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Investigation of Air Exergy from Condenser of Air Split-Conditioner Heat Pump and Its Exergetic Efficiency Depending on Outside Air Temperature

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Abstract

Rising prices for fuel and energy resources make the problem of using alternative energy sources and energy saving relevant not only for the economy of Ukraine, but also for the world economy. One of the ways to reduce energy consumption is the use of air split-conditioner heat pumps in building heating systems, which are using up to 1 kW of electricity from the grid to transport up to 5 kW of heat energy from the outdoor air to the indoor air. The energy perfection of air split-conditioner heat pumps can best be established only on the basis of the analysis of their exergy efficiency. And this allowed substantiating the relevance of such a study, which made it possible to establish the exergy of air from the condenser of the heat pump air split-conditioner and its exergetic efficiency. The author's innovative mathematical model for the analysis of operation of single-stage freon heat pumps of air split-conditioners by exergetic method is used in this article. The exergy of the air from the condenser of the air split-conditioner heat pump by Mitsubishi Electric and its exergetic efficiency with the standard heat capacity of 3200 W with R32 refrigerant depending on the outside air temperature have been established.

Keywords: heat pump; split-conditioner; outside air temperature; exergetic efficiency.

1. Introduction

Growing shortages and rising prices for fuel and energy resources, especially oil and gas, make the problem of using alternative energy sources and energy conservation relevant not only for Ukraine's economy, but in particular for world economies, which in the long run will reduce energy consumption [1].

One of the ways to reduce energy consumption is the use of heat pumps (HP) of air split-conditioners ("air-to-air") in heating systems of buildings, which use 1 kW of electricity from the network to transport up to 5 kW of heat from outdoor air to indoor air of the room of building [3], [12], [15] – [17]. Use of HP split-conditioners provides not only energy saving, but also ecological effect.

In developed countries, heat supply (municipal and industrial) is carried out by heat pumps up to 75%, according to the World Energy Committee. More than 30% of homes in the United States are equipped with HP.

Heat pumps of air split-conditioners need to establish their efficiency to reduce energy consumption, which is possible using a modern method of thermodynamics – *exergetic* [4] – [11], [13]. Exergetic analysis allows establishing the maximum thermodynamic capabilities of a system, and therefore is the most perfect way to define the efficiency.

Exergetic analysis has been introduced as a mandatory component of ongoing projects, as have plans to modernize production in the United States and some leading European countries.

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As a rule, companies-manufacturers of heat pumps split-air conditioners, unfortunately, do not indicate their efficiency at different ambient temperatures on the evaporator.

2. Analysis of recent studies and publications

The use of exergy method of analysis is substantiated in the works of J. Shargut, R. Petela, V. M. Brodyansky and other scientists to optimize various technical systems, including refrigeration machines, for technical and economic optimization of their operation, and in the works of I. Dincer, M. A. Rosen also for heat pumps and our works [4] – [11], [13], [14], [18]. We have adapted this method to the analysis of air split-conditioners heat pumps ("air-to-air") [15] – [17] and used in this article.

The most detailed exergy method of analysis of single-stage refrigerators is given in [5], which is not suitable for refrigerators of air split-conditioners, in which the evaporator and condenser are washed with appropriate air, and in the circuit of the refrigerator another refrigerant circulates. This method of analysis is also briefly covered in [4], [7]. The energy efficiency of heat pumps of these air split-conditioners is known to be conditioned by the parameters of both internal and external operating temperatures and the type of refrigerant [7]. Therefore, to determine the efficiency of operation of air split-conditioners heat pumps, we need a detailed exergetic analysis of their operation depending on the outdoor air temperature.

Based on [7], the authors developed an innovative mathematical model of exergetic analysis of the operation of air split-conditioners heat pumps adapted to different refrigerants and manufacturers, which makes it possible to establish an energy effective mode of operation. With the help of this mathematical model it is possible to conduct exergetic research of heat pumps [15] – [17]. The result of the analysis is definition of the exergetic efficiency depending on the outdoor temperature.

Thus, analyzing the available literature, we conclude that the determination of energy consumption consumed by of air split-conditioners heat pumps can be most fully achieved on the basis of exergetic analysis, which takes into account not only the quantity but also the quality of energy consumed [4] – [11], [13] – [18].

The scheme of a single-stage split-conditioner heat pump (*without effective cooling of the compressor*) and freon-32 (R32) refrigerant [19] was used for the research (see Fig. 1). Construction of the processes of its work was made on the (p, i)-diagram (Fig. 2).

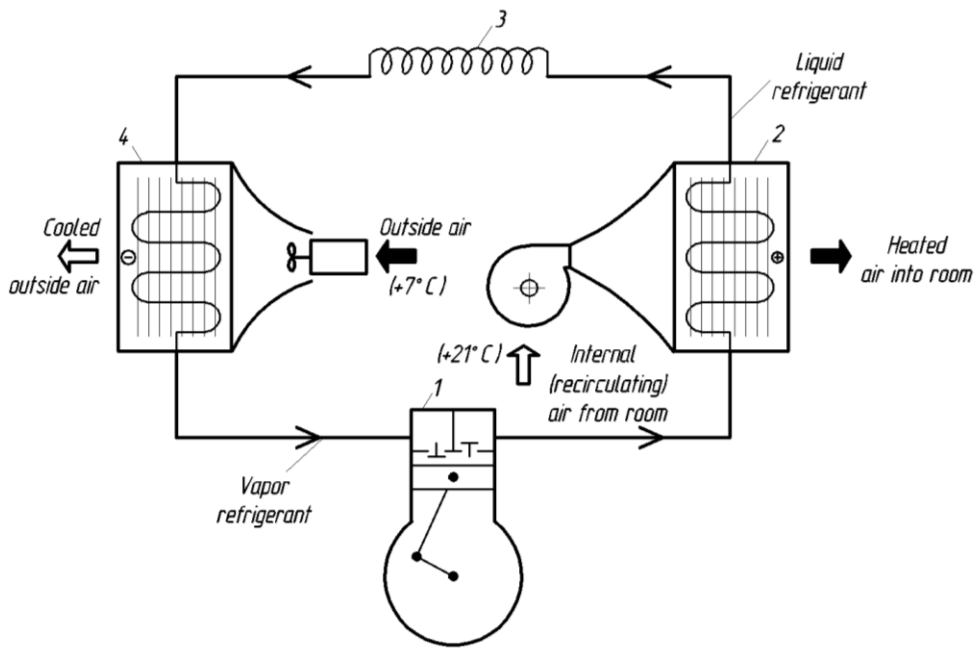

Fig. 1. Scheme of air split-conditioner heat pump: *1* is compressor; *2* is condenser; *3* is capillary tube; *4* is evaporator.

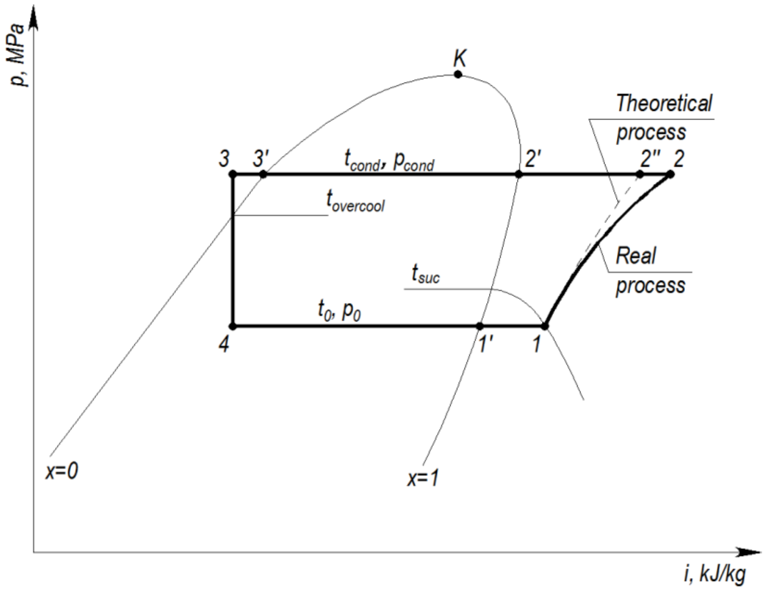

Fig. 2. Construction of the processes of work on (p, i)-diagram for air split-conditioner heat pump:
1, *2*, *3*, *4* are characteristic points of the thermodynamic cycle.

3. The purpose of the research

The purpose of this work is to determine the exergetic efficiency of the air split-air conditioner heat pump with R32 one-component refrigerant depending on the outside air temperature. To achieve this goal, the following main objectives were formulated:

- to determine the exergy efficiency of the air split-conditioner heat pump, for example, the one manufactured by Mitsubishi Electric with a standard heat capacity of 3200 W with R32 refrigerant under different operating outdoor temperature conditions;
- to define exergy of air from the condenser during operation of the air split-conditioner heat pump by Mitsubishi Electric with nominal heat capacity of 3200 W under standard temperature conditions with R32 refrigerant and its exergetic efficiency under different operating outdoor temperature conditions.

4. Research results

The exergetic balance of a one-stage vapor-compressor refrigerant (*without efficient cooling of the compressor*) air split-conditioner heat pump for 1 kg/s consumption of circulating working refrigerant has the form [4], [5], [7]:

$$e_{in} = e_{out} + \Sigma d \text{ , kJ/kg,} \tag{1}$$

where e_{in} is the amount of specific exergy, which is included in the of the air split-conditioner heat pump, kJ/kg; e_{out} is the amount of specific exergy emanating from the condenser of the air split-conditioner heat pump, kJ/kg; Σd is total specific exergy losses in all air split-conditioner heat pump units, kJ/kg.

Obviously, the higher the perfection of the air split-conditioner heat pump and its elements, the higher is the exergetic efficiency, which was also determined from the exergetic balance (in fractions of a unit), namely [4], [5], [7]:

$$\eta_e = \frac{\mathrm{e}_{out}}{e_{in}} \tag{2}$$

Therefore, the exergetic efficiency of the of the air split-conditioner heat pump was calculated by formula (2), in which the numerator is a useful exergetic effect, and the denominator is the cost of exergy.

The exergetic analysis was performed for Mitsubishi Electric air split-conditioner heat pump (standard heat capacity Q_H^{st} = 3200 W, power consumption N_{cons}^{st} = 780 W, condensate quantity W_{cond}^{st} = 1.10 l/h, air flow rate on the condenser L_{cond}^{st} = 490 m^3/h, and on the evaporator L_{ev}^{st} = 1200 m^3/h) with an exergetic efficiency of 0.379, which was determined under standard temperature conditions (indoor temperature in room $t_{in} = t_{H_1}$ = 21 °C, outdoor temperature $t_{out} = t_{C_1}$ = 7 °C) on refrigerant R32 [16], [20]. Determination of the specific exergy from the condenser of the air split-conditioner heat pump and exergetic efficiency was performed at operating outdoor temperature, i.e. under ambient temperature conditions other than standard ($t_{out} = t_{C_1} = -15...20$ °C). Air consumption was taken on the condenser (L_{cond} = 490 m^3/h), and on the evaporator (L_{ev} = 1200 m^3/h).

Operating heat capacity was determined by the following formula [2]:

$$Q_H^{op} = Q_H^{st} \cdot \left[1 + \left(t_{C\,1} - 7\right) \cdot 0.035\right], \text{ W.} \tag{3}$$

The results obtained during the research are given in Table 1 (**bold** font indicates the research results; in addition the results of research under standard conditions are given in *italics*).

Table 1. The results of research of air exergy from the condenser of Mitsubishi Electric air split-conditioner heat pump with standard heat capacity of 3200 W and its exergetic efficiency depending on the outside air temperature.

$t_{out} = t_{C_1}$, °C	$t_{in} = t_{H_1}$, °C	L_{cond}, m^3/h	Q_H^{op}, W	e_{in}, kJ/kg	e_{out}, kJ/kg	η_e
-15	21	490	736	**108.3**	**61.81**	**0.571**
-10	—"—	—"—	1296	**100.4**	**52.86**	**0.527**
-5	—"—	—"—	1856	**92.0**	**44.51**	**0.484**
0	—"—	—"—	2416	**83.3**	**36.74**	**0.441**
7	—"—	—"—	3200	*70.7*	*26.77*	*0.379*
10	—"—	—"—	3536	**65.3**	**22.80**	**0.349**
15	—"—	—"—	4096	**56.3**	**16.57**	**0.294**
20	—"—	—"—	4656	**47.7**	**10.80**	**0.226**

5. Conclusion

This article presents an exergetic analysis of the operation of one-stage refrigerant of split-conditioners heat pumps, which are used as local autonomous air conditioners to create comfortable and energy-saving conditions in buildings in the cold season, based on the author's innovative mathematical model for this analysis.

Research performed on the author's mathematical model established the specific exergy from the condenser of the air split-conditioner heat pump and its exergetic efficiency on the example of the air conditioner with standard heat capacity of 3200 W by Mitsubishi Electric with R32 refrigerant at different operating outdoor air temperatures. Analyzing the data obtained in Table 1, we can conclude the following. At an outdoor air temperature of –15 °C compared to 20 °C, the exergetic efficiency increases by (0.571 – 0.226)·100/0.226 = 153 %.

The author's mathematical model of air split-conditioner heat pumps used for this article can be applied to different types of refrigerants and air split-conditioner models, provided that the thermodynamic properties of the refrigerant and the characteristics of the air split-conditioner heat pump are known.

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Дослідження ексергії повітря з конденсатора теплової помпи split-кондиціонера та її ексергетичного ККД залежно від температури зовнішнього повітря

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Анотація

Зростаючий ріст цін на паливно-енергетичні ресурси роблять проблему використання альтернативних джерел енергії та енергозбереження важливою не тільки для економіки України, але зокрема для економік світу. Одним зі шляхів зменшення енергоспоживання є використання повітряних теплових помп split-кондиціонерів в системах теплопостачання приміщень будівель, які за використання 1 кВт електроенергії з мережі транспортують до 5 кВт теплової енергії від повітря зовнішнього середовища до внутрішнього повітря приміщень. Енергетична досконалість роботи теплових помп split-кондиціонерів найкраще може бути встановлена тільки на основі аналізу їх ексергетичної ефективності. А це дозволило обґрунтувати актуальність проведення такого дослідження, що дало можливість встановити ексергію повітря з конденсатора теплової помпи split-кондиціонера та її ексергетичний ККД. У статті використано авторську інноваційну математичну модель аналізу роботи одноступеневих фреонових теплових помп split-кондиціонерів за ексергетичним методом. Встановлено ексергію повітря з конденсатора теплової помпи split-кондиціонера та її ексергетичний ККД фірми “Mitsubishi Electric” зі стандартною теплопродуктивністю 3200 Вт на холодильному агенті R32 залежно від температури повітря зовнішнього середовища.

Ключові слова: теплова помпа; split-кондиціонер; температура зовнішнього повітря; ексергетична ефективність.