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ANALYSIS OF WATER-WATER TYPE HEAT PUMP OPERATION IN A BUILDING OBJECT

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Summary. The paper presents operation examination results of a heating system equipped with a heat pump, manufactured by the Sekut company, equipped with a scroll type compressor. The performed statistical analysis has shown a significant influence of external temperature and heat transfer coefficient to the COP value. Within the analysed period, the COP maintained a level of 2.6 at an average monthly temperature of -6°C, with a transfer coefficient of 15%.

Key words: heating system, heat pump, operational effectiveness, central heating, hot domestic water.

Membership in the European Union obligates Poland to significantly increase the share of energy harvested from renewable sources in total consumption, which, in fact, is included within the scope of the so-called EU (3x20) climate package. It is assumed that by 2020, the European Union as the whole shall emit 20% less CO_2, the effectiveness of electric energy consumption shall increase by 20% and the share in the renewable energy sources (including those that use heat from low-temperature sources) within the energy balance shall also be 20%.

Use of heat pumps for heating purposes is one of the methods of harvesting renewable energy from natural the environment. A heat pump is a device using low-temperature and waste heat for heating, venting and preparation of hot domestic water. Its basic role consists in drawing heat from a source of lower temperature (bottom) and transferring in to a source of higher temperature (top). This process requires energy to be provided from outside [Zalewski 2001]. The ratio of thermal energy for heating to the work provided from outside is the measure of the heat efficiency of the device and is identified by the COP (Coefficient of Performance). It is desirable for that coefficient to be as high as possible.

The Decision of the Commission 2007/742/EC specifies the energy and ecology criteria that should be met by heat pumps. It provides minimum values of the COP that should consider the energy consumption value by the circulating pumps of bottom and top source of heat and introduces an additional coefficient for seasonal operational effectiveness. A heat pump may be considered to be a device that uses a renewable energy source if the final energy gain significantly exceeds the quantity of energy necessary to drive the pump. Significantly means that the assessed coefficient of the seasonal thermal (heating) efficiency of an SPF heat pump must meet the following requirements stated in Directive 2009/28/EC (1):

$$SPF > 1{,}15 \cdot \frac{1}{\eta}, \tag{1}$$

where:

SPF – seasonal performance factor of the heat pump,

η – ratio of the total production of electric energy to the value of primary energy consumption within the whole European Union (acc. to Eurostat η=0.4),

1.15 – effectiveness of electric energy consumption by final user.

Presently, the heat pump seasonal performance factor should be at least 2.87.

Manufacturers and distributors of heat pumps, as a rule, give the theoretical value of the COP determined under laboratory conditions for accurately specified parameters of bottom and top source temperatures at a given thermal load of the system. The value of such given coefficient does not does not take into consideration energy consumption by auxiliary devices. This is why, in order to specify the actual effectiveness of a heat pump, it is necessary to perform operational examinations [Knaga 2008, 2009, Kołaczkowski 2004, Skonieczna, Ciesielczyk 2009] that would enable determining the seasonal performance factor of the system under real conditions and the influence of different external parameters to this value.

OBJECTIVE

The objective of the paper was to perform initial examinations of the operational nature of a water-water type compressor heat pump, which would allow one to determine the size and specify the variability of energy effectiveness of the heating system based on this type of heat pump in a real building object. The obtained examination results were used to develop the characteristics describing the energy effectiveness variability of the heating system.

SUBJECT AND METHODOLOGY OF EXAMINATIONS

The subject of examinations was a newly built residential building with a total area of 157 m^2 and a cubage of 625 m^3. The heated part of the building represents 55% of the total area, i.e. 86m^2. This is a one floor building with a usable attic and a cellar under a part of the building. It is a wooden structure made of solid balk. Balks are placed on each other in a horizontal plane with insulation material between them made of wooden tow. The heating system of the building is based on the water-water type compressor heat pump that cooperates with central floor heating. Hot domestic water (h.d.w.) is prepared in the dispenser system with a volume of 250 m^3, where the water is heated using a preliminary system of superheated steam cooling before the heat pump condenser (top source of heat). The bottom heat source is water drawn from an infiltration well with a depth of 4 m, where the water table is 1.5 m below the grade level. The temperature of the bottom source within the examined period was 9°C±0.5°C; thus for further analysis, its value is assumed to be constant. The heat pump selected for the examination, with a power rating of 11 kW on the heating side, with a Scroll type compressor, was manufactured by the Sekut company and was equipped with a Vizula control system made by Inveo (this system is a prototype model). The pump uses flat panel exchangers (compact construction) with a power rating of 13 kW. R407 is the cooling agent used in the compressor heat pump. The power of the circulating pump of the top heat source is 180 W and the bottom 370 W. Pt100 paired resistance sensors were used to measure the energy and power of the top heat source, and Pt100 and Pt500 sensors were used to measure the temperature at other points. The flow rate of the operating agent in the top and bottom source was measured by a water meter with a GMDX-R type pulse transmitter, and the quantity of consumed hot water was measured by a single-flux water meter equipped with a GSD8-45R type pulse sensor , whereas the pulse value in the above mentioned flow meters, regardless of the type, was 1dm^3. Consumption of electric energy was measured by the LE-03 type pulse active energy counter within the first accuracy class. The measurement devices used meet the quality requirements of the laboratory examinations. The system operation parameters were read and recorded by the Visula operator's panel equipped with RS-232, RS-485, CAN interfaces and remote Ethernet communication.

At this stage, the paper was limited to determine the quantity of heat transferred to the object to cover the losses on penetration and ventilation and to prepare h.d.w. Electric energy consumption by the compressor and auxiliary devices, such as circulating pumps of bottom and top source and control system was monitored together with measurement of thermal comfort parameters indoors and the outside temperature. The quantity of heat given up to the object by the compressor heat pump was calculated based on dependence (2).:

$$Q = \frac{1}{3,6}\int_{V_1}^{V_2} \rho \cdot c_w \cdot (t_{wej} - t_{wyj}) dV, \quad (2)$$

where:
Q – heat [kWh],
dV– change of the flowing operating medium volume [dm^3],
ρ – density of the operating medium [kg·dm^{-3}],
c_w – specific heat of the operating medium [MJ·(kg×deg)$^{-1}$],
t_{wej} – temperature at inlet to the system c.o. [^{o}C],
t_{wyj} – temperature at outlet from the system c.o. [^{o}C].

Dependence (2) was also used to calculate the quantity of heat for preparation of h.d.w. The quantity of heat determined in dependence (2) referred to the sampling period and recording of data by the control and measurement system. The sampling frequency was established arbitrarily at a level of 1/60 Hz and resulted mostly from the significant inertia of the observed phenomena. The determined heat was subsequently compiled for 24 hours. The daily volume of heat supplied by a pump determined this way was used to specify the COP (3) of this heating device:

$$COP = \frac{Q_{CO24} + Q_{cwu24}}{E_{tot}}, \quad (3)$$

where: COP – coefficient of performance of the heat pump,
Q_{CO24} – heat given up by the heat pump to the central heating system within 24 hours [kWh],
Q_{cwu24} – heat given up by the heat pump to the h.d.w. system within 24 hoursb [kWh],
E_{tot} – electric energy consumed by the compressor, circulating pumps and the control system of heat pump operation [kWh].

Analysis of operation of the compressor heat pump in the examined research object, at this stage, was limited to one month that was characterized be the highest variability of external temperature during the season. During the current heating season, this month was February. Calculations were performed using Excel and Statistica software, and all statistical hypotheses were verified at a level of significance of $\alpha = 0.05$.

EXAMINATION RESULTS

The analysis of operation of the heat pump in the single family building was performed within one month characterized by the highest dynamics of external temperature variability within the heating season 2010/11. The graph (Fig. 1) presents the course of external and internal temperature variations in the residential building. The graph shows two points where the internal temperature significantly deviates from the set temperature (preferred by the user, i.e. 20°C). Point B shows a considerable drop of the internal temperature to 15°C, which was caused by a pump shut down due to pump failure at the bottom source. However, a deviation in point A amounting ±1.6°C is related to a sudden change of external temperature.

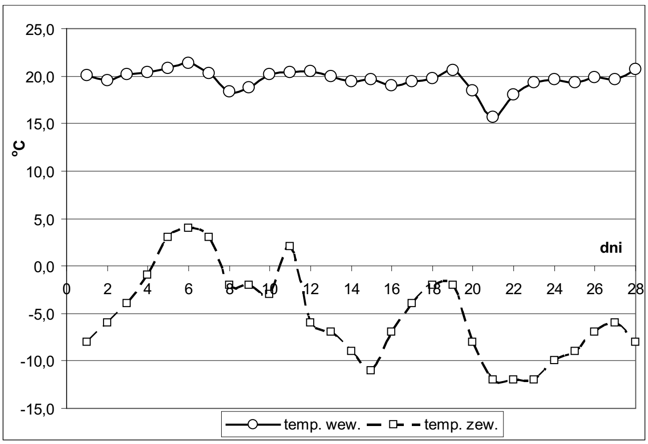

Fig. 1. Course of internal and external temperature changes within the analysed period

Energy characteristics were prepared for the analysed building based on the standard PN–EN 13790 [Decree of the Minister of Infrastructure 2008, Szul 2009]. This enabled theoretical determination of heat demand within individual days of the analysed month, considering the heating (Qco) and preparation of hot domestic water (Qcwu) [Trojanowska, Szul 2006]. The theoretical values were then compared with the values of actual heat consumption determined based on the measurements. Fig. 2 presents the comparable analysis results for preparation of hot domestic water. The apparent high amplitude of changes of actual heat demand for h.d.w. is the result of the variable nature of hot water consumption by the users. However, within the monthly balance, actual consumption of energy for h.d.w. only exceeds 5% of the calculated demand (Fig. 2).

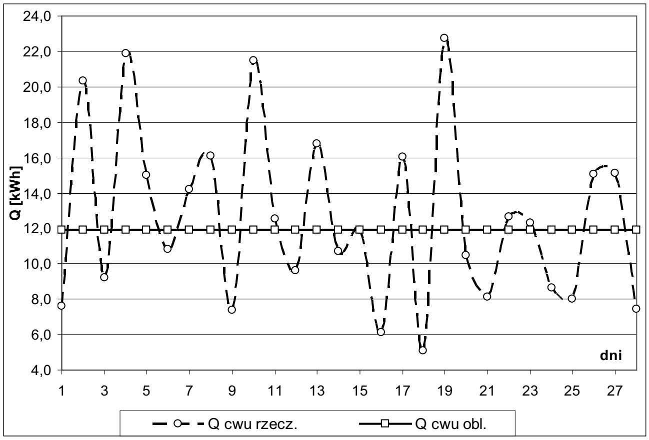

Fig. 2. Course of changes of actual and calculation heat consumption for preparation of hot domestic water

A similar analysis of heat demand was performed for the heating system. This allowed us to explain the causes of internal temperature changes in point A (Fig. 1). An increase of internal temperature in the object was caused by priority forcing of h.d.w. heating, which coincided with a sudden increase of external temperature. In spite of the fact that computational heat demand in the building decreases (Fig. 3), the central heating system had to supply heat due to h.d.w. forcing. This resulted in the system going into an intensified over-adjustment in the second phase by an external drop in temperature. After five days, the system returned to balance.

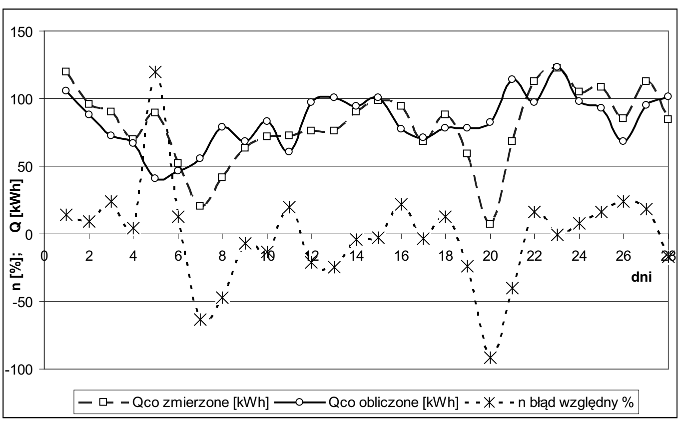

Fig. 3. Course of changes of actual and calculation heat consumption for heating

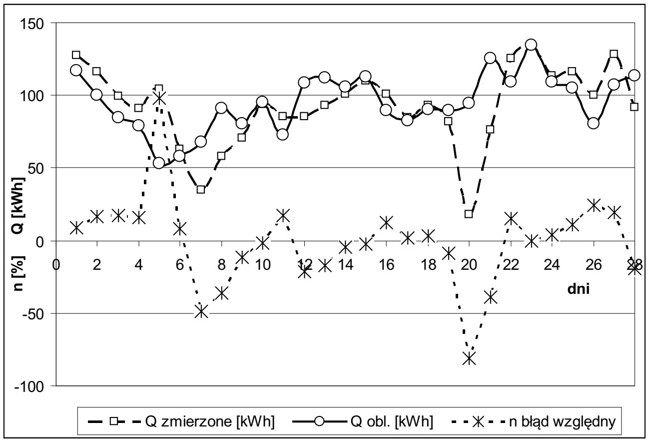

Fig. 4. Course of changes of actual and calculation heat consumption of the building

The course variations of total heat consumption (central heating + hot domestic water) within the analysed period is presented in Fig. 4. The relative error between the calculation and actual heat consumptions in relation to a 24 hour period does not exceed ±20% (Fig. 4), except in the above described analysed cases. However, within the monthly balance, actual heat consumption is less by almost 3% than the calculated consumption. At this stage, it is safe to say that the heat pump is properly selected for the energy needs of the building and provides continuity of heating supply (except for an emergency case).

In the next stage of examinations, the energy efficiency of the heating system based on the compressor heat pump was specified. This analysis consists in determining the operational COP according to the adopted methodology (dependence 3). Statistical analysis within the basic scope allowed us to determine the factors influencing the COP value.

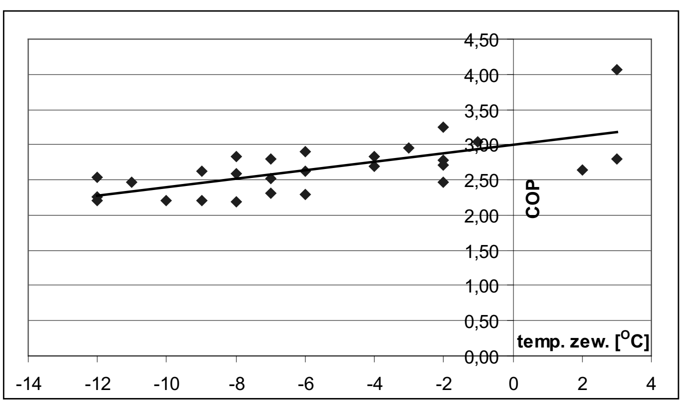

Fig. 5. COP dependence on external temperature

External temperature has a major influence on the COP value. This is described by dependence 4 determined with a determination coefficient of R^2 at a level of 0.42.:

$$COP = 0,054 \cdot t_{zew} + 2,94, \quad (4)$$

where:

t_{zew} – temperature outside the object ^{O}C,

Together with an increase of ambient temperature, the energy effectiveness of the heating system increases as well, and an increase of external temperature to 10°C translates to an increase of energy efficiency by 0.54. This effect can be explained by the low thermal inertia of the wooden building for which the time constant determined from the energy characteristics (calculated according to the standard PN – EN 13790) is 26 hours.

Parallel operation of the central heating system and hot domestic water system carried out by the examined heating system forced a coefficient to be determined that specifies the share of energy collected in the h.d.w. system in relation to the energy given up to central heating by the compressor heat pump.

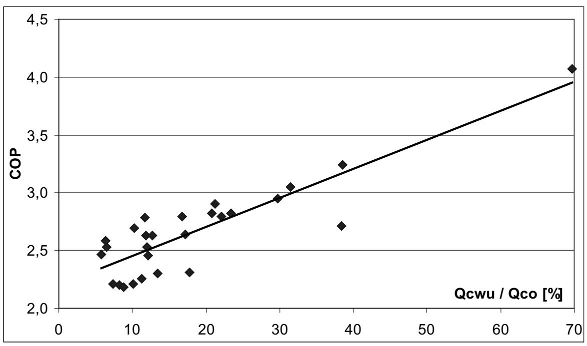

Fig. 6. COP dependence on the heat transfer coefficient

It appeared that this coefficient is closely correlated with the operational energy effectiveness of a heating system equipped with a heat pump. Based on this, dependence (5), which describes the operational effectiveness of the previously determined coefficient, was developed with adjustment of the model to data at a level of 73%:

$$COP = 0,025 \cdot w_{pc} + 2,2, \quad (5)$$

where:

w_{pc} – heat transfer coefficient specified as $w_{pc} = \frac{Q_{cwu24}}{Q_{co24}}$,

Q_{CO24} – heat given up by the heat pump to the central heating system within 24 hours [kWh],

Q_{cwu24} – heat given up by the heat pump to the h.d.w. system within 24 hours [kWh],

From the developed dependence and graph (6), it results that together with the increase of heat transfer coefficient, the energy effectiveness of the examined system increases as well, and it may reach an average value at a level of 3, which, in relation to the effectiveness of the national electric energy generation system, results in electric energy consumption by the final user at a level of 1.2. Moreover, it results from dependence (5) that in the case of a lack of energy consumption by the h.d.w. system, the operational effectiveness of the heating system shall not drop below 2.2. The maximum value reached by the energy effectiveness of the heating system within the analysed period is 4, and this took place with a high coefficient of w_{cp}=70% and with relatively high external temperature. Due to the above, this point was not rejected at this stage of the analysis. Undoubtedly, further analysis should be performed in the direction of reduction of the operation cycle (activation of heat pump).

CONCLUSIONS

As a result of the presented monthly analysis of operation, and subsequent determination of the operational energy effectiveness of the heating system based on the compressor heat pump, it can be ascertained that:

1. The heat pump was properly selected to the heating system of the residential building, providing continuity of heating supply within the considered period; this consisted of an energy stable bottom heat source and optimal selection of power for the heat pump.
2. Within the examined period, the average operational effectiveness COP of the entire system was 2.6. This can be acknowledged as good results due to the fact that the system worked at a relatively low average external temperature of -6°C and a low average heat transfer coefficient of w_{cp}=15%.
3. External temperature significantly influences the energy effectiveness of the system, and together with its increase, the effectiveness increases, too. At an average ambient temperature of 0°C, the energy effectiveness of the heating system is at level 3.
4. At lower temperatures, thermal load of the h.d.w. system should be higher in order to maintain an optimum value of energy effectiveness or a bivalent system of cooling superheated steam should be employed.
5. Further analysis of the system should be performed within the operational cycle range, i.e. from the moment of activation to deactivation of the compressor heat pump. Such analysis would allow for the development of a more effective control system.

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ANALIZA PRACY POMPY CIEPŁA TYPU WODA-WODA W OBIEKCIE BUDOWLANYM

Streszczenie. W opracowaniu przedstawiono wyniki badań eksploatacyjnych systemy grzewczego wyposażonego w pompę ciepła wyprodukowaną przez firmę Sekut ze sprężarką typu scrol. Przeprowadzona analiza statystyczna wykazała istotny wpływ temperatury zewnętrznej, oraz wskaźnika przekazania ciepła na wartość COP. W analizowanym okresie COP kształtowało się na poziomie 2.6 przy średniej miesięcznej temperaturze –6OC i wskaźniku przekazania 15%.

Słowa kluczowe: system grzewczy, pompa ciepła, centralne ogrzewanie, ciepła woda użytkowa.