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Performance Analysis of Air-to-Water Heat Pump in Latvian Climate Conditions

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Abstract **– Strategy of the European Union in efficient energy usage demands to have a higher proportion of renewable energy in the energy market. Since heat pumps are considered to be one of the most efficient heating and cooling systems, they will play an important role in the energy consumption reduction in buildings aimed to meet the target of nearly zero energy buildings set out in the EU Directive 2010/31/EU.**

Unfortunately, the declared heat pump Coefficient of Performance (COP) corresponds to a certain outdoor temperature (+7 °C), therefore different climate conditions, building characteristics and settings result in different COP values during the year. The aim of this research is to investigate the Seasonal Performance factor (SPF) values of air-to-water heat pump which better characterize the effectiveness of heat pump in a longer selected period of time, especially during the winter season, in different types of residential buildings in Latvian climate conditions. Latvia has four pronounced seasons of near-equal length. Winter starts in mid-December and lasts until mid-March. Latvia is characterized by cold, maritime climate (duration of the average heating period being 203 days, the average outdoor air temperature during the heating period being 0.0 °C, the coldest five-day average temperature being −20.7 °C, the average annual air temperature being +6.2 °C, the daily average relative humidity being 79 %).

The first part of this research consists of operational air-to-water heat pump energy performance monitoring in different residential buildings during the winter season. The second part of the research takes place under natural conditions in an experimental construction stand which is located in an urban environment in Riga, Latvia. The inner area of this test stand, where air-to-water heat pump performance is analyzed, is 9 m^2. The ceiling height is 3 m, all external wall constructions (U = 0.16 W/(m^{2}K)) have ventilated facades. To calculate SPF, the experimental stand is equipped with sensors which provide measurements for electricity consumption and gained heat energy.

Keywords **– Heat pump, air-to-water heat pump, Seasonal Performance Factor, SPF, Coefficient of Performance, COP.**

I. Introduction

Strategy of the European Union in efficient energy usage demands to have a higher proportion of renewable energy in the energy market. Since heat pumps are considered to be one of the most efficient heating and cooling systems, they will play an important role in energy consumption reduction in buildings aimed to meet the target of nearly zero energy buildings set out in the EU Directive 2010/31/EU [1].

Heat pump systems are based on renewable energy and they become more and more promising in both residential and commercial applications due to their high utilization efficiency compared to the conventional heating and cooling systems. Heat pump systems do not produce exhaust gases while heating any space and use less energy than other systems. In addition, heat pumps are capable to use inexhaustible resources such as air source, geothermal source, waste heat and the heat of the soil. Heat pump systems provide high levels of comfort, ensure significant reduction of electricity consumption and are environmentally-friendly [2], [3]. A simple heat pump system consists of four main components, which are a compressor, two heat exchangers (condenser and evaporator) and an expansion valve. Thermal characeristics and the types of heat sources and heat sinks are very important for the performance of heat pumps. Commonly used heat sources and heat sinks are ambient air, exhaust air, lake water, river water, ground water, earth, rock, wastewater and effluent. Most commonly used heat sources and heat sinks on heat pump systems around the world are ambient air and water. Ambient air is widely available and a free heat source for heat pumps. However, the thermodynamic performance of air source heat pump systems decreases during the heating season due to lower air temperatures and increases during the cooling season [4].

Continuous technical developments have been done to improve their seasonal performance and reliability, even in extreme conditions. Unfortunately, the declared heat pump COP (Coefficient of Performance), which is given by the manufacturer, is measured at a certain outdoor temperature (+7 °C), and therefore different climate conditions, building characteristics and settings result in different COP values during the year. The International Organization for Standardization (ISO) and the European Committee for Standardization (CEN) have both developed their standards [5], [6]. Air-source heat pumps are a particularly attractive alternative at locations characterized by a long heating season and not very cold winters. Coastal regions in the Northern Europe can be an example, with 7–9 months heating season and typical temperatures between −5 ºC and +10 °C. Therefore a better representative value for heat pumps in cold climates is SPF (Seasonal Performance Factor), which is defined as the ratio of the heat delivered and the total energy supplied over a period of time.

The energy performance of air heat pumps are affected not only by outdoor air temperature, but also by air humidity. In temperatures lower than +6 °C and when the relative humidity is high, frost formation can occur on the outside heat exchanger and the heat pump performance can be reduced. Frost formation in heat exchangers depends on various simple geometries (cylinders, flat plates and parallel plates) and it is a complex process [7].

Many authors have done research for heat pump performance, but mainly about COP. The Royal Institute of Technology in Sweden has conducted research on single room heat pumps for cold climates and positioned that the COP of modern air-to-air heat pump using R410A as a refrigerant are now reported above 5, at +7 ºC outdoor temperature. R410A seems to be the best available refrigerant [4].

Çakır et al. compared different heat pump systems and their COP values. This analysis showed that the heat pump unit, which has the maximum COP value, is water-to-air type with 3.94, the second is water-to-water type with 3.73, and the third is air-to-air type with 3.54. The heat pump, which has the lowest COP value, is water-to-air type heat pump system with 3.40. The author mentioned that the results presented in his study differ from some other studies because four heat pump types were combined on one system with constant heating capacity [2].

Nord et al. made a simulation model of an office building in EnergyPlus with Norway climate conditions and concluded that the best energy supply solution from heat pump systems seemed to be the air-to-water heat pump. He also admitted that a 50 % price increase for energy in Norway could make the solution with the solar assisted air-to-water heat pump economically attractive [8].

The aim of this research is to investigate the SPF values of air-to-water heat pump systems in the winter season in different types of residential buildings in Latvian climate conditions. In addition, the second part of the research takes place under natural conditions in an experimental construction stand which is localized in the urban environment in Riga, Latvia. To calculate SPF, the experimental stand is equipped with sensors which provide measurements for electricity consumption and gained heat energy.

II. Methodology

Latvia has four pronounced seasons of near-equal length. Winter starts in mid-December and lasts until mid-March. Latvia is characterized by cold, maritime climate (duration of the average heating period being 203 days, the average outdoor air temperature during the heating period being 0.0 °C, the coldest five-day average temperature being −20.7 °C, the average annual air temperature being +6.2 °C, the daily average relative humidity being 79 %.

COP ratio varies with the outdoor air temperature and the delivered indoor temperature. It should be specified that COP is the ratio of gained heat divided by consumed electric power at fixed outdoor temperature. To get a better performance parameter in cold climates instead of COP, the seasonal performance factor (SPF) should be used. SPF is the ratio of gained heat during a season (or a time period) divided by the consumed electric power per time period.

The SPF of air-to-water heat pump in residential buildings was evaluated during winter seasons of 2011/2012 and 2013/2014. In the season 2011/2012, the area of the building was 150 m^2, but in 2013/2014 it was 110 m^2. Residential buildings with an area 150 m^2 and 110 m^2 were equipped with air-to-water heat pump Panasonic AQUAREA SXC12 and Panasonic AQUAREA MDF06, respectively. The setup for the heat pump had measurement devices for the generated heat energy "Compact Heat Meter Sensostar 2 ESH MID DE-07-MI004" and for the consumption of electrical energy "UHER 7CA50-61-7", respectively. The nominal capacities of the tested heat pump units were 12 kW and 6 kW, respectively. The working fluid for both was R410A. The heat pump was used for heating and hot water preparation. Both heat pumps operated with an underfloor heating system.

The second part of the research took place under natural conditions in experimental construction stands which are localized in the urban environment in Riga, Latvia. The inner area of the test stand, where the air-to-water heat pump was analyzed, was 9 m^2. The ceiling height is 3 m, all external wall constructions (U = 0.16 W/(m^{2}K)) have ventilated facades. The experimental test stand field is shown in Fig. 1. An air-to-water heat pump WH-SDC03E3E5 (3 kW) is mounted in one of the stands. Since the heat pump was mounted only in February 2014, the real cold winter weather conditions were not measured. The monitoring campaign was subdivided into three sessions:

- from 25 February 2014 until 3 March 2014;
- from 11 March 2014 until 24 March 2014;
- from 2 April 2014 until 16 April 2014.

The operation set point was +19 °C in heating mode, which was automatically controlled via a wall-mounted thermostat. The outlet water temperature was about +35 °C.

Fig. 1. Experimental test stands.

III. Results and Discussion

An average temperature curve for climate in Riga over the years 2003 to 2013 is included in Fig. 2. It can be observed that the average heating season consists of 183 days and that most of the heating days have an average temperature below the standardized COP evaluation temperature +7 °C; therefore SPF should be considered as preferable.

The results from the residential building in winter season 2011/2012 are shown in Fig. 3. and Table I.

It can be concluded from the results that the SPF varies with the outdoor temperature fluctuations. Focusing on the average monthly temperatures near the standardized COP temperature (+7 °C), the SPF value at +5.4 °C is 3.96, but at +4.9 °C – 4.08. Solar insulation influence on the necessary heating capacity can be seen comparing April and November, when the average temperatures are similar, but the need for heating is higher in November. In February, which was the coldest month with an average temperature of −9 °C, the SPF value is 2.5. It is about

40 % lower than in November and April. In this case, an average winter season SPF was 3.2 with an average temperature of +0.2 °C.

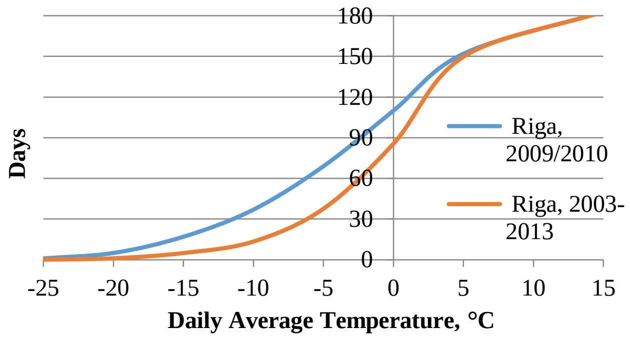

Fig. 2. Heating season climate in Riga for year 2009/2010 and from year 2003 to 2013.

The results from winter season 2013/2014 were collected as well and are shown in Fig. 4. and Table II. It is visible that this season was warmer with an average temperature of +1.9 °C. In November with the monthly average temperature of +5.1 °C, the SPF was 3.54 being the highest in this season. In April, with the highest average temperature of +7.1 °C, the SPF value was 2.89, but in the coldest month January, with the average temperature −5.8 °C, the SPF value was 2.46. In the whole season the SPF was 2.93. The average SPF value in this case was lower by 0.21 despite higher temperatures than in winter 2011/2012, which might be explained with higher hot water consumption.

A cost comparison of heat pump and other heating options is seen in Fig. 5. The cost comparison is based on the actual costs for each of the heat sources in the market of Latvia. As can be seen in Fig. 5, only the use of a furnace with granular pallets involves slightly lower costs than the air-to-water heat pump system with air-to-water heat pump system costs being 372 EUR per whole season of 2013/2014 and furnace with granular pallets − 310 EUR. In the summer, the heat pump prepares hot water with an SPF of 3.5 to 4.0 which makes this system even more economical. Even with an increase in electricity prices in Latvia from 5 % to 10 % in 2015, the heat pump technology becomes more and more competitive due to the COP and SPF increase in the last decade and due to the increasing cost of non-renewable resources like natural, liquefied gas and diesel fuel.

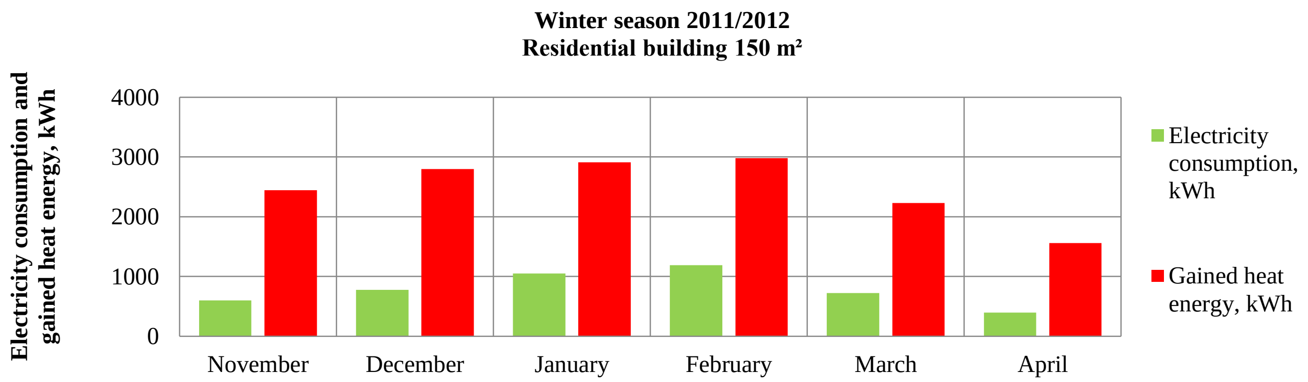

Fig. 3. Gained heat energy and electricity consumption results for the example residential building of 150 m[2] in season 2011/2012.

TABLE I

PERFORMANCE RESULTS FOR THE EXAMPLE RESIDENTIAL BUILDING OF 150 M[2] IN SEASON 2011/2012

	November	December	January	February	March	April	Total	Monthly average
Electricity consumption, kWh	600	777	1050	1191	722	394	4734	**5.26 kWh/m² = 0.80 EUR/m²**
Gained heat energy, kWh	2445	2797	2911	2982	2231	1559	14925	
Monthly average temperature, °C	+4.9	+1.9	−2.9	−9.0	+0.4	+5.4	**+0.2***	*Average in season
SPF	4.08	3.60	2.77	2.50	3.09	3.96	**3.2***	

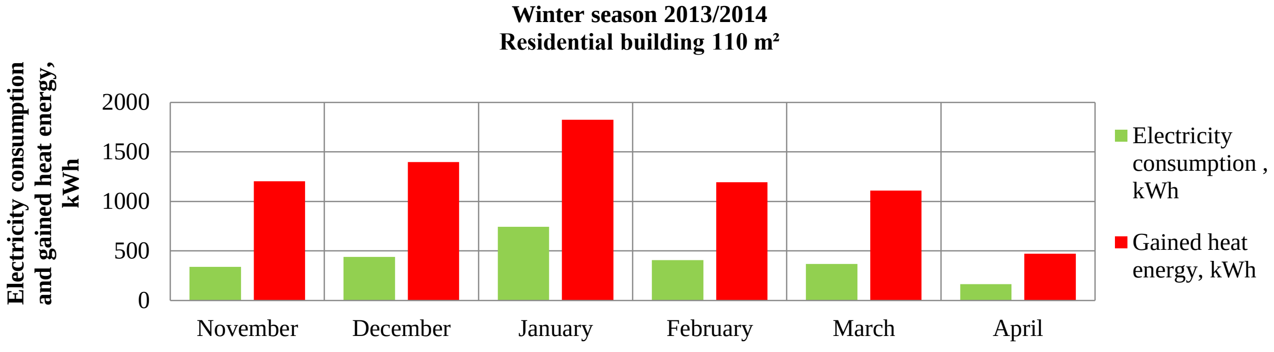

Fig. 4. Gained heat energy and electrical energy consumption results for the example residential building of 110 m^2 in season 2013/2014.

TABLE II

PERFORMANCE RESULTS FOR THE EXAMPLE RESIDENTIAL BUILDING OF 110 M^2 IN SEASON 2013/2014

	November	December	January	February	March	April	Total	Monthly average
Electricity consumption, kWh	340	439	743	406	367	163	2458	**3.72 kWh/m² = 0.56 EUR/m²**
Gained heat energy, kWh	1202	1397	1825	1193	1110	471	7198	
Monthly average temperature, °C	+5.1	+2.3	−5.8	−0.2	+3.0	+7.1	**+1.9***	*Average in season
SPF	3.54	3.18	2.46	2.94	2.94	2.89	**2.93***	

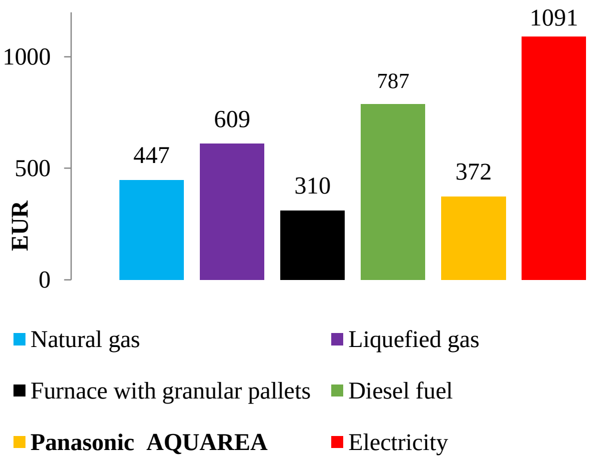

Fig. 5. Cost comparison of heat pump and other heating systems for 110 m^2 building in season 2013/2014.

The results for the air-to-water heat pump in the experimental stand are presented in Table III. It can be seen that the SPF varies from 2.45 to 2.62 for average temperatures from +2.4 °C to +6.0 °C in the three time periods included. The SPF values are quite low, which is related to the high power of heat pumps being more suitable for larger areas exceeding 9 m^2. Namely, the stand needs less energy than the heat pump can generate, so there are longer time steps between compressor startups which results in lower efficiency of the system. Also some adjustments are necessary for a more efficient operation of the system. Impact of these adjustments on the SPF results will be seen in the next winter season.

TABLE III

SPF RESULTS FOR THE EXPERIMENTAL TEST STAND

Period	**25.02 to 03.03**	**11.03 to 24.03**	**02.04 to 16.04**
Whole days	7	14	15
Electricity consumption, kWh	11	18	15
Generated heat energy, kWh	26	46	39
Average temperature, °C	+2.4	+4.3	+6.0
SPF	2.45	2.55	2.62

IV. CONCLUSION

From the experimental data it can be concluded that during the cold months air-to-water heat pumps can operate with an average SPF from 2.93 to 3.2 in the Latvian climate.

With an increase in both costs for non-renewable energy and air-to-water heat pump SPF, the economic benefit from use of air-to-water heat pumps is rising. Analyzing the acquired data, it can be concluded that air-to-water heat pump operating costs are lower than those of heating systems operating with natural, liquefied gas and diesel, and, of course, electricity. For an 110 m^2 building in season 2013/2014 use of air-to-water heat pump heating results in costs of 372 EUR per heating season where only lower cost is for wood pellet furnace with the cost of 310 EUR.

An experimental test stand with air-to-water heat pump system was created and the acquired data indicate SPF values from 2.45 to 2.62. These results are lower than expected due to power of the heat pump and also some necessary adjustments have to be made to the heat pump system.

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