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STATUS AND PROSPECTS OF IMPROVING ENERGY EFFICIENCY CLEAN ROOMS AIR CONDITIONING SYSTEMS

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The article is devoted to increasing the efficiency of the air conditioning systems of clean rooms, which maintain the microclimate parameters in a given range according to several indicators - the number and size per 1 m³ of dust particles, aerosols, microorganisms and pressure, humidity, temperature.

Clean rooms are used in microelectronics, instrumentation, medicine and medical industry, pharmacology, laboratories, optics production, food industry, biotechnology, aviation and space industry.

Recently, abroad and in Ukraine, with the aim of saving energy resources, fundamental research is being conducted in a number of technologies from the perspective of exergetic methodology. This contributes to an objective assessment of the degree of energy perfection of devices and processes related to energy conversion in modern technologies.

For this purpose, the authors developed an exergetic method of analyzing the operation of the direct-flow central air conditioning system of clean rooms.

Keywords: clean rooms, air conditioning, microclimate, exergetic balance, exergetic output-input ratio (OIR), energy efficiency.

Introduction

Clean rooms are rooms where the parameters of the microclimate are maintained in a given range according to several indicators - the size and number of dust particles, aerosols, microorganisms and temperature, humidity, and pressure in the room per 1 m3 of the room volume (Fedotov, 2003; Hayakawa, 1990; White, 2002; White, 2004; GOST ISO 14644-1-2017, 2017). Depending on pollution per 1 m3 of volume, clean rooms are divided into cleanliness classes, which are determined by the number of pollution particles (0.1, 0.3, 0.5 microns) in a unit of air volume. Solid, aerosol, bacteriological pollution with a size from 0.005 to 100 microns is controlled.

Clean rooms are used in microelectronics, instrumentation, medicine and medical industry, pharmacology, laboratories, optics production, food industry, biotechnology, aviation and space industry. They can be used both for industrial workshops (Fig. 1) and for small rooms (Fig. 2) (Fedotov, 2003; Hayakawa, 1990; White, 2002; White).

Understanding the need to use clean rooms arose a long time ago. Thus, in the 1860 s, attempts were made to eliminate the threat of bacterial infection in operating rooms by disinfecting rooms, instruments, and air filtration in supply ventilation systems. In the 1940 s, systems of forced ventilation of premises using excess pressure, which prevented the appearance of unwanted pollution, began to be used. At the same time, attempts to use clean rooms in industrial production began in the 1940 s. The Western Electric Company used for the production of aviation horoscopes in 1955 the first room with minimal parameters for dust accumulation thanks to the materials covering the walls, floor, ceiling, and the placement of lighting. At the same time, excess pressure in the room was maintained, filters in supply ventilation retained up to 99.95 % of particles with a size of 0.3 microns.

Fig. 1. Production line in a clean room for the needs of microelectronics

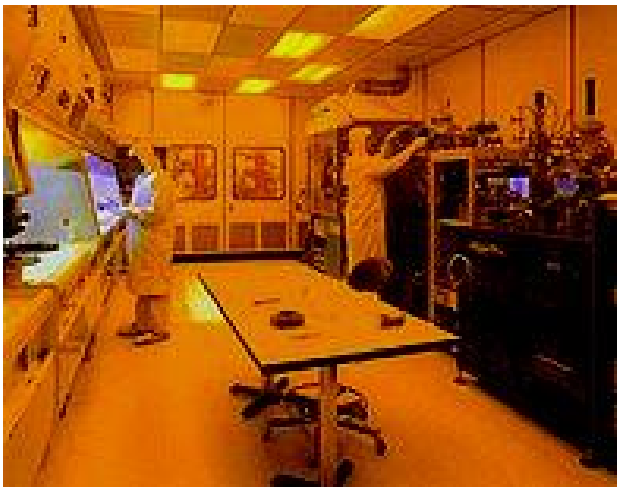

Fig. 2. A small clean room for the production of microelectronics

In 1960, a directed laminar flow of air from the entire plane of the ceiling was tested in England. And Willis Whitfield developed in 1961 the theory of laminar air flows, which were supplied through filters and passed in a directed manner through the room without excessive turbulent eddies and were discharged through a perforated false floor. During this, the air flow removed particles of pollution from the working area of the room) (Hayakawa, 1990; White, 2002; White).

Materials and methods

The clean room should have a simple shape to counteract the accumulation of contamination in the "dead zones" with hermetic wall constructions with an antistatic coating. Most often, air is supplied through filters in the false ceiling and removed through the false floor (Fig. 3). Workers in special clothes enter the premises through special vestibules-gateways. For premises of a lower class of cleanliness, less attention is paid to the parameters of temperature, humidity, lighting, equipment design, and the presence of an entrance vestibule.

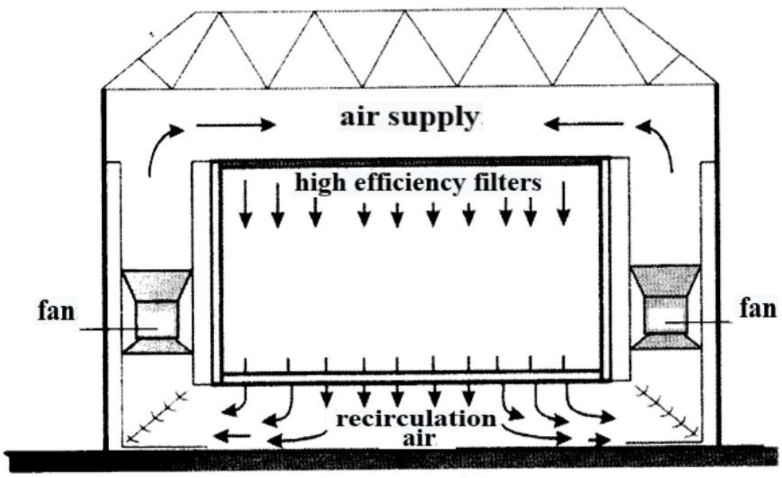

Fig. 3. Scheme of a clean room with a vertical unidirectional laminar flow of incoming air and an extractor in the false floor

Air exchange and excess pressure is provided by an air preparation system, usually air conditioning, consisting of fan systems, that take recirculated air (if possible) from the room and outside

(20–30 %), drive it through the distribution system together with filters before returning it in the room The air flow passes through the entire volume of the room in one vertical direction with a uniform speed, usually equal to 0.3–0.5 m/s (White, 2002). The air exchange and room cleanliness parameters are monitored by the control system. Individual modules with autonomous air purification systems of the highest class can be used inside the premises. The parameters of clean rooms, their construction and operation are determined by the State Standards system.

In cases, where the recirculation of internal air is prohibited due to sanitary and hygienic requirements or when the amount of external air required for a given clean room is approximately equal to the amount of supply air G_{in}, kg/h, calculated based on the hazards identified in the room, a direct-flow air conditioning system (ACS) is used for a clean room. Direct-flow air conditioning is the simplest air conditioning system, when 100 % of the outside air is supplied to the room. This system is uneconomical, since all the air G_{out}, kg/h, which enters the room, goes through a full cycle of preparation – from the parameters of the outside air to the required parameters of the air of the clean room. This system is characterized by high energy consumption and a reduced service life of filters.

The performance of this system can be improved by heat utilization with a recuperative heat exchanger. Thanks to heat utilization, energy savings for air heating up to 60 % are achieved.

Direct-flow systems, due to their uneconomical nature, are used only where they are necessary and where air recirculation is unacceptable (work with harmful substances, dangerous pathogenic microorganisms, etc.).

At the same time, in order to increase the energy efficiency of the air conditioning systems of clean rooms, we have chosen the direct flow air conditioning system, which needs it the most.

Results and discussion

When using central air conditioning, an important question is: how effective will the selected air conditioning system work under these conditions? After all, the correct choice of operation of the ACS is not only the best provision of the microclimate and air cleanliness in the premises, but also saving energy and money.

Different central air conditioning systems for the same outdoor air parameters will have different operating efficiency for different operating parameters and serving the same room.

The purpose of this research work is to evaluate the efficiency of the direct flow central air conditioning system for clean rooms by the method of exergy analysis (Cokolov, 1981; Shargut, 1968; Brodyansky, 1991; Silvio, 2013; Bejan, 1988; Morozyuk, 2006; Tsatsaronis, 2002; Labay, 2020; Labay, 2021; Labay, 2021; Labay, 2021; Labay, 2023).

Therefore, the authors developed an exergetic method of analyzing the operation of the direct-flow central air conditioning system of clean rooms. This method is designed to determine and compare the efficiency of a direct-flow central air conditioning unit that serves a clean room in the warm period of the year (WPY) under different modes of its operation. Such a method of thermodynamic study of a direct-flow ACS of clean rooms makes it possible to study it both in general and its individual parts in order to obtain complete information about the energy conversion processes that take place in this ACS. The result of the analysis is the finding of exergy losses in individual elements of the SCP and the exergy efficiency of the process in general. The developed method makes it possible, for example, to determine the exergetic efficiency of direct-flow central heating systems depending on various parameters of the outside air.

For research, we adopted a central air conditioner of the CACT2 type. The facility served by this air conditioner is a clean room.

Losses to the environment are not taken into account in the calculations; it is assumed that the polytropic process of cooling and drying the air in the WPY takes place in the irrigation chamber.

Exergetic efficiency (output-input ratio (OIR)), which characterizes the efficiency of the direct-flow air conditioning system in WPY, was determined by the formula:

$$\eta_e = \frac{E_{out}}{E_{in}} = \frac{\Delta E_{II}}{\Delta E_{i.c} + \Delta E_{heat} + N_{use}^{c.w} + N_{use}^{h.w} + N_{use}^{fan} + N_{use}^{RM}}, \quad (1)$$

where $\Delta E_{II} = E_{inc} - E_{int}$ is the decrease in exergy of conditioned air in a clean room, W; E_{inc} and E_{int} is respectively, exergy of incoming and internal air in a clean room, W; $\Delta E_{i.c} = E_{w_f} - E_{w_i}$ is change in exergy of water in the irrigation chamber (respectively, increase in exergy of air in the irrigation chamber), W; E_{w_i} and E_{w_f} is accordingly, the exergy of water in the irrigation chamber at its initial and final temperature, W; $\Delta E_{heat} = E_{heat} - E_{rev}$ is change in the exergy of the heat carrier (hot water) in the air heater second heating (respectively, a decrease in the exergy of the air in the air heater second heating), W; E_{heat} and E_{rev} is accordingly, the exergy of the heat carrier in the supply and return pipes of the air heater second heating, W; $N_{use}^{c.w}$ is power consumption of the cold water pump for the irrigation chamber, W; $N_{use}^{h.w}$ is power consumed by the hot water pump for the air heater second heating, W; N_{use}^{fan} is power consumption of the fan motor of the adopted central air conditioner, W; N_{use}^{RM} is power consumption by the refrigerating machine for the central air conditioner, W.

We determined the exergetic efficiency (OIR) for the selected direct-flow central ACS with a capacity of 10,000 m^3/h, which served a clean room in the city of Dnipropetrovs'k, which was η_e = =1.47 % (η_e = 0.0147), which is quite insignificant. Hence, the conclusion that it is necessary to look for ways to increase it.

Conclusions

The method of exergy analysis of central heating systems was created and will be tested at «Polikor» LLC (Lviv) to determine and compare the energy efficiency of a direct-flow central air conditioning unit that serves a clean room in the warm period of the year under different operating modes. The exergy analysis will allow to establish the maximum thermodynamic capabilities of the central direct-flow ACS, to determine exergy losses in it, and to justify recommendations for the improvement of its individual elements. And for this, it is necessary to thoroughly study all aspects of the operation of the central direct-current ACS. Using the results obtained in the research work will not only provide an opportunity to significantly improve the energy efficiency of clean rooms, but also increase the profitability and competitiveness of these rooms for high-tech, medical and other processes.

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СТАН І ПЕРСПЕКТИВИ ПІДВИЩЕННЯ ЕНЕРГОЕФЕКТИВНОСТІ СИСТЕМ КОНДИЦІЮВАННЯ ПОВІТРЯ ЧИСТИХ ПРИМІЩЕНЬ

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Стаття присвячена підвищенню ефективності роботи систем кондиціонування повітря чистих приміщень, що підтримують у заданому діапазоні параметри мікроклімату за декількома показниками – кількості та розміру на 1 м^3 частинок пороху, аерозолів, мікроорганізмів та тиску, вологості, температури.

Чисті приміщення використовують у мікроелектроніці, приладобудуванні, медицині і медичній промисловості, фармакології, лабораторіях, виробленні оптики, харчовій промисловості, біотехнологіях, авіаційній та космічній промисловості.

Останнім часом за кордоном та в Україні з метою заощадження енергетичних ресурсів ведуться фундаментальні дослідження у ряді технологій із позицій ексергетичної методології. Це сприяє об'єктивній оцінці ступеня енергетичної досконалості апаратів та процесів, пов'язаних з перетворенням енергії у сучасних технологіях.

Наведена історія виникнення та застосування чистих приміщень та систем кондиціонування повітря, що ними обслуговуються.

Вказано про розподілення чистих приміщень за класами чистоти. Залежно від забруднення на 1 м^3 об'єму, чисті приміщення поділяють на класи чистоти, які визначаються за кількістю частинок забруднення (0,1; 0,3; 0,5 мкм) в одиниці об'єму повітря. Наведені приклади застосування чистих приміщень у мікроелектроніці. Подано схему повітрообміну під час кондиціонування повітря у чистому приміщенні, коли рециркуляція внутрішнього повітря приміщення заборонена. Найчастіше повітря подається через фільтри у фальшстелі і виводиться через фальшпідлогу Робітники у спеціальному одязі потрапляють у приміщення через спеціальні тамбури-шлюзи.

Для цього авторами розроблено ексергетичний метод аналізу роботи прямотечійної центральної системи кондиціювання повітря чистих приміщень. Наведено визначення всіх складових, які потрібні для розрахунку ексергетичного ККД системи кондиціювання повітря чистого приміщення.

Ключові слова: чисті приміщення, кондиціонування повітря, мікроклімат, ексергетичний баланс, ексергетичний ККД, енергоефективність.