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DEVELOPMENT OF A SYSTEM FOR GENERATING HEAT AND COLD FOR THE NEEDS OF PHARMACEUTICAL COMPANIES

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The article investigates the efficiency of using a heat pump to simultaneously generate heat and cold at a pharmaceutical enterprise in order to reduce energy costs. The proposed scheme, where the source of heat is a refrigeration network with constant parameters, ensures the stability of temperature conditions required for technological processes and product storage. The economic feasibility of using a heat pump in comparison with such a technology as freezing is analyzed at different periods of the day. Particular attention is paid to the automatic regulation of the system through the SCADA system, which minimizes the human factor and guarantees continuous maintenance of the required conditions. Taking into account the requirements of pharmaceutical production, including the need to comply with strict temperature parameters, a water-to-water heat pump was chosen. This scheme allows efficient use of energy between the cooling and heating systems, which ensures stable climate conditions in production and storage facilities. During periods of downtime, the heat pump maintains the required temperature in the refrigeration network, preventing the use of energy-intensive chillers. This solution increases energy efficiency, reduces operating costs, and meets the requirements of good manufacturing practice. Promising areas for further research include the development of algorithms for automatic control of heat pumps, as well as the integration of energy storage systems to improve efficiency under variable load conditions.

Keywords: *renewable energy, FreeCooling, heat pump, refrigeration machine, heat recovery.*

РОЗРОБКА СИСТЕМИ ОТРИМАННЯ ТЕПЛОТИ ТА ХОЛОДУ ДЛЯ ПОТРЕБ ПІДПРИЄМСТВ ФАРМАЦЕВТИЧНОЇ ПРОМИСЛОВОСТІ

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У статті досліджено ефективність використання теплового насоса для одночасного отримання теплоти та холоду на фармацевтичному підприємстві з метою зниження енергетичних витрат. Запропонована схема, де джерелом теплоти виступає холодильна мережа з постійними параметрами, забезпечує стабільність температурних режимів, необхідних для технологічних процесів та зберігання продукції. Аналізовано економічну доцільність використання теплового насоса в порівнянні з такою технологією як FreeCooling, у різні періоди доби. Особливу увагу приділено автоматичному регулюванню роботи системи через SCADA-систему, що мінімізує людський фактор і гарантує безперервне підтримання необхідних умов. З урахуванням вимог фармацевтичного виробництва, включаючи необхідність дотримання строгих температурних параметрів, вибрано тепловий насос «вода-вода». Така схема дозволяє ефективно використовувати енергію між системами холодо- та теплозабезпечення, що забезпечує стабільність кліматичних умов у виробничих та складських приміщеннях. У періоди простою тепловий насос підтримує необхідну температуру в *холодильній мережі, запобігаючи використанню енергоємних холодильних машин. Це рішення підвищує енергоефективність, зменшує експлуатаційні витрати та відповідає вимогам належної виробничої практики. Перспективними напрямками подальших досліджень є розробка алгоритмів автоматичного керування тепловими насосами, а також інтеграція систем накопичення енергії для підвищення ефективності в умовах змінного навантаження.*

Ключові слова: *відновлювана енергетика, FreeCooling, тепловий насос, холодильна машина, утилізація теплоти.*

List of symbols and abbreviations used:

RES – renewable energy sources

HP – heat pump

SW – software

CORP – coefficient of performance of a heat pump (Coefficient of Performance), which is the ratio of the amount of heat the pump delivers to the system to the amount of energy consumed

HWS – hot water supply

SCADA – supervisory control and data acquisition

FREECOOLING – a cooling system that provides a natural cooling mode

Introduction. The development of renewable energy is a key direction in achieving sustainable development goals, including reducing the negative impact of the energy sector on the environment and enhancing the energy efficiency of production. Renewable energy sources have significant potential due to their environmental friendliness and inexhaustibility. However, their main drawback remains inconsistency, as energy production depends on natural conditions that can change stochastically. This creates risks for the stability of energy supply, especially in local energy systems. Pharmaceutical production requires high precision in maintaining the climatic parameters of the premises, which is ensured by the simultaneous operation of cooling and heating systems. The main source of cooling in such enterprises is powerful refrigeration units. Rational use of energy resources in this process is critically important. The FreeCooling technology allows significant reduction of cooling costs during the cold season by using external climatic conditions for cooling without involving compressor units. At the same time, the heating of pharmaceutical enterprises is traditionally based on the use of thermal devices that operate on fossil fuels. A practical solution for optimizing energy consumption is the implementation of heat pumps, which can use the cooling circuit as a heat source. This allows efficient redistribution of energy between systems and reduces fuel consumption in heating installations, contributing to lower operating costs and environmental impact.

Scientific research and development work on improving the efficiency of heat pumps have been conducted both in Ukraine and worldwide for a long time. The prospects of using heat pumps have been studied in works [1,2,3]. In works [6,7,8], the efficiency of various types of heat pumps has been evaluated. The authors [9, 10] have performed a comparative energy analysis of heat pumps. Active research is being conducted to create an effective control system in the design of complex local energy supply systems (clusters) using renewable energy sources [14,15,16].

The results of these studies confirm the prospects of increasing energy efficiency through the use of low-potential thermal energy systems of industrial enterprises for heating, air conditioning, hot water supply, and meeting the technological needs of consumers.

Task Statement. Rational use of energy resources in the pharmaceutical industry is critically important, as maintaining stable climatic conditions in production facilities directly affects product quality. The implementation of energy-efficient technologies, such as heat pumps and FreeCooling, not only reduces energy supply costs but also enhances the environmental sustainability of the enterprise.

The aim of this work is to develop and implement an energy-efficient system that provides simultaneous heating and cooling for a pharmaceutical enterprise with minimal costs. The proposed solution is based on the use of a heat pump with a heat source in the form of a refrigeration network, which ensures continuous year-round operation of the system according to production needs. The research also aims to determine the optimal ratio between FreeCooling and heat pump technologies to maximize cost reduction, increase profitability, and automate processes using a SCADA system.

Presentation of the Main Material

The heating system at pharmaceutical enterprises is of great importance, as creating stable temperature and humidity critically affects product quality, especially in the production of medicines and storage of pharmaceutical products. Typically, systems based on gas boilers, steam boilers, or electric heaters are used. Their main disadvantages are carbon emissions into the atmosphere and high fuel costs. Heat pumps are a more modern, efficient, and environmentally friendly way of heating, which is beginning to replace traditional systems. Their significant advantages are that they can provide efficiency up to 400%, meaning for each unit of electrical energy, they can deliver 4 units of heat, they do not produce CO_2 emissions and help reduce the enterprise's environmental footprint, they have significantly lower maintenance costs, and their use requires less fuel expenditure compared to traditional systems, modern heat pumps are capable of not only heating the premises but also cooling them in the summer, which is important for maintaining a stable climate inside the premises where pharmaceutical products are stored. Also, heat pump systems can be integrated with other technologies for precise microclimate control, which is critical for pharmaceutical enterprises.

The use of FreeCooling technology allows significant reduction in cooling production costs during the winter period. The FreeCooling system uses external climatic conditions to lower the temperature of the water circulating in the cooling system without the need for compressor refrigeration machines. This can significantly reduce electricity costs, especially in colder periods of the year when the outside temperature is lower than the temperature that needs to be maintained in the system.

Refrigeration machines TRANE consist of two TRANE refrigeration machines (launched in 2010) to maintain the coolant at 6°C-12°C. The refrigeration machines ХМ№1, ХМ№2 each have 2 independent circuits in one refrigeration machine, which include two evaporators, two compressors, two condensers, automation devices, and two remote condensers. ХМ№1 and ХМ№2 also have a FreeCooling system with additional heat exchangers.

The refrigeration machines maintain the coolant temperature at 6°C-12°C. When the outside air temperature is above 5°C, the refrigeration machines operate. Depending on the load, the controller turns on one or both refrigeration machines. When the outside air temperature is below 5°C, the refrigeration machines turn off. FreeCooling, installed on ХМ№1, is activated. When the water temperature in the cooling circuit exceeds 12°C, both refrigeration machines are activated to reduce it.

An analysis of existing methodologies for building complex systems was carried out. Based on the criteria of minimal capital costs and maximum efficiency with minimal seasonal impact, it was decided to install a water-to-water heat pump. Using heat pumps in a configuration where the cooling circuit serves as a heat source and heat is dissipated in the heating circuit allows for the necessary heat exchange between continuously operating systems, resulting in reduced fuel consumption for heating devices. In the absence of production and the need to maintain comfortable conditions in the premises (e.g., on weekends), a low-capacity heat pump provided the necessary temperature in the cooling network and prevented the operation of a more powerful refrigeration machine.

To illustrate the operation of the heat pump system and the FreeCooling system at a pharmaceutical enterprise, a mathematical model can be developed to describe the interaction of the energy parameters of such systems and determine the efficiency of energy use.

The total energy consumption for heating or cooling premises at a pharmaceutical enterprise can be determined as:

$$E_{total} = \frac{Q_{out}}{COP}, \quad (1)$$

where:
E_{total} - total energy consumption for the operation of the heat pump system.

This equation allows for the assessment of energy consumption for heating or cooling depending on the COP value, which can vary depending on temperature conditions.

The FreeCooling system can use the outside temperature to reduce cooling costs in the winter period. Mathematically, this can be expressed as:

$$Q_{cool} = \begin{matrix} Q_{ext}\, if\, T_{ext} < T_{target} \\ 0....if\, T_{ext} \geq T_{target} \end{matrix}, \quad (2)$$

where:
Q_{cool} - the amount of heat removed from the system through FreeCooling;
Q_{ext} - the amount of energy transferred through FreeCooling (this depends on the temperature difference between the external environment and the internal premises);
T_{ext} - the temperature of the external environment;
T_{target} - the set temperature for starting FreeCooling, which is optimal for cooling the premises.

An important part of this model is that FreeCooling actively works when the outside temperature is low enough to provide cooling without the use of refrigeration machines. If the outside temperature is higher than a certain threshold T_{target}, the system switches to regular cooling using refrigeration machines.

Changes in energy tariffs can significantly affect the efficiency of using heat pumps and FreeCooling systems. To model this effect, the following model can be used, which takes into account tariff changes throughout the day.

Let $P_{elec}(t)$ - be the electricity tariff at time t, and Pgas(t) the gas tariff at the same time. The energy cost model considering tariffs can be expressed as:

$$E_{cost}(t) = (P_{elec}(t) \cdot E_{total}(t)) + \left(P_{gas}(t) \cdot Q_{gas}(t)\right), \quad (3)$$

where:
$E_{cost}(t)$ - energy costs for a specific time period t;
$Q_{gas}(t)$ - gas consumption for heating depending on time t.

Considering the variability of tariffs, the system can be configured to use cheaper energy during periods when electricity or gas tariffs are low.

For comprehensive management of the entire energy system, a model can be created that combines all the aforementioned components: heat pumps, FreeCooling, energy tariffs. The total energy consumed and costs can be described as follows:

$$E_{total} = E_{heat} + E_{cool}, \quad (5)$$

where:
E_{heat} - energy spent on heating;
E_{cool} - energy spent on cooling (including FreeCooling);

This model allows for accurate calculation of energy resource costs depending on weather conditions, energy tariffs, and the efficiency of using heat pumps and FreeCooling.

For analysis, data obtained during the operation of the existing cooling system, which includes refrigeration machines with Free cooling function, a heat pump, and energy consumption data during the cold season, were used. The calculated economic efficiency results for the technologies considered are shown in the Table.

For the pharmaceutical company "Darnitsa", a heat pump of the Italian brand Aermec, model WRK0350HL was chosen, designed for heat recovery from the refrigeration circuit (coolant temperature 6°C-12°C) to the heating system (heat carrier temperature 45°C-65°C). This heat pump has a thermal capacity of 103.8 kW and a cooling capacity of 81.9 kW, ensuring efficient operation in the heating and cooling system. Additionally, it can be integrated with existing FreeCooling systems to optimize energy costs.

Table. The ratio of economic efficiency of using a heat pump depending on electricity and natural gas tariffs over a period of 120 days

	Cost of electricity, UAH/kWh·hr					
Cost of gas, UAH/m3	**5**	**6**	**7**	**8**	**9**	**10**
10	21 958	-36 258	-94 474	-152 691	-210 907	-269 124
12,5	100 219	42 002	-16 214	-74 431	-132 647	-190 864
15	178 479	120 262	62 046	3 829	-54 387	-112 603
17,5	256 739	198 523	140 306	82 090	23 873	-34 343
20	334 999	276 783	218 566	160 350	102 133	43 917

A result with + means that the use of the heat pump is economically feasible

A result with - means that the use of the heat pump is not economically feasible

One of the important features of the heat pump system is the ability to automate its operation depending on changes in electricity and natural gas tariffs. With modern control systems such as SCADA, the heat pump's operating schedule can be automatically adjusted, significantly reducing energy costs. SCADA software allows for monitoring and analysing energy consumption, as well as forecasting cooling and heating needs for the next day

The software takes the following data from the database: the cost of gas (updated once a month), the cost of electricity (data updated hourly), the cost of electricity transmission and distribution (updated once a month). Based on the received information, the actual cost indicator is calculated and compared with the planned one. If the actual indicator is below the threshold, the heat pump is allowed to turn on. In the absence of emergencies and confirmation that all other operating parameters are normal (heat carrier temperature, coolant temperature, system pressure...), the heat pump is turned on. If the actual indicator is above the threshold, the controller prohibits the operation of the heat pump until the actual indicator is below the threshold.

During commissioning, it was noted that by default, all heat pumps are set to automatic control of the temperature of the received heat carrier, assuming that the heat source is conditionally infinite. This led to the fact that during daily temperature fluctuations in the heat network and its threshold values, the heat pump unloaded the compressors (operated at 50% capacity) or stopped upon reaching the set temperature. It was decided to "Reverse the control scheme" to rebuild the automation scheme, moving the control point from the heat consumer to the source. Thus, the automation began to control the temperature of the cold circuit, considering the heat consumer conditionally infinite. In the winter period, when the freon vapor temperature is below the heat carrier temperature in the network, to prevent emergency stops due to condensation temperature, the control of this parameter was transferred to an external SCADA that allows or prohibits the operation of the heat pump. Since the cooling system's cold consumption is constantly higher than the heat pump's capacity, it constantly operates at 100% load, transferring all the heat to the heating system. This allowed eliminating partial load mode and using the heat pump at maximum productivity.

One of the important features of heat pump systems is the ability to automate their operation depending on changes in electricity and natural gas tariffs. With the help of modern control systems such as SCADA, it is possible to automatically adjust the heat pump's operating schedule, significantly reducing energy costs. SCADA software allows monitoring and analysing energy consumption, as well as forecasting cooling and heating costs for the next day. Real-time dispatch control, data collection, processing, display, and archiving, and SCADA control of the entire considered cooling system is carried out using the software product from Siemens – Desigo CC.

Desigo CC is an open integrated platform for building automation and dispatching. It simplifies operation, monitoring, control, optimization, and management of facilities from a single interface, enhancing comfort, efficiency, and safety. Desigo CC provides the technological foundation for smart buildings, offering an open and modular platform that grows with management requirements.

The electricity tariff changes every hour and can be significant for an industrial enterprise in Ukraine, depending on many factors. The average price for a company, including transmission and distribution, in February was 8.07 UAH/kWh excluding VAT. At the same time, the minimum DAM price excluding transmission and distribution in February was 0.5 UAH/kWh, and the maximum price was 10 UAH/kWh. The price differs more than 10 times. The price difference is especially pronounced in the spring-autumn period, which is due to solar generation.

The natural gas tariff is determined once a month on a contractual basis. As of February 2025, the cost of $1m^3$ of gas is UAH 16.97 excluding VAT.

The Desigo CC software, through an intermediate database, allows automatic retrieval from the Market Operator's website of the DAM tariff forecast and the natural gas cost for the current period. The tariff data allows for the calculation of ratio coefficients and the prediction of the heat pump operation schedule for the current and next day.

On the example of the SCADA video page from 20.02.2025 (Figure) it is seen that the time interval between 0:00 to 17:00 and from 22:00 to 24:00 has a positive ratio between the natural gas tariff and electricity, so the system algorithm allows the heat pump to operate, which is indicated by a "green circle" next to the electricity tariff. In the period from 17:00 to 22:00, when the ratio of the cost of natural gas to electricity is unprofitable, the programmed algorithm does not give a command for the heat pump to operate. On the video page, this period is marked with "gray circles". After the end of the day, the data is automatically updated with the calculation of the heat pump operation schedule depending on the DAM tariffs and the cost of natural gas.

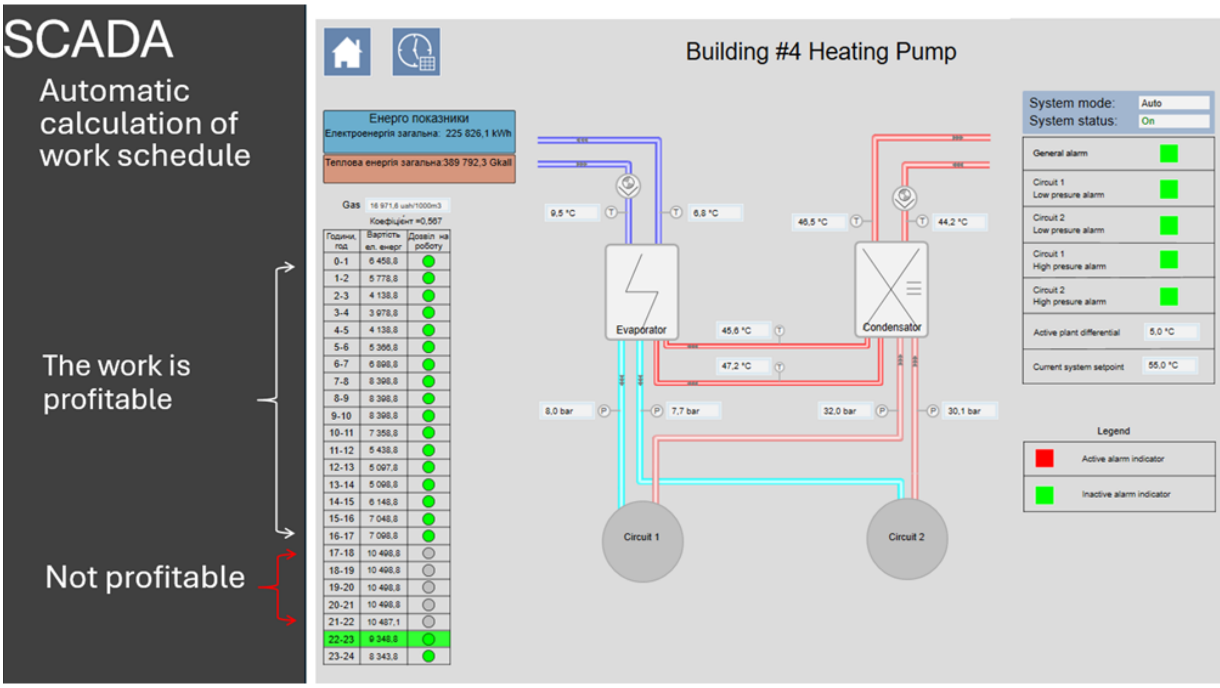

Figure. SCADA page of Decigo CC with the structural diagram of the Aermec heat pump, Model WRK0350HL, and automatic scheduling of the operation schedule depending on the tariffs

According to the calculation of daily electricity consumption, cold and heat production, in the case of the heat pump operating in constant mode, i.e., without considering tariff variability, the savings from using the technology amount to 881 UAH/day. In the case of the heat pump operating in adaptive mode, considering the ratio of energy carrier costs, the savings from using the technology amount to 1024 UAH/day. Thus (on the example of 20.02.2025), the profitability of the heat pump operation increases by 16% and amounted to an additional 143 UAH/day. On an annual scale, the potential increase in profitability could amount to an additional UAH 35 - 40 thousand.

Conclusion:

Modern heating and cooling technologies, such as heat pumps and FreeCooling systems, are important tools for increasing the energy efficiency of pharmaceutical enterprises. They not only reduce fuel and electricity costs but also help to reduce the environmental impact of production. Taking into account changes in energy tariffs and automating the operation of heat pumps can significantly increase the economic efficiency of the enterprise, which is an important factor in the current competitive market conditions.

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