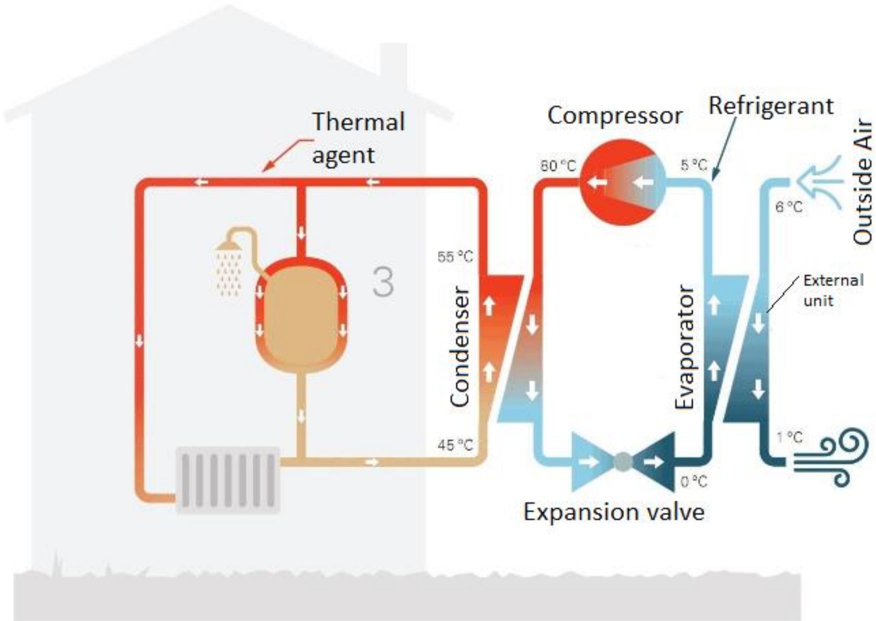

Fig. 2. Air source Heat pump [www.trust-expert.ro]

The energy consumption and the operating performance of air source heat pumps depend on many parameters such as: the climate zone, the thermal demand of the building, the indoor heating system, the number of hydraulic loops, thermal inertia, the size of the heat pump, the modulation of the pump and the automation adapted for each component of the HPS (terminal units, heat pump, circulation pumps, etc.).
For high efficiency, it is important that HPS are used both for heating and domestic hot water in the winter and in reversible mode during the summer, ensuring cooling and domestic hot water.
There are studies and analyses, in the literature, related to the operation of heat pumps with different types of heating installations: cast iron radiator, bimetal radiator (steel-aluminium), fan convectors and radiant floor. The operating costs of HPS with cast iron radiator, bimetal radiator, fan coil and radiant floor heating are 33%, 41%, 42% and 47% lower than the operating cost of an electric heating system. [4]

The performance of heat pumps can be assessed through a series of factors (specific electricity consumption, renewable energy supplied, seasonal performance coefficient) but the most important indicator that characterizes the operation of the heat pump is the coefficient of performance (COP). It is defined as the ratio between the useful thermal power produced ($E_{thermal}$) and the drive power of the heat pump ($E_{electrical}$). [5]

2. Objective

The reduction of electricity consumption for the same amount of thermal energy produced by an air-water type heat pump, in same climatic conditions, can be obtained by changing the temperature of the primary source (the air) that bathes the vaporizer (the heat exchanger from the primary source to refrigerant).
A passive method of heating or cooling the air taken from outside used in the ventilation of houses is climatic (Canadian or Provençal well, figure 3), is a simple and shallow geothermal system, capable of taking advantage of the stable temperatures of the subsoil surface layer. Its functioning is based on the fact that the underground temperature differs from that of the environment. This difference is accentuated at approximately two meters of depth, where it remains stable in increasingly lower temperature ranges (depending on the area at 10 m depth, the temperature variation throughout the year can be in the range of 9-11°C, figure 4 for Romania). As disadvantages of using climatic wells in ventilation, can mention those related to the possibility of infiltration of dangerous chemical substances in the case of the use of inappropriate materials or the poor installation of pipes and the creation of mold due to condensation.

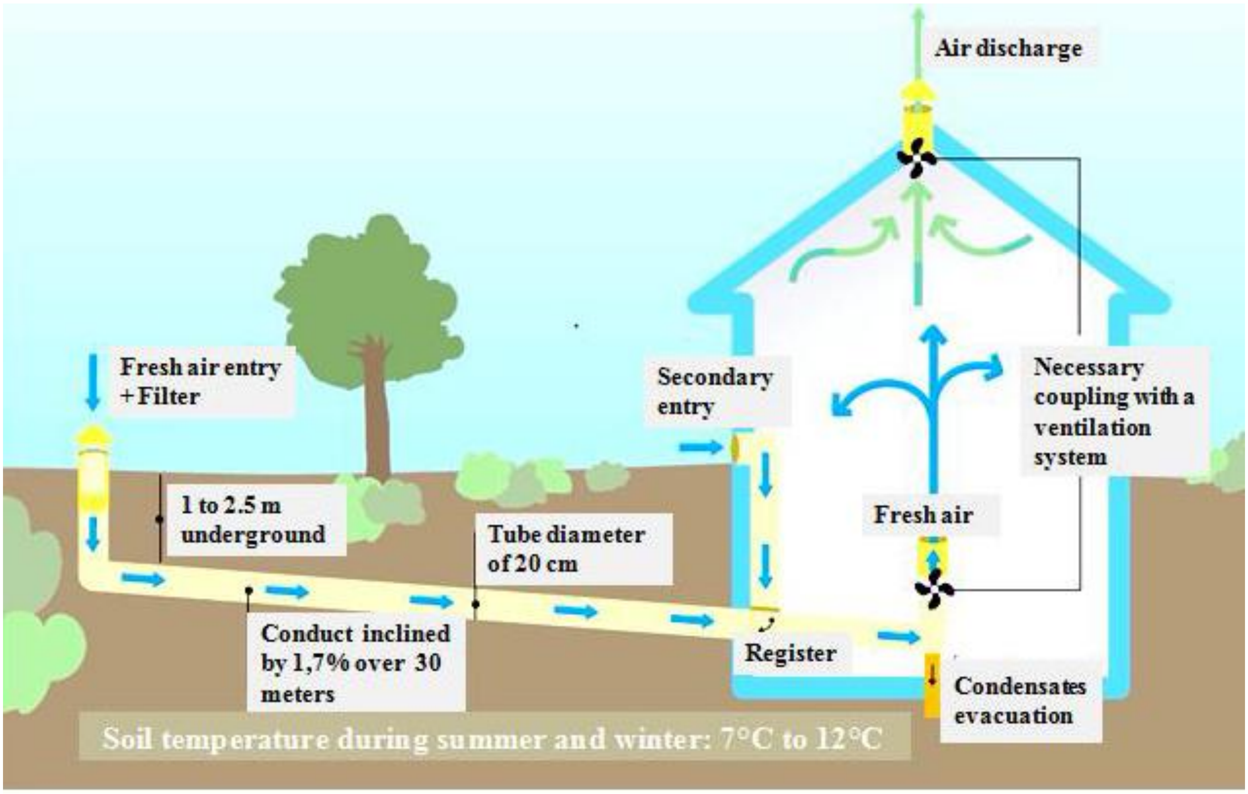

Fig. 3. Diagram of operation of a climate well. Source: ADEME-2012 (The French Agency for Ecological Transition)

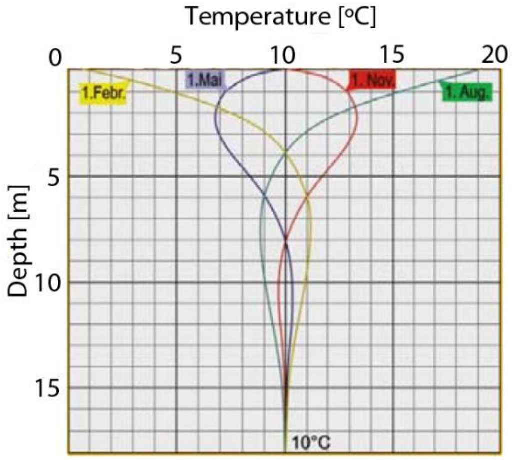

Fig. 4. Soil temperature variation [6]

Thus, the purpose of the work is the creation of an experimental stand, which, through temperature, humidity, pressure and speed sensors, allows establishing the influence of the physical quantities in the system that affect the consumption of electricity, as well as the variation of the functional parameters in different climatic scenarios, in the case coupling a heat pump whose source is outside air, with a climatic well. The system can be used in the passive version (without auxiliary fans), only the heat pump fan is used for the air flow from the Evaporator, or semi-passive in which the air flow through the underground pipes is created with the help of low power auxiliary fans.

3. Experimental setup

The components that are part of the experimental stand are shown in figure 5.

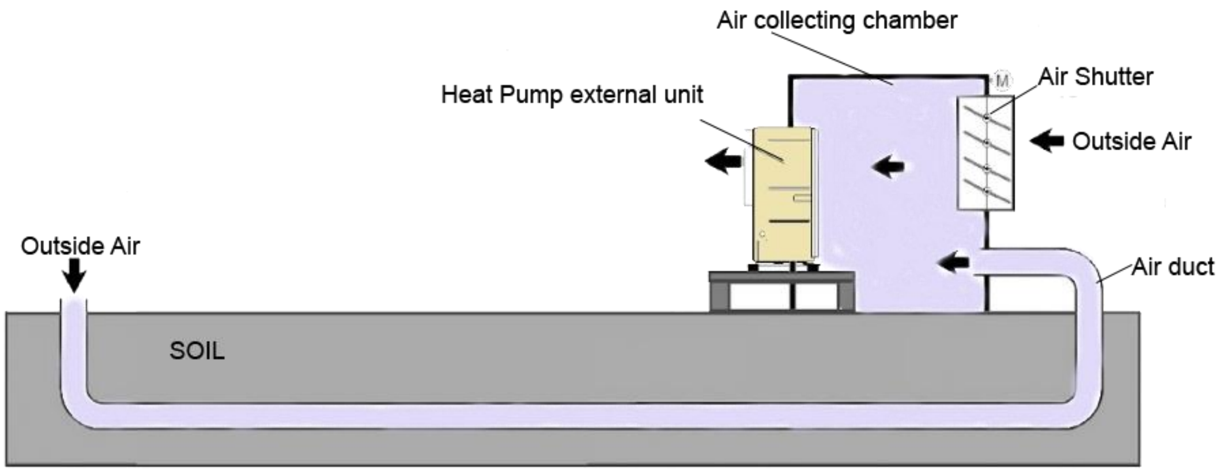

Fig. 5. Schematic experimental stand

The stand contains an air-water heat pump with a power of 6 kW, which provides the heat required for a residential house. The maximum air flow to the fan of the external unit of the heat pump in heating mode is 2530 m^3/h. For an optimal thermal transfer through the piping below the ground level, the speed should be between 2 and 4 m/s, thus the required section is (A=Q/v) 0.17...0.35 m^2. For the stand described in the paper, a number of 6 pipes with an internal diameter of 190 mm, i.e., a total area of 0.17 m^2 was chosen. The speed of the air through the ducts, for different values of the flow rate, is presented in figure 6.

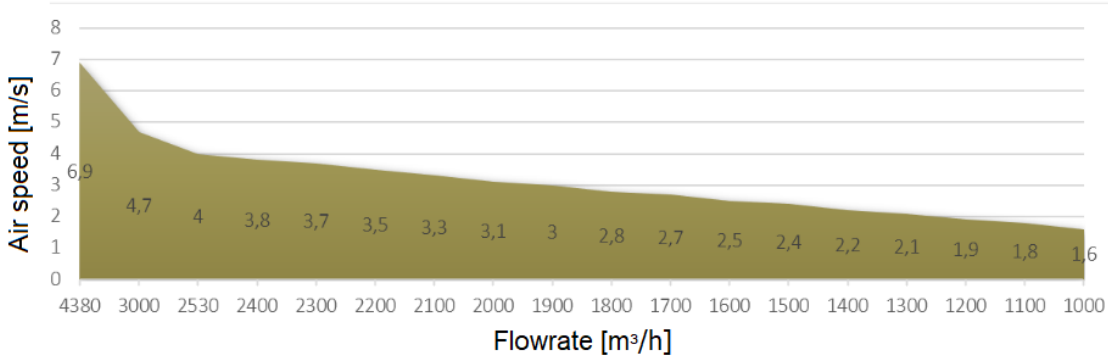

Fig. 6. Air speed in the climatic well depending on the flow rate

The total length of the pipes is 24 m, the depth below the ground surface is 2 m for three pipes and 1.5 m for the other three. The distance between them is 1 m. The useful volume of the collector chamber is 7 m^3 and it is provided with an opening for the admission of outside air, without passing through the climatic well, controllable with a motorized shutter.
To calculate the total pressure loss in the air circuit, we must add up the pressure loss in each element of the circuit. The pressure loss due to the friction when air flows, is calculated according to the empirical known relationship:

$$\Delta P = f_a \cdot \frac{L}{d} \cdot \rho \cdot \frac{v^2}{2} \quad (1)$$

where: L - represents the length of the pipes [m]; d - inner diameter [m]; ρ - density of the fluid [kg/m3]; v - average flow velocity [m/s]; f_a - Darcy's coefficient of friction.
In order to ensure the flow rates entering the collection chamber at the entrance in the climatic well, auxiliary axial fans with a maximum power of 10 W were installed.
The propagation model of heat conduction in a semi-infinite solid (soil) proposes an analytical solution when the surface temperature of the solid is sinusoidal. The outside air temperature, T_{air} will be conveniently expressed [7]:

$$T_{air}(t) = m + A\sin(\omega t - \varphi) \quad (2)$$

Solving the heat equation for a transient semi-infinite environment whose surface temperature is imposed by equation (2) we obtain the soil temperature function of depth x, in equation (3). In this model the solutions are also sinusoidal with the same period and pulsation as the temperature signal but whose phase and amplitudes vary with the depth considered. [7]

$$T_{soil}(x,t) = m + A \cdot e^{-x\sqrt{\frac{\omega}{2\alpha}}} \cdot \sin\left(\omega t - \varphi - x\sqrt{\frac{\omega}{2\alpha}}\right) \quad (3)$$

where: α - thermal diffusivity, the ratio of the thermal conductivity to the volumetric heat capacity. It is an indicator of the rate at which a temperature change will be transmitted through the soil by conduction; m - mean period temperature [°C]; A - amplitude of the temperature variation [°C]; ω - pulsation [rad/s]; φ - phase shift [rad].
The experimental stand with the air source heat pump, climatic well and air collecting chamber was made at a residential building in Cluj County, Romania, as can be seen from figure 7. The experimental stand has just been completed and equipped with sensors and data acquisition so that the measurements that last a year will begin.

Pipe 1.5 m depth | Pipe 2 m depth Temperature sensor | Heat pump air source Air collecting chamber | Outside air shutter

Fig. 7. Air source heat pump with climate well experimental setup

4. Conclusions

The efficiency of the climatic well upstream of the heat pump, will vary depending on the nature of the soil, its rate of aeration and moisture, the air flow speed in the pipes, pressure drop, etc.
The proposed solution increases the efficiency of the heat pump in the same climatic conditions, which uses the thermal inertia of the ground to preheat or cool the air taken by the evaporator fan.
The built stand allows the measurements for the four seasons and the determination of the coefficient of performance (COP) of the new system.

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