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DATA ACQUISITION SYSTEM FOR ANALYZING THE THERMODYNAMIC PERFORMANCE OF AN AIR–WATER HEAT PUMP

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Abstract: The carbon dioxide emissions that lead to climate change, together with the increase in the price of electricity and fossil fuels, make it necessary to reduce energy consumption and increase the use of renewable energy in buildings, in addition to the field of mobility. An efficient solution for preparing domestic hot water and heating homes is represented by heat pumps. The development of new models of heat pumps that include new technical and technological solutions for heat exchangers, compressors, motors, inverters and controllers, requires the evaluation of the coefficient of performance (COP). This article presents a data acquisition system for testing a heat pump made with a low–cost programmable logic controller.
Keywords: DAQ, heat pump, PLC, coefficient of performance

1. INTRODUCTION

An efficient solution for preparing domestic hot water and heating homes is represented by heat pumps.

The heat pump is a thermal machine that transfers thermal energy from an environment with a lower temperature to an environment with a higher temperature with an input of work. The work is done by a compressor, driven by an electric motor, which circulates a refrigerant.

The energy supplied by the higher temperature exchanger, (E), comprises the energy collected by the low temperature exchanger, (Q), from the heat source summed with the auxiliary energy, (q) (1). Auxiliary energy is represented by the energy used by the compressor, fan and circulation pumps.

$$\mathrm{E} = \mathrm{Q} + \mathrm{q} \tag{1}$$

In real operating conditions, in the above relationship losses also occur; these cannot be fully recovered, and the relationship becomes:

$$\mathrm{E_{HP}} = \mathrm{Q_{out\ HP}} + \mathrm{Q_{lost\ HP}} - \mathrm{Q_{in\ HP}} - \mathrm{k_{rt\ HP}} \mathrm{W_{HP}} \tag{2}$$

where: E_{HP} – the electrical energy used by the heat pump; $Q_{out\ HP}$ – the energy supplied by the heat pump; $Q_{lost\ HP}$ – the energy lost by the heat pump; $Q_{in\ HP}$ – thermal energy taken by the heat pump from the ambient environment; $k_{rt\ HP}$ – the fraction recovered from the auxiliary energy; W_{HP} – auxiliary energy.

The development of new models of heat pumps, which include new technical and technological solutions for heat exchangers, compressors, motors, inverters and controllers, requires the evaluation of the coefficient of performance (COP).

The efficiency of a heat pump depends on factors such as:
- a climatic zone in which it operates – which affects the coefficient of performance of the heat pump and the demand for heat and the maximum load
- the performance of auxiliary equipment such as fans, circulation pumps and controllers
- technology – the types of components used such as compressor motors and heat exchangers and the way the system is designed
- the quality of the heat pump controller which influences the fidelity of tracking the thermal energy delivery with the heating demand and how close the actual operating temperatures will be to the theoretical optimum temperatures

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— the sizing of the heat pump and its components in relation to the heat demand will affect the delivery of thermal energy and the times of low load operation.

One way to improve the performance of a heat pump is by using heat exchangers that provide, in addition to the usual subcooling, respectively desuperheating and cooling of the oil in the compressor, as well as an additional subcooling, thus increasing the efficiency of the system, i.e. increasing the coefficient of performance COP.

Other authors have also created data acquisition systems with PLCs or various monitoring and remote control systems based on sensors and networks. Thus, *Puchun and Jinhai, 2013* developed a data acquisition system for leak detection of pipeline, and *Diniș et al., 2017* developed an automation for a heating and pumping based on a PLC. Also, *Joshi and Ahire, 2015* and *Yin et al., 2023* created a data acquisition system for monitoring some industrial processes and condition monitoring of the manufacturing process in real time by calculating the statistics.

Kumar et al., 2023 created a remote monitoring and control system for electrical devices by integrating sensor networks, wireless communication protocols, and cloud–based platforms.

Dong et al., 2017; Liu et al., 2018; Patel, 2023; Song et al., 2016 conducted experiments to determine the efficiency of a heat pump or various experiments for heating systems.

Companies like *Shenzhen Wayjun, 2014* and *Yokogawa Electric Co., 2014* have published articles on data acquisition applications with PLCs.

The paper presents the implementation of a data acquisition system for testing a heat pump made with a low–cost programmable controller.

2. MATERIALS AND METHODS

To test a heat pump, a scheme was developed for a heating and storage installation of hot domestic water in a boiler (Figure1). The installation contains an air–water heat pump whose heat exchanger is connected in the hydraulic circuit by means of a thermal energy meter composed of a flow meter, two Pt500 type temperature sensors and an energy calculator (Figure 2a). The installation also contains a series of taps and valves, a circulation pump, a boiler for storing hot water and a fan convector used to exhaust heat. A power meter with RS485 Modbus communication interface is used to measure the electricity consumed by the heat pump (Figure 2b). Sensors were installed to measure temperature variation in points such as: compressor suction, compressor discharge, water return, exit of the heat exchanger, boiler, convector coil, temperature from outside and room temperature.

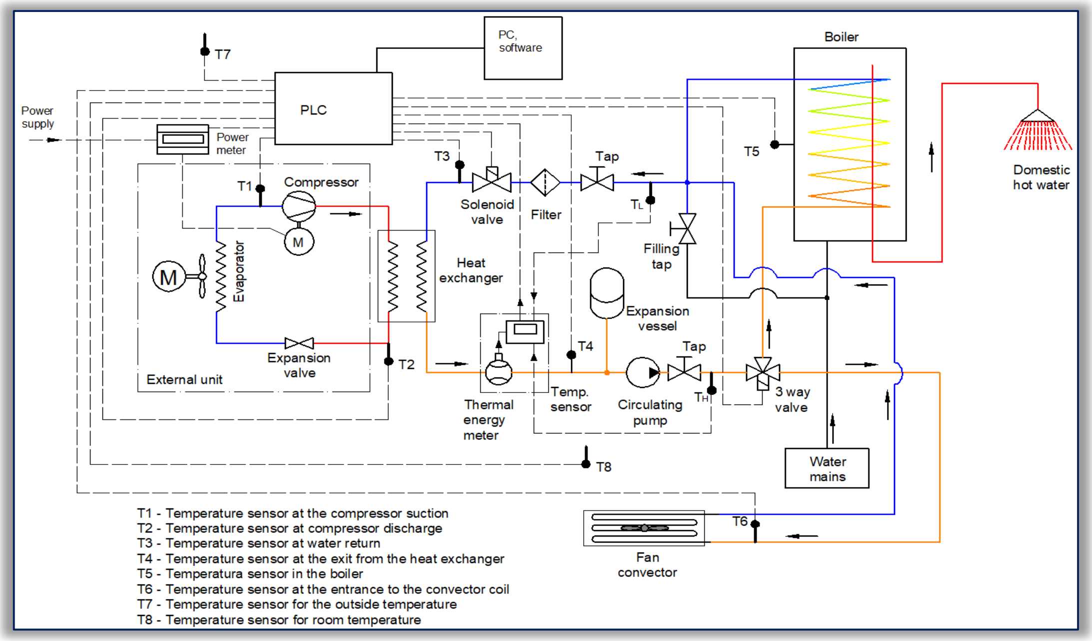

Figure 1 – Scheme of the heating installation with a heat pump equipped with measuring elements

The main characteristics of the heat pump:
- thermal power: 18 kW
- energy class: A+++
- compressor and fan motors with DC inverter
- refrigerant R32, ecological
- outlet water temperature up to 55℃

(a) (b)
Figure 2 – Meters for measuring energy: a) thermal energy; b) electricity

The data acquisition system (Figure 3) for testing the thermodynamic performance of the heat pump is assembled in a box that contains, in addition to the main component, the PLC type TM221CE24T produced by Schneider Electric, a module with 8 analog inputs type TM3AI8 and an automatic fuse. A 24V DC power supply and a power supply module are used to power the 8 LM135 type temperature sensors (Figure 4, Figure 5).

A ladder diagram program (Figure 6, Figure 7) has been implemented in the programmable controller that allows receiving signals from sensors and energy meters and transmits their variables, through the Modbus TCP/IP protocol, in the LAN network. The variables for temperatures are of type Int16, and those for energy are of type Float (Table 1).

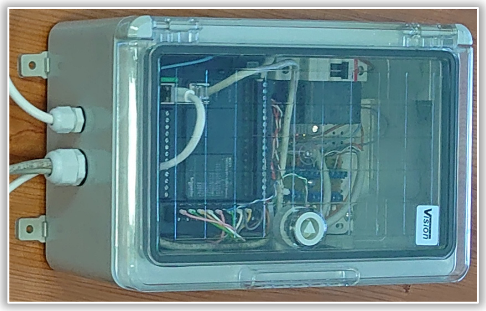
Figure 3 – Data acquisition system with a PLC equipped with analog input module and RS485 port

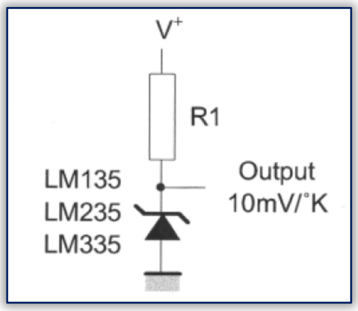

Figure 4 – Typical connection diagram for the LM135 temperature sensor

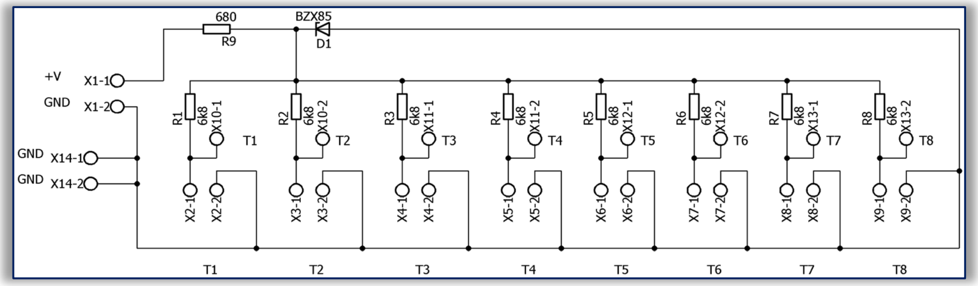

Figure 5 – Schematic of the LM135 type temperature sensor power supply module

To record the values, an application is used that connects to the IP of the PLC on port 502. The application allows the calibration of the temperature sensors and the adjustment of the data acquisition speed. The values of the parameters can be displayed graphically and can be exported in Excel format.

Table 1. List of equipment for measuring operating variables for the heat pump

Variable	Adress	Type	Measuring equipment	Symbol	Measure Unit
Mains voltage	20	Float	Lumel NR10	U	V
Electric current	22	Float	Lumel NR10	I	A
Electric power	24	Float	Lumel NR10	P	W
Electric energy	26	Float	Lumel NR10	E_E	kWh
Thermal energy	28	Float	Siemens WFM543	E_T	kWh
Current flow temperature	30	Float	Siemens WFM543	T_{IN}	℃
Return flow temperature	32	Float	Siemens WFM543	T_{RE}	℃

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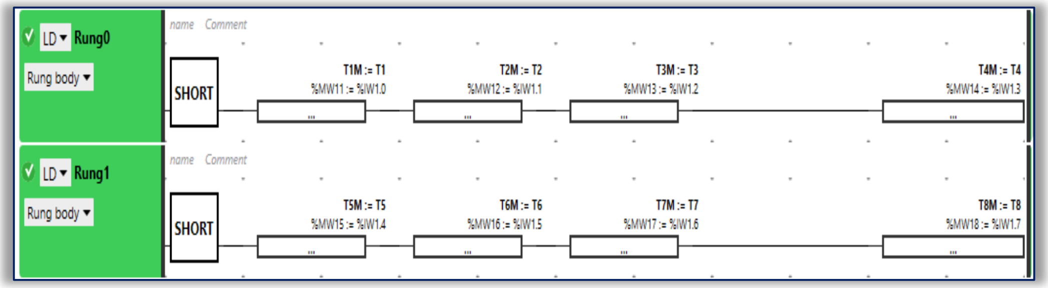

Figure 6 – Portion of ladder diagram implemented in PLC for temperature monitoring

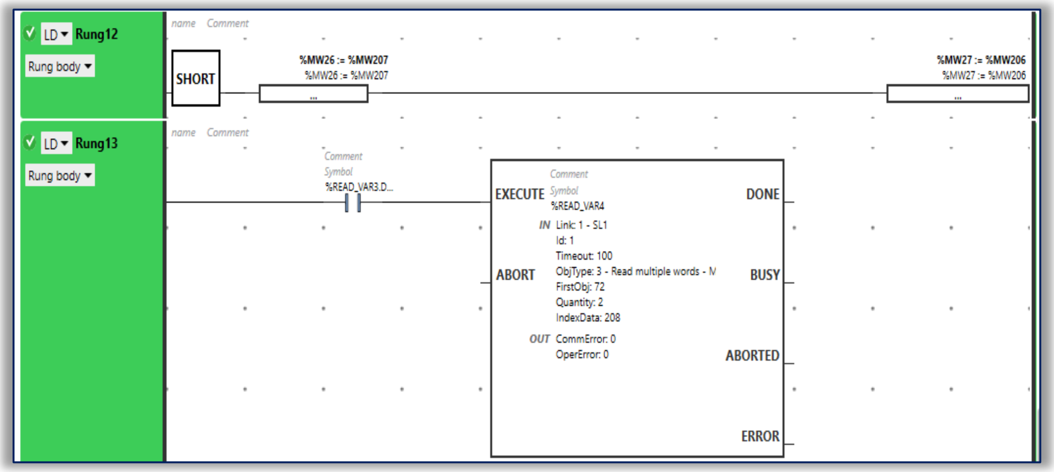

Figure 7 – Portion of ladder diagram implemented in PLC for monitoring electricity through the RS485 Modbus interface

3. RESULTS

The first law of thermodynamics defines the internal energy (E) as equal to the difference of the heat (Q) supplied to a system and the work (W) done on/by the system (3).

$$\Delta E = Q - W \tag{3}$$

The heating capacity of the heat pump is equal to the rate at which heat is released by the condenser which, by the first law of thermodynamics, is equal to the rate of heat absorbed in the evaporator summed with the power needed by the compressor. Heating capacity for the tested heat pump can be found in figure 9.

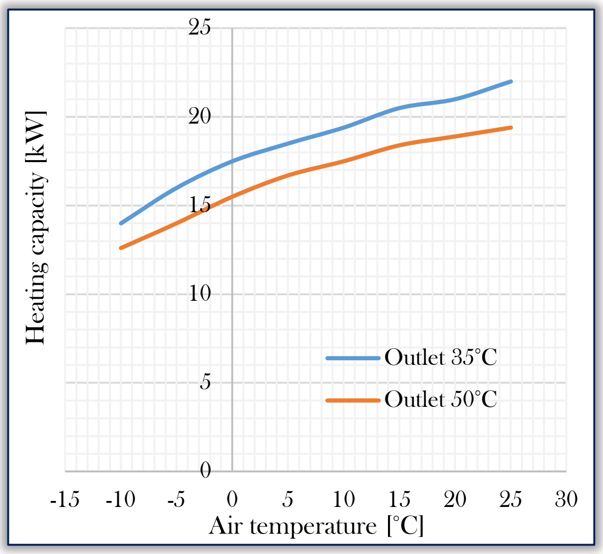

Figure 9 – Heating capacity for water temperature values at the outlet of 35°C and 50°C

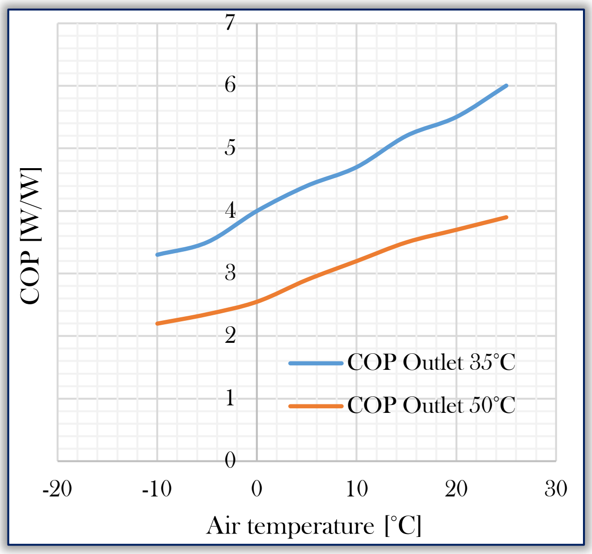

Figure 10 – Heat pump COP for water temperature values at the outlet of 35°C and 50°C

The coefficient of performance of a heat pump (COP) is defined as the ratio between the thermal power given by the heat pump (Q_R) and the power (P) consumed to operate the compressor (4).

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$$COP = \frac{Q_R}{P} \quad (4)$$

Figure 10 shows the determined COP for the heat pump for water temperature values at the outlet of 35°C and 50 °C.

4. CONCLUSIONS

With the help of a basic automation PLC, a data acquisition system, for not very fast processes, can be implemented very simply and can be used in laboratories or even in the industrial environment.

The data acquisition system equipped with data transmission in the LAN network through the ethernet port of the PLC with which it is equipped allows remote process monitoring.

Reconfiguration of the data acquisition system, for example, by increasing the number of transducers / channels can be done by adding analog input modules to the PLC.

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