EXPERIMENTAL INVESTIGATIONS OF THE OPERATION MODE OF A HEAT PUMP APPROPRIATE TO AN AIR HANDLING UNIT

A. Frik, J. Bielskus
Vilnius Gediminas Technical University
Saulėtekio al. 11, LT-10223 Vilnius – Lithuania
anton.frik@vilniustech.lt

EXTENDED ABSTRACT

OVERVIEW

More than a third of the world's final energy consumption is in the buildings sector [1]. In the European Union (EU), the main consumers of energy in buildings are heating, ventilation and air conditioning (HVAC), which account for half of the EU's energy consumption [2]. Among HVAC systems, mechanical ventilation systems play an increasingly important role in the engineering systems of buildings. In modern, well-insulated and airtight buildings, a mechanical ventilation system is a necessity to ensure the highest level of indoor air quality (IEQ) without compromising thermal comfort in buildings in cold climates [3]. Therefore, it is worth looking for technological solutions that increase the energy efficiency of the ventilation system. Appropriate adaptation of a heat pump (HP) to work in a ventilation system is one way to effectively ensure the required but constantly changing heat demand of a system in a cold climate zone [4]. It is important to note that in our case, the heat pump is adapted to the needs of the ventilation system and does not perform the function of the main heating system. The heat pump performs the function of heat recovery/regeneration for the ventilation system, allowing the air supplied by the air handling unit to be heated to the design temperature due to the thermal energy of the exhaust air. This means that the heat pump does not have to compensate for heat losses through external walls or internal heat gains. Thus, in this case, the ventilation system has a certain design supply air temperature, which must be provided over the entire range of outdoor air temperature changes, regardless of internal heat accumulation, the thermal resistance of enclosing structures, or inflow. A change in the temperature of the exhaust air from the room will affect the operation of the heat pump, but the design temperature of the supply air will remain the same. Since there is no heat accumulation in this type of system, the HP for the air handling unit (AHU) must respond immediately to the ever-changing heat demand of ventilation; otherwise, the ventilation system may supply low-temperature air directly to the occupant area, which may cause discomfort or a feeling of the draft, which adversely affects human health. Therefore, ON / OFF or staged operating modes of HP compressors are not suitable for integration into AHUs. In addition, the operation of a variable speed compressor is more efficient compared to staged or ON / OFF operating modes [5–7]. The previous parametric analysis of an AHU [8] revealed the dependencies between the change in the operating cycle of an HP built into the AHU and the change in the outdoor air temperature, which determine its high momentary and seasonal energy efficiency.

The purpose of this work is to determine the correspondence between the operation of an HP with two degrees of control (variable speed compressor and electronic expansion valve) and the dependences obtained in the analytical model in the presence of an energy demand generated by a variable outdoor temperature. For this purpose, experimental studies were carried out on a specially designed stand.

METHODS

In previous studies [8], a thermodynamic analysis of the characteristic energy conversions of an AHU with an integrated HP has been performed, relating the parameters of air and refrigerant. Figure 1 shows the tendencies of HP condenser, and evaporator isothermal temperature changes obtained in this parametric analysis, which would allow to achieve high efficiency of the HP integrated into the AHU (Fig. 2). These tendencies dictate the concept of optimal HP control, the implementation of which is planned to be experimentally verified in this paper.

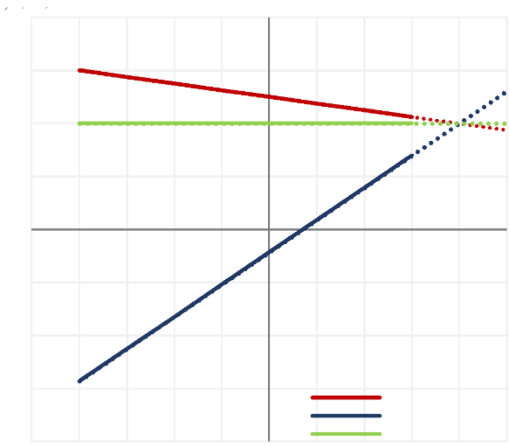

Fig. 1. Refrigerant temperatures T^{CNizot}, T^{EVizot} and room air temperature T^{R} depending on outdoor air temperature T^{e} [8]

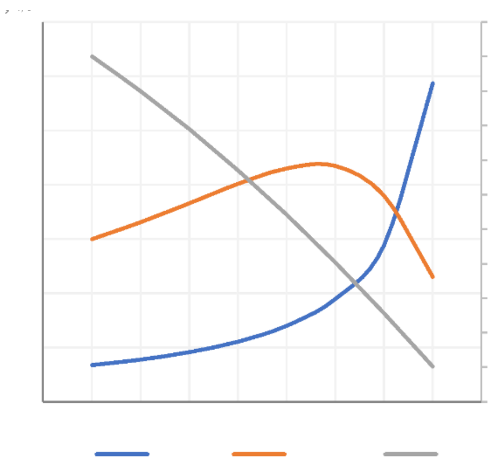

Fig. 2. Coefficient of performance (COP) of HP, AHU and refrigerant flow rate depending on outdoor air temperature T^{e} [8]

For experimental verification of the dependences obtained in the parametric analysis, an experimental stand of an HP for an AHU was designed and manufactured. At the design stage of the stand, a review and analysis of experimental stands of other researchers of a similar design or purpose were carried out [9]. This experimental study analyses the energy conversion processes in an AHU, the main energy converters of which are an HP and a heat recovery exchanger (HRE). The scheme of the experimental stand is shown in Figure 3. The HP consists of a condenser (CN), 2 evaporators (EV^1 and EV^2), a compressor (CM) and electronic expansion valves (EEV^1 and EEV^2). Together with two fans (supply - F^s and exhaust - F^e) and the already mentioned ventilation HRE, we have an experimental stand that simulates the functionality of an AHU. The connection of the air supply, exhaust fans and heat exchanger to the HP heat exchangers is provided via flexible ducts. A photo of the installed stand is shown in Figure 4.

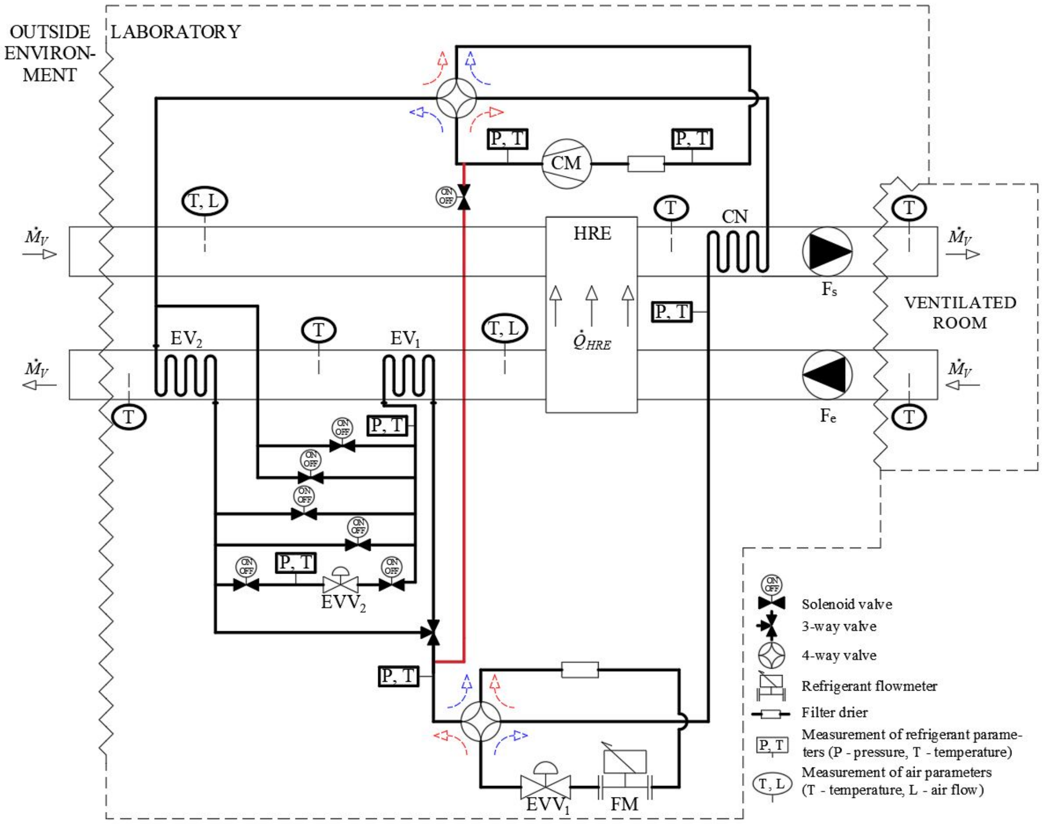

Fig. 3. Scheme of the experimental stand of the HP for the AHU

The stand is also equipped with equipment for measuring air and refrigerant parameters. On the air side, temperature sensors and calibrated diaphragms are installed to measure the air flow. Differential air pressure sensors are installed near the diaphragms to determine the flow rate of air supplied and exhausted by the system. Devices for measuring the pressure and temperature of the refrigerant are provided in the HP circuit after each of the main units (CM, CN, EEV^{1-2}, and $EV1^{-2}$). A flow meter is provided on the liquid phase side of the refrigerant.

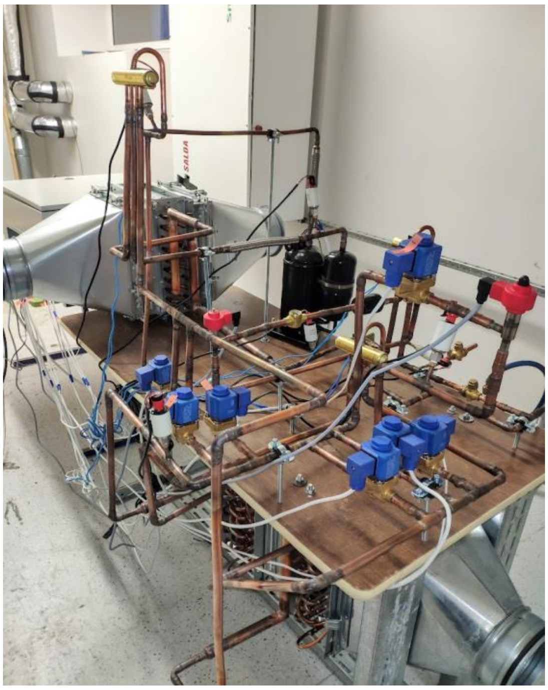

Fig. 4. Experimental stand of an HP for an AHU

RESULTS

Experimental tests were carried out on the operating mode of an HP for an AHU, in which the compressor speed (from 3000 to 8000 rpm) and the throughput of the EEV (from 20 to 80%) were changed. One of the graphs of the obtained results is shown in Fig. 5.

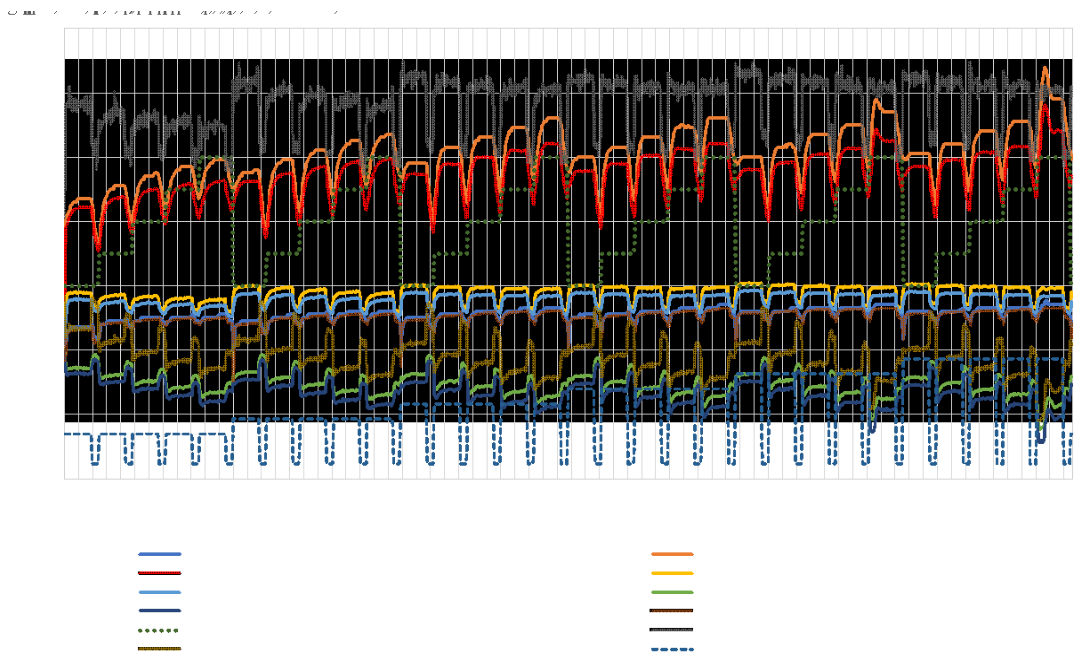

Fig. 5. Summary graph of refrigerant parameters obtained during the experiment

The graph in Figure 5 shows the range of change in the refrigerant parameters. The temperature of the refrigerant after the EEV represents the isothermal temperature of the evaporator. The isothermal temperature of a condenser is represented by the temperature of the refrigerant after the condenser. Although the changes in the evaporator isotherm in the selected range of outdoor air temperatures (3–8 °C) resemble the optimal trends obtained in the parametric analysis, the course of change in the condenser isotherm is not close to them.

CONCLUSIONS

Preliminary experimental studies show that the change in the operating cycle of the HP in the investigated or extrapolated range of parameters is not close to optimal. It is necessary to look for additional cycle control measures since the traditional ones (VSC and EEV) are not enough to achieve the trends in the operation of the HP obtained in theoretical studies. One such measure could be a compressor with operating characteristics obtained from these studies.

Keywords: air handling unit with integrated heat pump, experimental studies, operating mode, air source heat pump.

REFERENCES

1. Global status report for buildings and construction: towards a zero-emission, efficient and resilient buildings and construction sector. United Nations Environment Programme, 2021 [referred on the 7th of January in 2022 y.]. Link to the internet <https://globalabc.org/resources/publications/2021-global-status-report-buildings-and-construction>.

2. EUROPEAN COMMISSION 2016. An EU strategy on heating and cooling 2016.

3. LST EN 16798-1. Pastatų energinis naudingumas. Pastatų vėdinimas. 1 Dalis. = Energy performance of buildings – Ventilation for buildings. Part 1. Vilnius: Lietuvos standartizacijos departamentas (Lithuanian Standardization Department), 2019.

4. MARTINAITIS, V.; STRECKIENE, G.; BAGDANAVICIUS, A.; BIELSKUS, J. A comparative thermodynamic analysis of air handling units at variable reference temperature. Applied Thermal Engineering, 2018, Vol. 143, P. 385-395.

5. DONGELLINI, M.; MORINI, G.L. On-off cycling losses of reversible air-to-water heat pump systems as a function of the unit power modulation capacity. Energy Conversion and Management, 2019, Vol. 196, P. 966–978. Doi:10.1016/j.enconman.2019.06.022.

6. APREA, C.; MASTRULLO, R.; RENNO, C. Experimental analysis of the scroll compressor performances varying its speed, Applied Thermal Engineering, 2006, Vol. 26, No. 10, P. 983-992.

7. DONGELLINI, M.; ABBENANTE, M.; MORINI, G.L. A strategy for the optimal control logic of heat pump systems: impact on the energy consumptions of a residential building. Proceedings of the 12th IEA Heat Pump Conference, 2017.

8. FRIK, A.; MARTINAITIS, V.; BIELSKUS, J. Energy conversion modes depending on the outdoor temperature for an air handling unit with a heat pump. The 11th International Conference “Environmental Engineering”. Vilnius: Vilnius Gediminas Technical University. 2020.

9. FRIK, A.; BIELSKUS, J. Experimental test stand of a heat pump integrated in air handling unit. Mokslas – Lietuvos ateitis / Science – Future of Lithuania, 2020, Vol. 12, P. 1-6