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Stanisław KOZIOŁ[a], Andrzej ZBROWSKI[a, *], Tomasz SAMBORSKI[a]
Beata NIEZGODA-ŻELASKO[b], Kazimierz WOJTAS[b], Jan WRONA[b]
Marek PRYMON[c]
[a] Institute for Sustainable Technologies – National Research Institute, Radom, Poland
[b] Tadeusz Kościuszko University of Technology
[c] Thessla Green sp. z o.o
* Corresponding author: andrzej.zbrowski@itee.radom.pl

THE DESIGN OF RECUPERATOR AND HEAT PUMP TEST SYSTEMS IN CONFORMITY WITH THE "ErP" EU DIRECTIVE

Key words: recuperators, heat pumps, efficiency, testing.

Abstract: The article presents the structure of a system designed to test heat pumps with heating power of up to 12 kW and recuperators with air streams of up to 700 m^3/h. The system's design is based on appropriate thermal calculations and provides for testing a variety of heating equipment including heat pumps and recuperators in line with applicable standards, mainly for single-family dwellings. Parameters and the assumed method of controlling the system's operation allow for regulatory testing and research and development to test the design and functional properties of the equipment.

Struktura systemu badania rekuperatorów i pomp ciepła zgodnie z dyrektywą unijną „ErP"

Słowa kluczowe: rekuperatory, pompy ciepła, sprawoność, badania.

Streszczenie: W artykule przedstawiono strukturę systemu badawczego przeznaczonego do badania pomp ciepła o mocy grzewczej do 12 kW i rekuperatorów o strumieniu powietrza do 700 m^3/h. Struktura systemu została opracowana na podstawie odpowiednich obliczeń cieplnych i zapewnia możliwość testowania, zgodnie z obowiązującymi normami, różnych wariantów urządzeń grzewczych z pompami ciepła i rekuperatorów przeznaczonych głównie dla budownictwa jednorodzinnego. Parametry i zakładany sposób sterowania pracą układu umożliwiają realizację badań normatywnych oraz prac badawczo-rozwojowych w zakresie testowania konstrukcji i właściwości funkcjonalnych urządzeń.

Introduction

The Directive of the European Parliament and the Council of Europe No. 2010/31/UE of 19 May 2010 on the energy performance of buildings stipulates that all new buildings in the member states should be facilities of 'near zero energy consumption' by 31 December 2020. These are defined as buildings of a very high energy standards erected by means of appropriate installation and structural solutions. Almost all of the nearly zero, or very low, energy used in connection with typical use of a building, that is, heating, ventilation, preparation of hot water, and cooling, should come from renewable sources located in or very close to a building. The very low energy consumption, additionally balanced with energy from renewable sources, should apply to all buildings by the end of 2050. Each engineering system of a building consists of installations where such equipment as air handlers, including heat recovery and heat pumps, play increasingly important roles. All such equipment has appropriate energy performance that largely depends on parameters of its operation. It is important, therefore, that designers selecting such equipment and compiling energy performances of buildings use equipment energy assessment indicators provided by reliable, independent laboratories that have measurement installations and systems allowing for the determination of this performance in compliance with the following applicable standards: PN-EN 14511-2014-2, PN-EN 14825-2016-08, PN-EN 16573:2017-03E, PN-EN 16147:2017-04, PN-EN 13141-7:2010. This is particularly important because heat pumps and air handlers, including recuperators, are construction solutions that substantially reduce energy demand for heating water and space [1]. The dynamic development of the market for this equipment entails the need to assess their energy performance, efficiency, and quality [2, 3].

1. Problem statement

The basic version of a compressor device producing a chilling and heating thermodynamic cycle (Fig. 1) consists of two heat exchangers (evaporator and condenser), a compressor, and an expanding element. The device collects heat from the "bottom source" (via a low-temperature fluid across the evaporator) and uses (most often electrical) energy supplied by the compressor to release heat in the condenser (by heating fluid flowing across the condenser). The process is made continuous by a substance known as a chilling agent that circulates inside the equipment and transports heat between both the exchangers (sources of heat) [4, 5].

Energy performance of this equipment is defined with EER and COP in line with 1 [6, 7]:

$$EER = \frac{\Phi_o}{P_s} \quad \text{and} \quad COP = \frac{\Phi_k}{P_s} \tag{1}$$

where: Φ_o – cooling capacity (heat stream collected by the evaporator) [W],
Φ_k – heating capacity (heat stream discharged by the evaporator) [W],
P_s – (electric) power consumed by the compressor [W].

The energy efficiency ratio of compressor chilling equipment (EER) and compressor heat pumps' coefficient of performance (COP), as well as cooling and heating capacities of this equipment are closely dependent on the following design and performance parameters [4]:

- The design of the compressor, evaporator, and condenser;
- The type of chilling agent;
- Equipment facilities (the unit);
- Temperatures and streams of fluids exchanging heat in the evaporator and condenser; and,
- Load (method of controlling cooling or heating capacity of the equipment).

The above list implies fundamental performance parameters of a heat pump, such as heating capacity and energy performance, and they are highly variable in real conditions. Hence, both these quantities (heating capacity and energy performance) must be determined in experimental testing under very specific operating conditions.

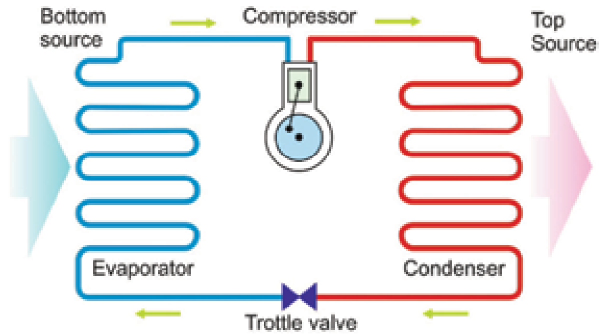

Fig. 1. Operating principle of a compressor heat pump (compiled by the authors)

In state-of-the-art buildings with good insulating power of external partitions, provided with mechanical ventilation or air-conditioning, heat fluxes removed from spaces as exhaust air constitute maximum losses of thermal energy, even as much as 60% of total heat losses in residential buildings. Using exhaust air streams to heat or cool the air supplied to spaces – heat recovery – plays a key role in minimising energy losses associated with ventilation. The temperature differences between used and external air serve to exchange heat between the two streams as a heat energy recovery section is installed that includes an air-to-air heat exchanger (Fig. 2).

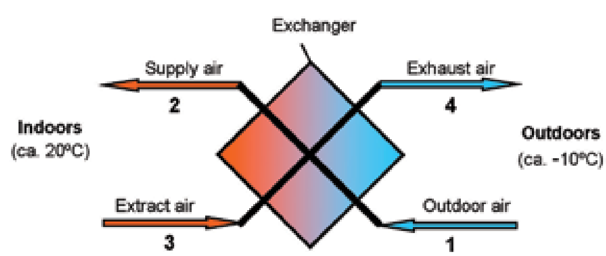

Fig. 2. Flow chart of a heat recovery system in a ventilation installation (compiled by the authors)

A 'temperature efficiency' coefficient of heat recovery is determined to assess heat exchange performance, assuming that the mass flow streams of the external and exhaust airs are balanced:

$$\eta_t = \frac{t_2 - t_1}{t_3 - t_1} \cdot 100\% \text{ [\%]} \tag{2}$$

where: t – temperature of the appropriate air streams [°C] (as designated in Figure 2).

Panel and spiral recuperators of stainless steel, aluminium, or plastics are the most common exchangers. The heat recovery performance of a recuperator depends on the shape and arrangement of panels, the ratio of intake and exhaust air flow intensities, and the temperature differences between the two streams. Depending on these parameters, heat recovery performance may vary widely. When the performance is stated, it should be noted in what conditions it is achieved [13].

The Directive of the European Parliament and the Council of Europe No. 2009/125/EC (the so-called 'ecodesign' or ErP – Energy related Products – Directive) concerning requirements of space and multifunctional heaters and the Directive 2010/30/EU ('ecolabel') concerning energy performance labelling of space heaters, ventilation and air conditioning equipment suggest a high demand for certification testing of such equipment in the near future in conformity with standards harmonised with the above Commission documents [8].

The standards [9–13] harmonised with the said directives help to the establish energy performance of ventilation and air-conditioning units and heat pumps below 12 kW, cooling/ heating capacities, power consumption, EER/COP performance ratios, and classes of product energy performance.

Heating and cooling capacities, efficiencies, and electricity consumption by equipment operated in regulatory, stable temperature conditions are the key magnitudes to be determined as part of heat pump and recuperator testing.

The principal objectives of the efforts described in this paper were to develop the following versions of a structural solution and the design of an installation for comprehensive testing of recuperators with air streams of up to 700 m^3/h and heat pumps with capacities of up to 12 kW:

- 'Liquid-water'('brine-water', B-W) compressor heat pumps;
- 'Air-water'(A-W) compressor heat pumps, both 'monoblock' and split;
- Compressor heat pumps for the heating of domestic hot water (DHW) including a DHW tank;
- Compressor heat pumps for ventilation units and ventilation heat recuperators; and,
- Ventilation units including heat recuperators operating in extreme ambient air conditions.

Equipment with power below 12 kW and an air stream below 700 m^3/h is a characteristic, very large group dedicated mainly to single-family dwelling applications [14].

2. Idea of the test installation

Following on a review of possibly applicable test methods and thermodynamic calculations, the test installation is assumed to meet the following assumptions:

- Working conditions of a recuperator are simulated by two air-conditioned chambers where air flowing across a tested ventilation unit is prepared; a 'summer' chamber reproduces climatic conditions in a building and parameters of air exhausted from a building, whereas a 'winter' chamber simulates parameters of air taken from outside a building in different seasons.
- Two climatic (calorimetric) chambers K1 and K2 serve to stabilise operating conditions and parameters of the tested equipment in the ambient air, where the installation is located,
- The chambers K1 and K2 are supplied by a monovalent source of cooling energy, namely, a 2-degree chilling unit, with the two degrees connected by means of a medium. This type of system provides for heat pump measurement conditions at a number of temperature levels (from very low (below -25°C) through average – ca. -5°C to high, up to 70°C).
- To stabilise conditions of equipment (recuperators and heat pumps) measurements as required by the standards [6–10], a hydraulic installation, including three heat tanks and a pumping and regulation system, is used to stabilise the technical parameters.
- K1 (and the necessary installations) is designed to test air-water (A-W) compressor heat pumps of rated heating capacity $\Phi g \leq 12$ kW (in conditions A-7(-8)/W45) and comes in the following versions:
  - Monoblock to heat flowing water including an evaporator supplied with air by axial flow fans; and,
  - Monoblock to heat domestic hot water, including a tank and an evaporator supplied with air by axial flow fans.
- K2 (and the necessary installations) is primarily dedicated to simulate ambient conditions when testing recuperators by means of 'summer' and 'winter' chambers in the temperature range -25–35°C. It is additionally programmed to test fluid-water (B-W and W-W) compressor heat pumps of rated heating capacity $\Phi g \leq 12$ kW (in conditions B0/W45) placed in a chamber simulating a variety of locations in the temperature range from -25 to 35°C. The following equipment will be tested in this chamber:
  - Monoblock heat pumps heating flowing water, including an evaporator supplied with fluid;
  - Monoblock heat pumps heating domestic hot water, including a tank and an evaporator supplied with air by centrifugal fans;
  - 'Split' heat pumps (split version of the above equipment), with an evaporator in the chamber K1 and the core part of the unit located in K2;
  - Ventilation units including a recuperator and incorporated heat pump;
  - Ventilation units including a recuperator but without a heat pump.
- All the test chambers are located in a laboratory room with the air temperature ranging from 15 to 30°C

(in winter and summer conditions, respectively) and a relative humidity φ<60%.

- Geometric dimensions of K1 and K2, 'Summer' and 'Winter' chambers, meet requirements of PN-EN 14511 [6] within the space limitations of a laboratory.

3. Diagram of the test installation

The installation will be able to test all of the equipment listed above. Its configuration is illustrated with simplified diagrams (Figs. 3, 4, and 5) showing variant connections of its functional module with heat pumps and recuperators tested. The calorimetric chambers and fluid tanks in the diagrams fulfil the following functions:

Chamber K2 simulates conditions in a room where a tested recuperator or heat pump is installed. It may be a warm boiler room or an unheated attic or loft, which generates additional heat losses and condensate freezing. The chamber is equipped with an A/C unit containing a specialised 'low-temperature' cooler supplied with a non-freezing fluid from a low-temperature tank V0, an electric heater, and a fan section of a continuously controlled capacity.

Chamber K1 is the bottom heat source of a tested air/ water pump and simulates regulatory external conditions (down to -25°C). The chamber features an A/C unit, including a cooler for initial generation of measurement conditions and compensation for cold losses to the environment, an electric heater, and a steam moistener to equalise heat losses caused by operation of a tested pump and the need to stabilise air temperature and humidity at the evaporator inlet of the tested heat pump.

Tank V1 simulates the bottom heat source of a tested brine/water pump (a soil heat exchanger) and contains a low freezing point fluid cooled down to (-10 –15°C). An external cooling cycle is used for initial fluid cooling prior to testing and an electric heating element compensates for heat losses caused by operation of a tested heat pump.

Tank V2 is the top heat source of tested heat pumps and simulates a central heating or domestic water heating installation. It holds water that is heated to (30–70°C) depending on test parameters. The tank features an external cooling cycle to compensate for heat gain caused by the operation of a tested pump and an electric heating element for initial water cooling to reach a temperature required by testing.

Tank V0 is a 'cold' buffer for coolers in the chambers K1 and K2. It contains a low freezing point fluid cooled by the 1st degree of the cooling unit Agr2. The fluid temperature is -35– +30°C.

SUMMER chamber reproduces indoor climate conditions (20–30°C, 30–55%RH) and is the course of air stream removed from a space and supplied to a tested recuperator. It is equipped with an electric air heater that compensates for heat losses and a stabilising moistener.

WINTER chamber simulates outdoor climate in the temperature range (-20 – +15°C) and supplies a tested recuperator with an air stream from an external intake. It is provided with a direct evaporation cooler supplied from the unit Agr1 and an electric heater to stabilise stepwise temperature changes as the unit is switched on and off.

Figure 3 presents a configuration for testing of a brine/ water heat pump. The pump is placed in the chamber K2 with a temperature corresponding to the installed conditions of the equipment reproduced as part of the testing. The fluid tank V1 is the bottom heat source and the water tank V2 the top heat source. The testing is designed to determine the thermal capacity and performance characteristics of the pump, energy performance ratios and seasonal performance ratios in line with the standard methodologies [6, 7]. The test procedure requires an initial stabilisation of temperature in K2 and the tanks V1 and V2 according to the test parameters adopted. Once the tested heat pump is switched on, fluid temperatures at the condenser and evaporator inlets and outlets and flow values are stabilised. In these stabilised operating conditions, temperature and pressure differences, and volumetric flow streams across the condenser and evaporator, electric power consumed by the pump, and ambient temperatures in the chamber K2 and in the laboratory are recorded. Standardised formulas are employed to calculate parameter values, which are test results.

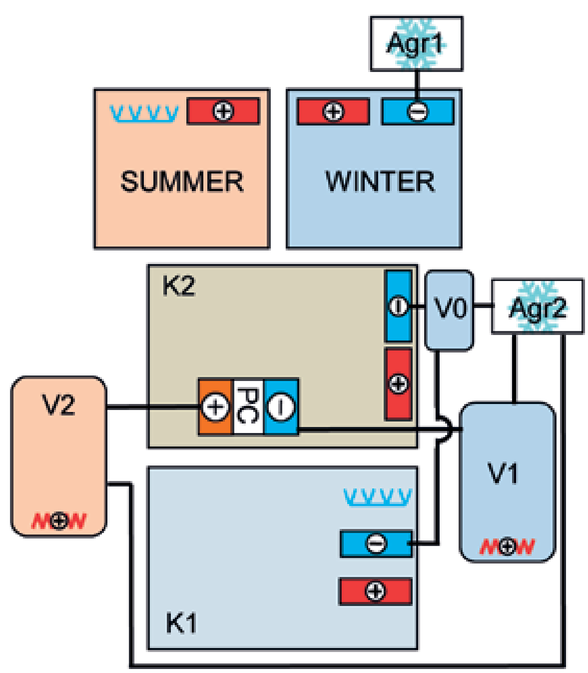

Fig. 3. Diagram of a recuperator and heat pump test installation – as configured for testing of a brine/ water (B-W) heat pump: PC – the tested heat pump

The diagrams (Fig. 4) show a configuration for testing of air-water (A-W) heat pumps. Air in the conditioned chamber K1 is the bottom source of heat and the fluid tank V2 is the top source.

Testing of two design varieties of (A-W) pumps is envisaged. The monoblock version (Fig. 4A) is all placed in the chamber K1 and connected with insulated pipelines to the tank V2. Its surroundings (the interior of K1) reproduce mounting conditions of a pump outdoors. The 'split' variety (Fig. 4B) is divided into an internal part (condenser, compressor, and regulation systems) inside chamber K2 and an evaporator in K1. Such an arrangement reflects real pump installation conditions, with its internal section mounted indoors and only the evaporator outside.

Test procedures carried out as part of these configurations are designed, as in the case of B-W heat pumps, to determine thermal capacity characteristics, performance characteristics, energy and seasonal performance coefficients of a pump in line with applicable standards [6, 7]. The test procedure requires an initial stabilisation of the temperature in K2 and in the tanks V1 and V2 according to the test parameters adopted. Once a tested heat pump is started, fluid temperatures at the condenser and evaporator inlets and outlets and flow values are stabilised. In these stabilised operating conditions, temperature and pressure differences, and volumetric flow streams across the condenser and evaporator, electric power consumed by the pump and ambient temperatures in the chamber K2 and in the laboratory, are recorded. Standardised formulas are employed to calculate parameter values, which are test results.

The diagram (Fig. 5A) shows a configuration for testing of heat recovery performance by an A/C unit including a recuperator according to the standard [10]. The SUMMER and WINTER chambers supply R unit with air streams exhausted from a space and taken from outside a building whose parameters conform to the standard. The unit tested is placed in chamber K2, where a possible installation environment, e.g., an unheated loft, is simulated. This method of testing heat performance enables one to address heat gains and losses across the unit casing and monitor the effects of low temperature on its operation, e.g., the freezing of a condensed water steam.

The test procedure in such a system is not different from the standard procedure in compliance with the standards [10], except that the temperature in chamber K2 must be stabilised as envisaged by the test programme prior to a test series. Temperature, humidity, pressure, and the expenditure of four air streams at the inlet and outlet of a tested unit are measured. Heat recovery performance is measured for temperature, humidity, and the capacities of air stream flowing across the unit and conditioned in the WINTER and SUMMER chambers as set out in the standard.

Figure 5B presents a configuration for the testing of a ventilation unit including heat recovery or not, provided with an (A-W) heat pump and serving to heat heating water for a building. The air stream exhausted from a building across the ventilation unit is the bottom source of heat for the heat pump. The top source of heat is constituted by the water tank V2. Two air streams of controlled parameters (temperature and humidity) and

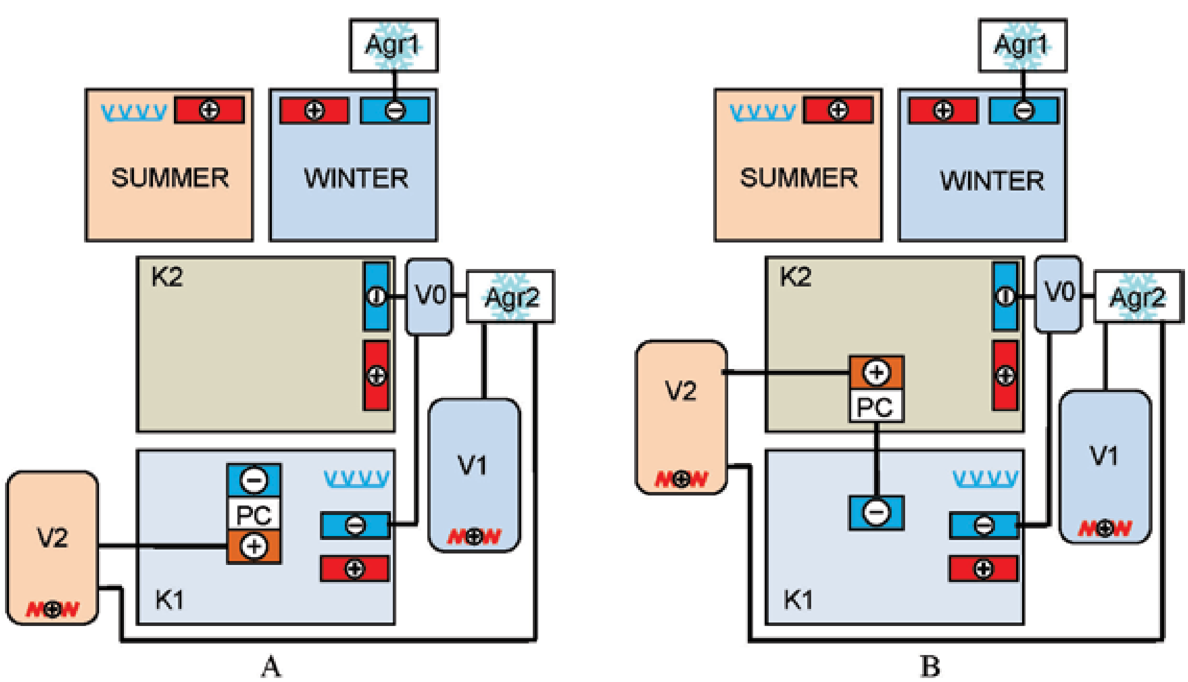

Fig. 4. Diagram of a recuperator and heat pump test installation: A – as configured for testing of a monoblock air-water (A-W) heat pump, B – as configured for testing of a split air-water (A-W) heat pump (A-W): PC – heat pump tested

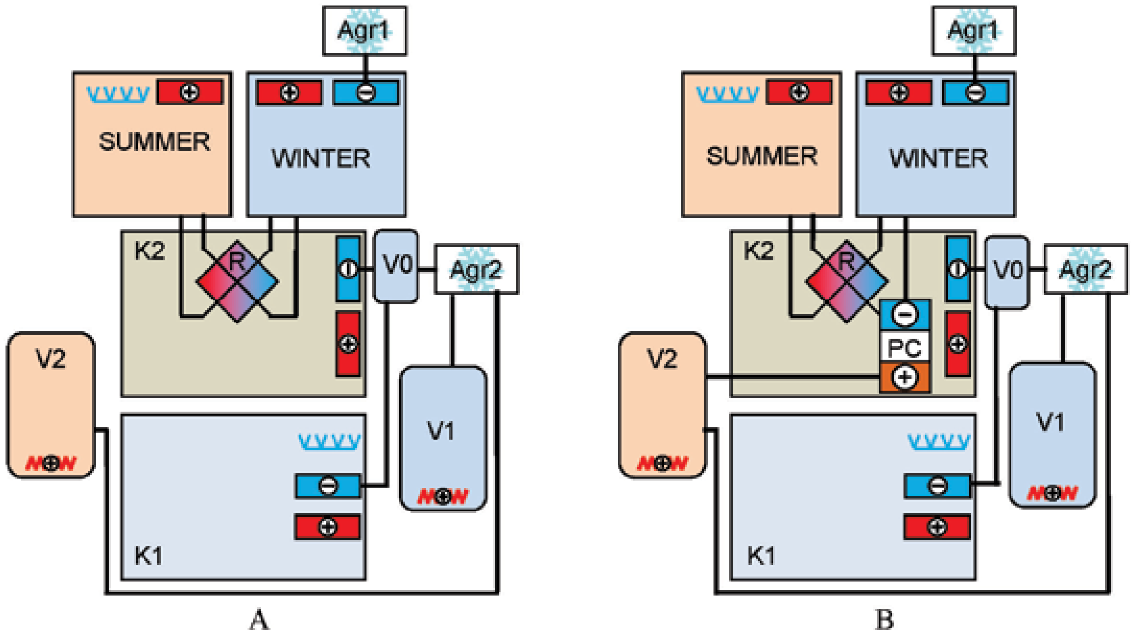

Fig. 5. Diagram of a recuperator and heat pump test installation: A – as configured for testing of heat recovery performance by a recuperator, B – as configured for testing of a ventilation unit including a heat pump: R – ventilation unit including a recuperator, PC – heat pump

predefined volumetric flow streams from the WINTER and SUMMER chambers need to be supplied to the ventilation unit for the purposes of testing ventilation units including heat recuperators. A heat pump is tested in chamber K2 in the thermal air conditions defined in PN-EN 16147 [9].

The procedure involves the testing of the following quantities in specified conditions:

- Mass stream, flow resistances, and increment of water temperature across the pump condenser;
- Temperature, humidity, pressure, and the expenditure of all the four air streams across the ventilation unit's inlets and outlets;
- Electric power and energy consumed by the tested heat pump and the fans of the tested unit; and,
- The quantity of condensate recovered from the defrosting of the heat pump evaporator.

Average measurement results can be recalculated to determine thermal capacity characteristics of a heat pump, energy performance ratios, performance characteristics, seasonal performance coefficients in regulatory conditions, and characteristics of fans installed in the ventilation unit.

The test installation is a complex measurement system of four air-conditioned atmospheric chambers, hydraulic systems, and units that assure physical parameters providing operational conditions of tested heat pumps and recuperators. Figure 6 contains a 3D model of the installation addressing its spatial arrangement in a laboratory. The system is controlled by

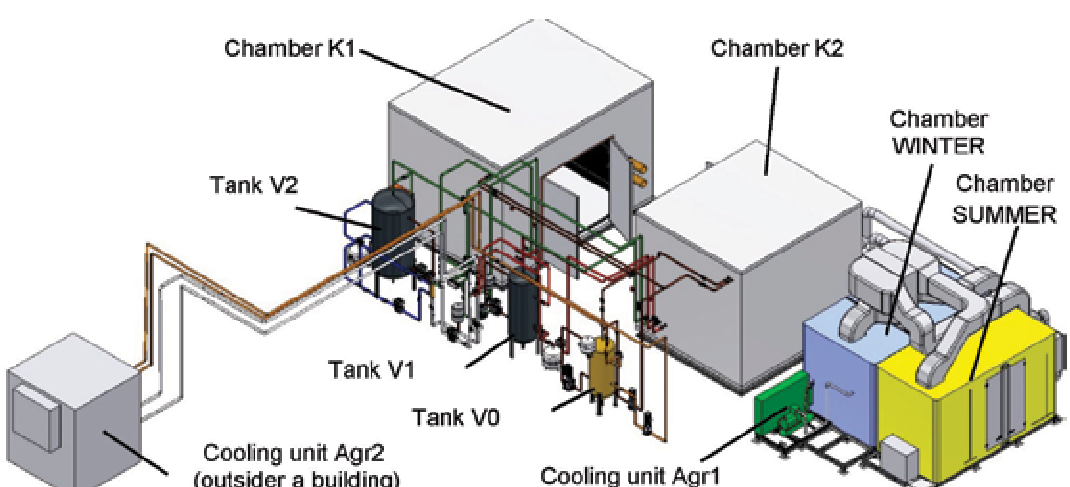

Fig. 6. 3D model of an installation for testing of heat recuperators and pumps showing its spatial configuration

means of a system helping to programme experiments and conduct them automatically. Dedicated software enables the recording of the progress of testing and computing its results as laid down in the standards. The variability ranges of test parameters adopted at the stages of assumption and system documentation and the option of flexible programming of its progress help to both automatically carry out regulatory testing and execute specific testing as part of development work.

The Institute for Sustainable Technologies' years of experience cooperating with ventilation unit manufacturers points to a high demand of construction equipment producers for the testing of prototype solutions in order to test the design and performance parameters.

Conclusion

An installation for the testing of ventilation units, including heat recovery, air – water pump heats, and brine – water heat pumps used in energy-efficient buildings, consists of air-conditioned chambers simulating environment conditions inside and outside a building during various seasons, and a hydraulic part for precise generation of operating conditions of tested equipment within regulatory ranges and other conditions that may occur in actual operation. The designed system of installation control and test programming will allow for automatic regulatory testing of energy performance, efficiency, and use characteristics of heating and ventilation equipment. The regulation range of the test environment extended beyond regulatory requirements and the flexible test programming will enable R&D work involving the testing of prototype solutions as they are developed. The comprehensive system configuration and extensive measurement instrumentation will help to model the physical effects and processes associated with heat exchange and gas flows in ventilation and hydraulic installations used by the construction industry. The ability to identify energy balances of heating and ventilation equipment and thermodynamic processes in such equipment will enable the comprehensive assessment and optimisation of solutions in energetic terms.

The installation is a response to the market demand arising from the European Union directives that oblige equipment suppliers to define its energy performance and class. In particular, the solution serves the testing of the following:

- The efficiency of heat recovery and the capacity of ventilation units including heat exchanger;
- Cooling/ heating capacity, power consumption, EER/COP performance ratios, and the efficiency of heat pumps; and,
- Energy performance of ventilation units and heat pumps and their performance classification.

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