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An Experimental Analysis of Heat-Pump Integrated With Solar Energy

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Abstract: *The objective of the present work is to analyze the performance of an equipment used in water heating for domestic and commercial use. The hot water is obtained by conventional vapor compression heat pump machine, using the R-134a as primary fluid refrigerant. This way, the plate evaporator or thermodynamic panel is in contact with the hot source originated from incandescent lamp, simulating the solar energy and the condenser is in contact with the cold source represented by the thermal storage tank. Two radiators are used to collect the hot water that comes from the thermal storage tank. The parameters analysed in the research are the energy dissipated by the radiator, the COP of system and the variation of the water flow rate.*
Keywords: *Heat-pump, thermal energy storage, solar energy*

I. Introduction

This article shows a heat pump working with thermodynamic panel. A heat pump is an electrical device that extracts heat from one place and transfers it to another, similar to an air conditioner, but inversely working and are quite efficient equipment but the heat they produce from their renewable energy varies only according to changes in the temperature of the environment. Heat pumps transfer heat by circulating a substance generally a fluid refrigerant through a cycle of evaporation and condensation. A compressor pumps the fluid refrigerant between two heat exchanger coils. In one coil, the refrigerant is evaporated at low pressure and absorbs heat from its surroundings. The fluid refrigerant is then compressed to the other coil, where it condenses at high pressure. At this point, it releases the heat it absorbed, for example, for the water, where water heating is a significant user of energy. Heat pumps can use many sources to provide energy to heat the working fluid, generally using electricity or gas. The solar energy also represents an interesting source, after all is a free energy. The basic difference between the conventional solar heater and thermodynamic panels, is that solar thermal panels heat water in the panels, where thermodynamic ones heat a fluid refrigerant. Heat pump water heaters utilizing thermodynamic panel have received a higher degree of attention in the literature and hence shall be discussed here. According Hepbasli et al. [1] with water heating being the second largest use of home energy in most locations, there has been renewed interest in the development and use of energy-conserving domestic water heater since the 1973 oil embargo. Also was made several informations about heat pump water heater (HPWH) operated on an electrically driven vapor-compression cycle and pumps the energy from the air in its surroundings to water in a storage tank**.** In accordance with Wang et al. [2] was made one experimental research under typical spring climate in Shanghai with direct expansion solar- assisted heat pump to water heater. The authors analyzed the performance with results of exergy analysis, been able to calculate that the highest exergy loss occurs in the compressor, followed by collector/evaporator, condenser and expansion valve, respectively. Chaturvedi et al. [3] developed a study with energy solar two-stage direct expansion assisted by heat pump for high temperature applications were analyzed. Comparisons between the solar two-stage and the single-stage direct expansion, assisted by heat pump systems were performed and presented, since the two-stage cycle has higher performance level. According to Bakirci et al. [4] a solar source heat pump system was experimentally investigated. The authors investigated the COP of the whole system and the heat pump systems. Besides, they also highlighted the solar source heat pump systems as presenting tremendous environmental benefits when compared to the conventional systems. Moreno et al. [5] proposed the development of a theoretical model to determine the operating parameters and consumption of a domestic hot water installation, which uses a direct expansion solar-assisted heat pump. The model's results have been compared and validated the experimental results obtained with the equipment installed at the Charles III University of Madrid. In accordance with Banister et al. [6] a computer's model was validated for an experimental test apparatus and a method were presented for testing multiple configurations of solar-assisted heat pump systems. The performance of many system components is dependent on the fluid temperature(s) at the inlet and the experiments conducted indicated that thermal storage tank models are a key factor determining the accuracy of overall results. By means of Wagar et al. [7] the work explores the operation and performance of a solar-assisted heat pump system which employs a single domestic hot water (DHW) tank. The simulations tool is validated using a purpose-built experimental test apparatus and it was noted that the biggest discrepancies between model and experimental test is the response rate of temperature changes. Praveen et al. [8] developed a methodology combining, a quadratic model for predicting solar collector temperature and a model for predicting the overall DX-SAHP system performance for domestic applications. According to the authors, the thermal performance results calculated, using the proposed methodology, for six locations in the USA shows that the DX-SAHP water heater has significant energy conservation potential compared to the electric-only hot water heater. It was compared [10] a experimental and numerical study of DX-SAHPWH system and conventional ASHPWH system is taken in various environmental conditions under the climate situation of Shanghai, China.

II. Experimental Investigation

Fig.1 shows a schematic diagram of the experimental setup. The thermal storage tank is made of steel with 350 mm internal diameter, 1500 mm in length, and 10 mm thickness, insulated by a 50 mm layer expanded polyurethane. The refrigeration unit is a simple vapor-compression cycle, operated with R-134a. It includes a hermetic compressor (1/4hp), condenser (natural type), filter drier, thermostatic expansion valve, a thermodynamic panel with 1.6m^2 area and two radiator connected in series with 0.63m^2 of total area of each radiator.

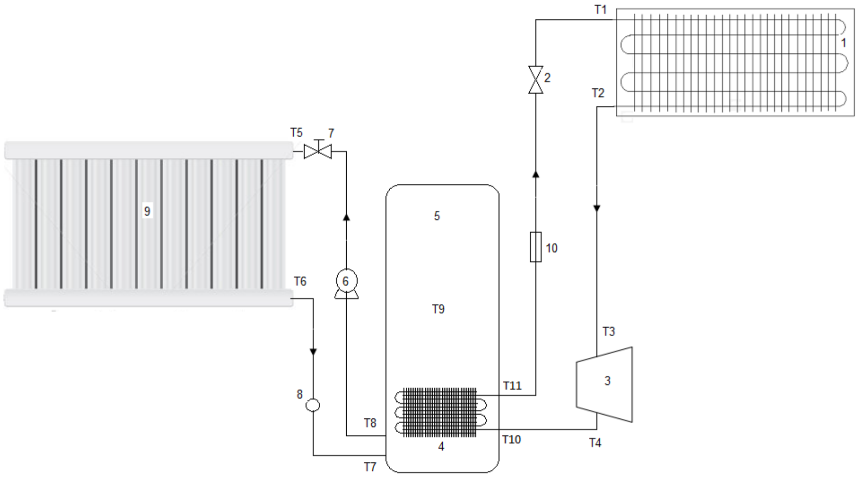

Fig. 1. Schematic diagram of experimental setup. (1) thermodynamic panel, (2) expansion valve, (3) hermetic compressor, (4) condenser, (5) thermal storage tank, (6) circulating pump, (7) flow control valve, (8) digital flow meter, (9) radiator, (10) filter drier.

The solar energy is simulated by an incandescent light bulb with a power of 250W and the thermal energy released by the light bulb goes in to the thermodynamic panel by the irradiation primary process. Then, the thermal energy is transferred to the fluid refrigerant that is circulating through the refrigeration cycle. The fluid refrigerant in form of gas then passes through a compressor which increases the temperature and finally through a heat exchange coil inside the thermal storage tank. So, part of the thermal energy received by the light bulb goes in to the water of the thermal storage tank, the remaining portion is lost by heat transfer processes by conduction through the walls of the thermal storage and pipes of conduction. When the water reaches the prescribed temperature, the entry to the radiator is opened to receive the hot water circulated by pump. The results were analyzed by means of adjustment the inlet valve of each radiator, that is, one of the main results are the effects of thermal energy dissipated by the radiators in respect of the electricity consumed by the compressor. The measuring unit consists of 11 platinum resistance temperature sensors (Pt100) and a flow meters to measure the volumetric water flow rate. Also, is used the data acquisition unit and a personal computer for data recording and analysis. Temperature and flow rate measure points were arranged accordingly in the system, and the measuring range and the accuracy of measurement devices are listed in Table 1.

Table 1- Range and accuracy of measurement devices

Nº	Measuring point name	Device accuracy
T1	Inlet coolant temperature in the thermodynamic panel	±0,3°C
T2	Outlet coolant temperature in the thermodynamic panel	±0,3°C
T3	Suction temperature of the compressor	±0,3°C
T4	Discharge temperature of the compressor	±0,3°C
T5	Inlet water temperature in the radiator	±0,3°C
T6	Outlet water temperature in the radiator	±0,3°C
T7	Inlet water temperature in the thermal storage tank	±0,3°C
T8	Outlet water temperature in the thermal storage tank	±0,3°C
T9	Temperature in the thermal storage tank	±0,3°C
T10	Inlet coolant temperature in the condenser	±0,3°C
T11	Outlet coolant temperature in the condenser	±0,3°C

Fig. 2 - 5 shows the photographs of the experimental setup and PC data acquisition system. All equipment's shown in figures, can be found and visited in Superior Institute of Engineering of Porto, specifically in thermal and fluids laboratory.

Fig. 2. Thermal storage tank and compressor

Fig. 3. Thermodynamic panel

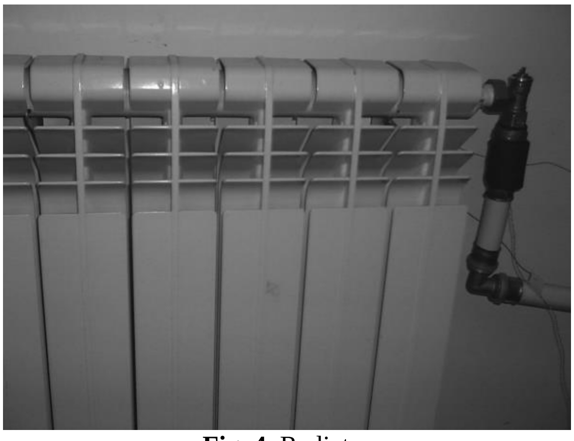

Fig. 4. Radiator

Fig. 5. Data acquisition unit

III. Results And Discussions

The question is: how much electric energy is consumed for obtain specific amount thermal energy? the answers to this, will be found in the results obtained. The analysis of experiments was made in a total duration of 24 hours for each reporting period. The process does not need constant supervision, that is, the data acquisition unit is automatic during the course of time.

3.1 Energy dissipated by the radiator and electrical energy compressor

The electric energy consumption of the compressor during the heat pump operation is shown in Fig.6 with the maximum flow rate of radiators. This way, how greater the energy dissipated by the radiator, greater the energy consumption of the compressor will be. The energy dissipated by the radiator was measured according to measurement the energy consumed by the compressor while working. The energy dissipated can also be determined by relation between the circulating hot water flow and the temperature difference at the inlet and outlet of the radiator. The coefficient of performance (COP) of the system is obtained by the ratio of energy transferred to the radiators to the electric power consumption of the compressor. In general, typical COP values for air conditioning and heat pump systems are in the range 2 to 4. It was reported a COP of 3.8 in applications a ground source heat pump (GSHP) [9].

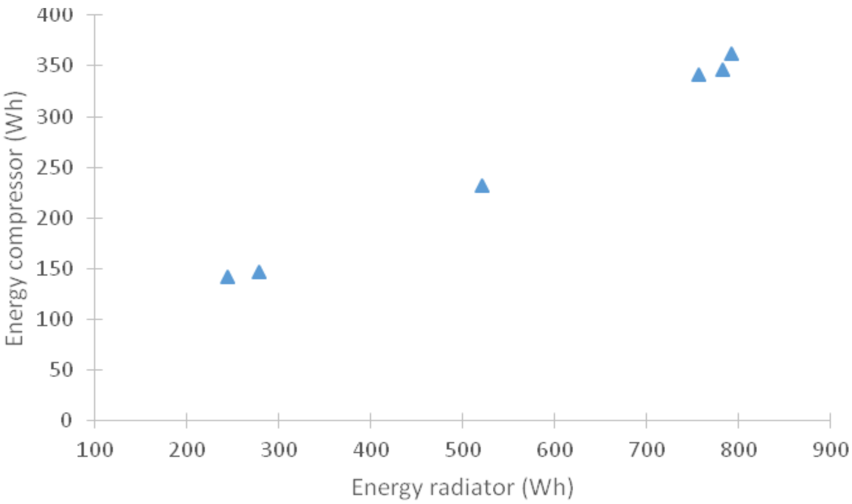

Fig. 6. Energy dissipated by the radiator and energy compressor

3.2 Analysis of the flow rate control valve

The purpose of flow control in a heater water is practically to regulate fluid speed. Flow rate also determines rate of energy transfer at any given pressure. Therefore, the energy dissipated by radiator is dependent of hot water flow rate that is circulating through the heat exchanger in the radiator. Fig. 7 and 8 shows the results of energy dissipated by radiator, the COP system and the hot water flow rate. It can be seen that the increase of the flow rate and energy dissipated by radiator increase the system COP. Due to the hot water flow rate variation, greater pump consumption resulted in larger dissipation of energy by the radiator. It can also be seen, the curves are similar, for, increasing the flow of hot water also increases the energy dissipated, staying more obvious in Fig. 9.

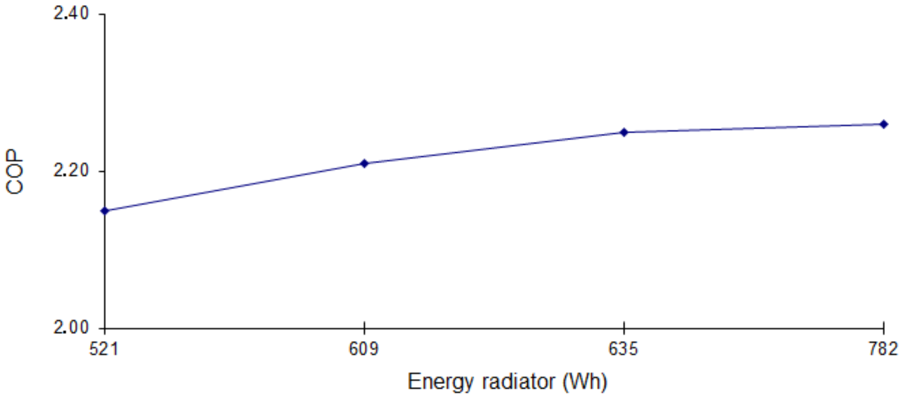

Fig. 7. Effect of the energy radiator on the COP

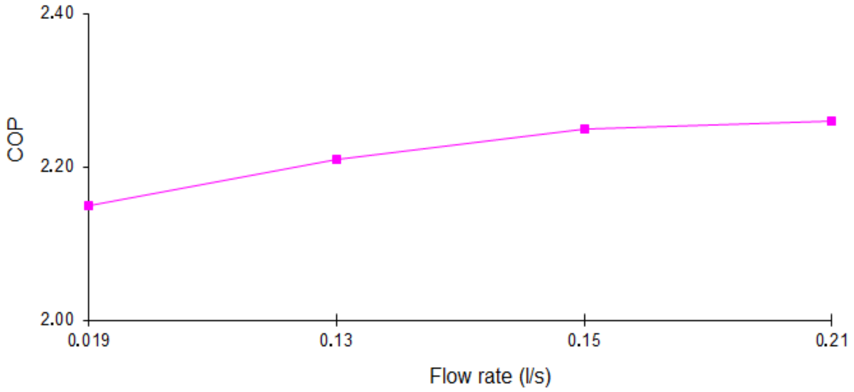

Fig. 8. Effect of the flow rate on the COP

Fig. 9 show comparative results of the energy compressor and energy radiator in the COP effect, during operation of the experiment with the flow rate variation. It can be seen that the increase of the flow rate, greater the energy dissipated by the radiator with high value of COP. In case of residential or commercial use, the control valve serves for the regular to heat intensity in the environment. In doing so, the correct ajustment of valve directly influences the results of the intensity of the thermal energy transferred by radiators.

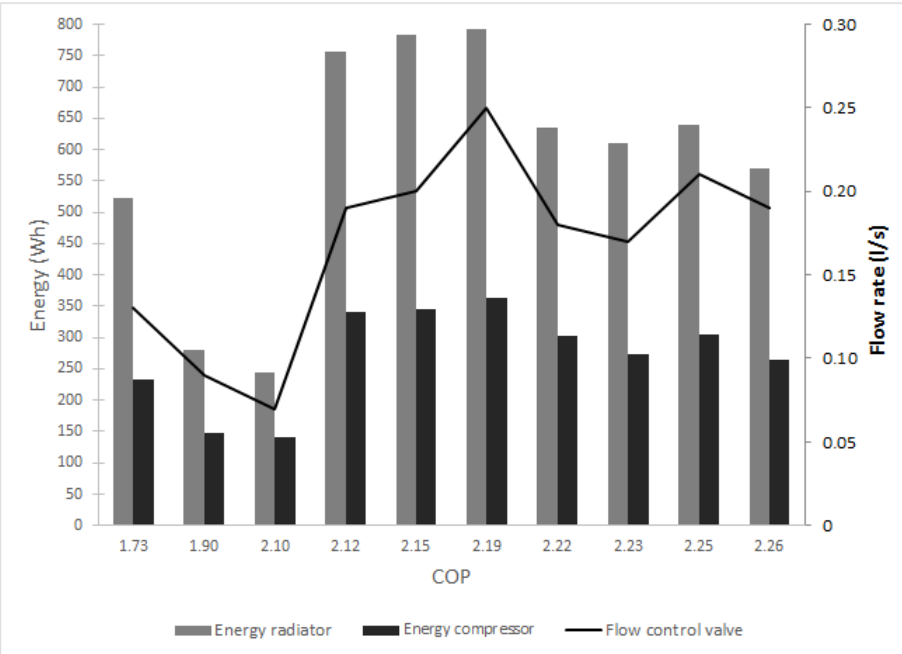

Fig. 9. Effect of the energy on the COP

Fig. 10 shows the variation of temperature in the water storage and the energy radiator in full operation. It is expected that according to the temperature increase, greater is the energy dissipated by radiator. There is also a certain relationship with the temperature of the thermal storage tank and the COP system, for example, higher temperatures offer higher energy dissipated by the radiator for smaller amounts of energy consumed by the compressor. Fig. 11 illustrates the temperature of the radiator inlet and outlet versus time day. As shown in Fig.11, the inlet temperature it is almost the same the thermal storage tank. When passing through the radiator coils, the hot water loses heat to the environment, this way, transmitting the thermal energy coleted of the thermodynamic panel. It can also be seen after 5:00, the inlet and outlet temperatures is decreased because the thermal storage tank loses heat to the enviroment during the experiments, also, due to decreasing enviroment temperature.

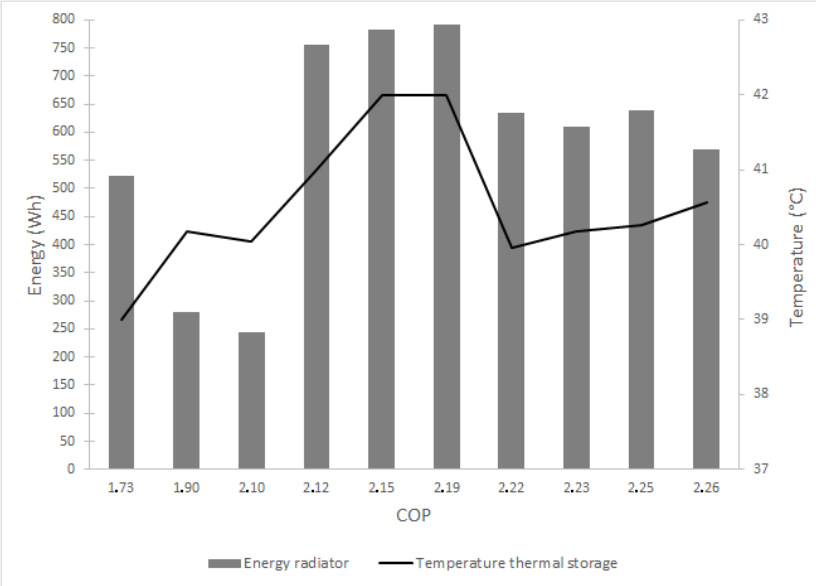

Fig. 10. Effect of the temperature of thermal storage on the COP

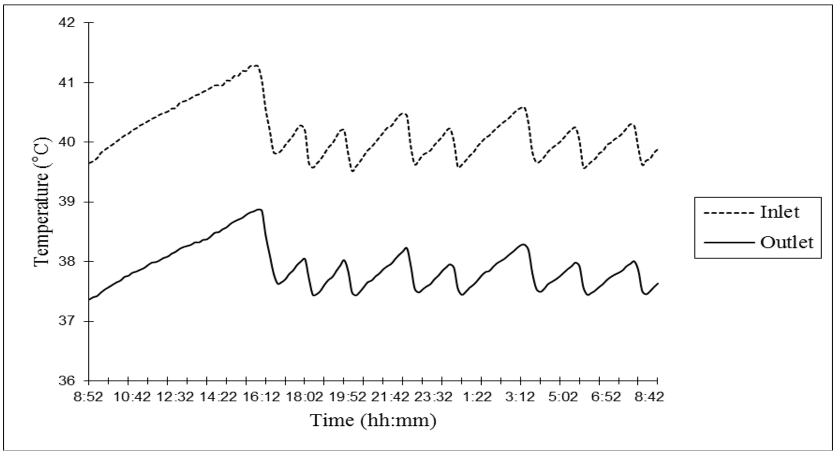

Fig. 11. The temperature in the radiator versus time of day.

IV. Conclusions

This paper investigated the thermal performance of a domestic hot water and space heating installation with analysis of the electric energy consumption of the compressor and energy dissipated by the radiator. It was observed that it is not recommended that radiators work with their reduced hot water flows rate, thus compromising the release of thermal energy and the consequent decrease in the COP. The energy consumed by the compressor will depend exclusively on thermal energy dissipated by the radiators. The phenomenon observable in the experiment, for example, the energy transfers to thermodynamic panel, the storage tank and the radiator contributed to the direct results of the process efficiency. The present study shows that the overall performance can be better if the thermal storage operates in higher temperature, for this reason, the thermodynamic panel will have to receive the maximum possible energy where practically it depends on the climate of the region in the equipment installation.

Acknowledgements

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