COMPUTER-AIDED DESIGN SYSTEMS

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COMPUTER-AIDED DESIGN OF CLEANROOM VENTILATION AND AIR CONDITIONING SYSTEM

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Abstract. *The structure of computer-aided design of cleanroom ventilation and air conditioning system is proposed. The algorithms of air ducts design and optimal selection of ventilation equipment is developed.*

Keywords: clean rooms, computer-aided design, ventilation and air conditioning, ducts, fan, filter, air exit grilles.

I. INTRODUCTION

Space requirements, in which it must be ensured conditions that it is necessary for technological processes of microelectronics were and are very tough. Top quality products, constant struggle to raise the productivity requires the precise control and coordination between the technological equipment, engineering and work organization, and all this is based on the strict observance of the surrounding space parameters, in turn, is based on cleanroom modern technologies.

Microelectronic devices manufacturers are widely used cleanrooms, where in the air it is supported size and number per cubic meter of particles such as dust, microbes, aerosol particles and chemical vapors in a certain predetermined range. In such premises it is necessary to minimize the entering, generation and storage of such particles indoors. The system of structural elements, pollution control system, Ventilation and Air Conditioning System (VACS) are responsible for it. The ventilation process includes the solution of following tasks: removing the exhaust air from the room and replacing it with the outer, air conditioning, filtering, heating or cooling, humidification or dehumidification, ionization. Ventilation type is selected based cleanliness class of room [1], which is determined by the type of technological process (Table 1). The main functions of ventilation and air conditioning consist in the achievement and maintenance such parameters of cleanrooms as:

– specified cleanliness class (counting particle concentration);

– differential pressure between the clean rooms and ancillary zones;

– the required air flow rate in zones with a unidirectional flow of air (in case it is achieved by the ventilation system, instead of using the autonomous process unit);

– restoration time after making the cleanliness class of contaminants in clean room;

– microclimate parameters (temperature, relative humidity, air velocity), the required volume of outdoor air by sanitary-hygiene standards, removing harmful substances formed during the technological process, and, where appropriate, ensuring of smoke extraction during the fire.

These parameters must be performed for each cleanroom by providing the necessary air changes per hour, air flow rate, etc.

TABLE 1

Dependence of the type of production and purity class

ISO	FS 209D	GMP	Manufacture
ISO 1	–	–	Nanotechnology
ISO 2	–	–	Special equipment
ISO 3	1	–	Only the manufacture of integrated circuits with submicron geometry
ISO 4	10	–	Manufacture of integrated circuits with spacing between the conductors less than 2 microns

ENDING OF THE TABLE 1

ISO	FS 209D	GMP	Manufacture
ISO 5	100	A, B	Aseptic manufacturing of injectable preparations, requiring the absence of microorganisms and particles. Surgical procedures for implantation or transplantation of organs. Isolation of patients with immune deficiency, including after bone marrow transplantation
ISO 6	1000	–	Manufacture of optical elements of high accuracy class. Assembly and testing of precision gyroscopes. Assembly of miniature bearings
ISO 7	10000	C	Precision machinery, hydraulics and pneumatics, assembly of precision hydraulic and pneumatic equipment, valves with servomotors, precision watch mechanisms, transmissions of high quality
ISO 8	100000	D	Optical manufacture, assembly of electronic components, assembly of hydraulic and pneumatic devices
ISO 9	–	–	Auxiliary premises, stocks of precision equipment, changing rooms

II. BLOCK DIAGRAM OF THE VACS SYSTEM

Block diagram of the ventilation system is shown in Fig. 1, and includes the following constituent elements: the air exit grilles, air valve, air ducts, filters, fans, silencers, central conditioning and air distributor.

Below it is a list of the main components that consist of the ventilation system and a brief description of each item:

Air exit Grille: through the air exit grille (outer) grid fresh air enters the plenum ventilation system. Outer grill performs not only decorative, but also protects the ventilation system inside from falling outsider objects, drops of rain and snow.

Ducts: ducts connect all components of the ventilation system and, together with molded products, grilles, valves and other elements form the air distribution network. The main characteristics of ducts are cross-sectional area, shape and stiffness.

Air valve: after external grille installed air valve, which must be securely block the ventilation channel at shutdown of ventilation. If this is not done, in the winter due to the difference of pressure, even when the fan off, the outside air will penetrate in space. This glacial airflow will cause the condensation of water droplets on cooled ducts, adapters and grilles these drops will flow downward, forming puddles on the floor.

Filter: The air filter is installed in all ventilation systems and to protect against dust, lint and insects not only serviced office space, but also the components of the ventilation system. It is used the filters of gross, subtle, especially fine cleaning.

Fan: The fan is a base of any system of ventilation. It is selected on the basis of two main parameters: capacity (quantity of "pump" air), and created pressure for a given capacity.

Noise suppresser: if the noise generated by the fan is required to reduce to an acceptable level, the fan must be installed after the noise suppresser. To reduce this noise-absorbing material is used, with help of which is faced one or more walls of the noise suppresser.

Central air conditioner: air enters the central air conditioner, filtered, humidified and cooled or heated to the design parameters. Then it is supplied to the room by ducts.

Cleaning distributors: air distributor is installed at the outlet of the duct and serves for uniform air distribution over the serviced apartment.

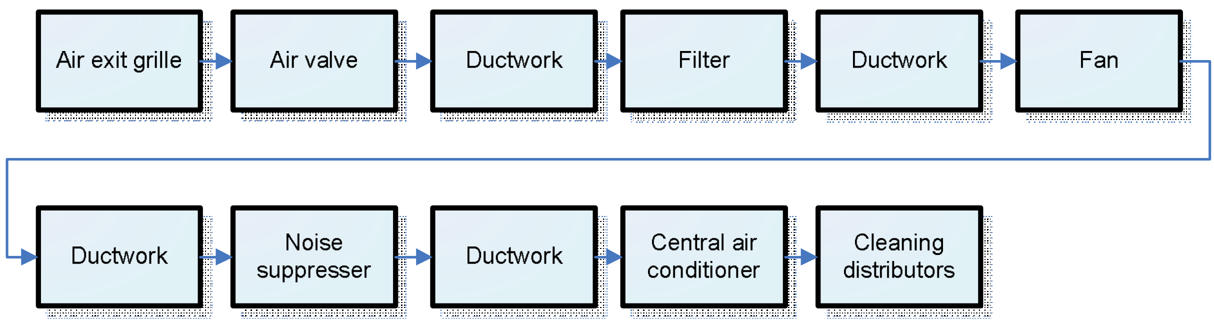


Fig. 1. Block diagram of the VACS system

III. CLASSIFICATION OF VENTILATION TYPES USED IN CLEANROOMS

In cleanrooms it is used plenum-exhaust ventilation system. Depending on the method of plenum-exhaust ventilation system realization cleanrooms are divided into three main types [1].

1. *Turbulently ventilated cleanroom.* They are also called clean premises with non-unidirectional airflow or premises with conventional ventilation. They are characterized by the traditional method of air supply – through air distributor or filters on the ceiling (Fig. 2a).

2. *Cleanroom with unidirectional airflow.* Previously it is used the term "laminar flow". Fig. 2b shows how clean air is supplied to the premise through the high efficiency filters and passes through the space, keeping the direction of motion.

3. *Cleanroom with a mixed stream.* As can be seen from Fig. 2c, this type is a turbulent ventilated cleanroom, but where the product can be exposed by pollution, it is used a laboratory cabinet (box) with unidirectional airflow.

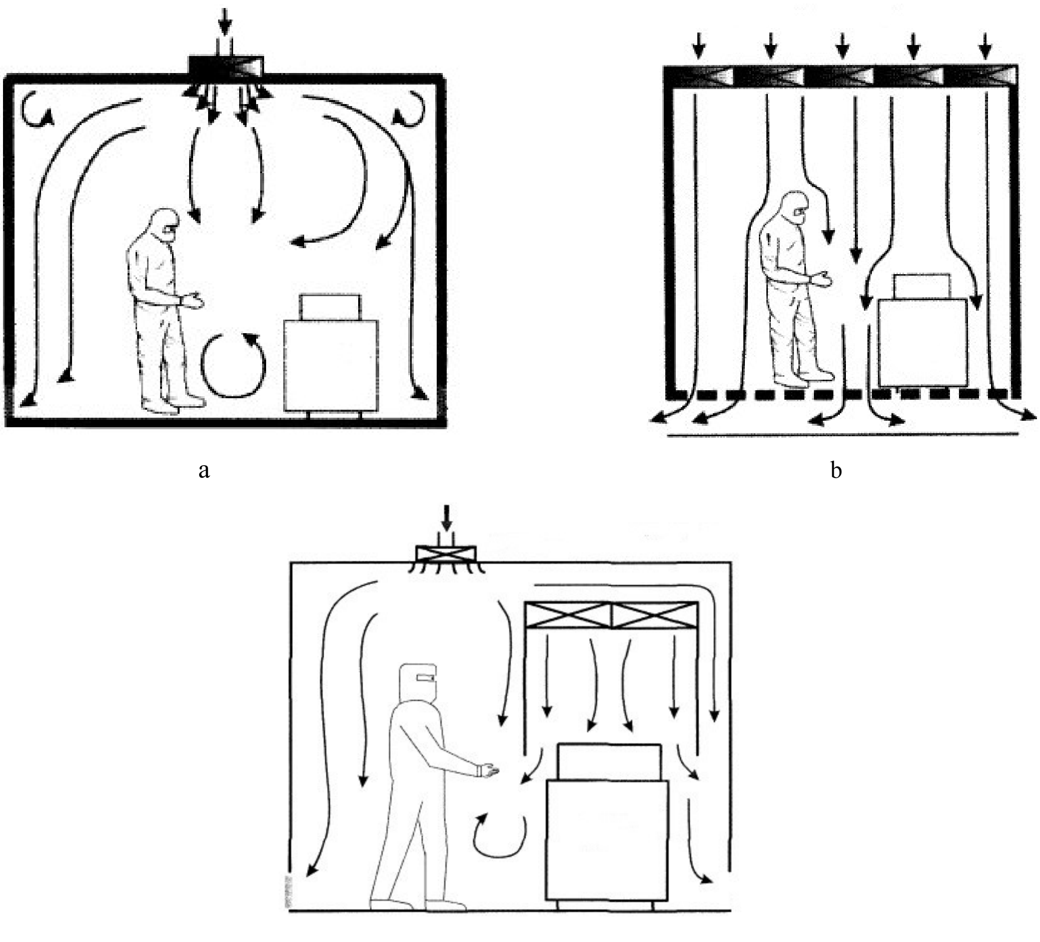


Fig. 2. Turbulently ventilated cleanroom (a); Cleanroom with unidirectional airflow (b); Cleanroom with a mixed flow (c)

In cleanroom ISO class 5 and cleaner it is used a directional air flux. In premises of class 6 ISO 7 and ISO 8 – unidirectional – flux (Table 2).

Problems solved at VACS systems design include:

– calculation of air change;

– aerodynamic calculation of the ducts network;

– calculation of demand parameters of equipment: fan, air distributors;

– the optimal selection of equipment: air grille, air valve, fan, noise suppresser, air ducts, filters, central air conditioning, air distributors.

IV. STATEMENT OF THE PROBLEM

The task of ventilation and air conditioning design is considerably simplified if for its solution it is used computer-aided design. In this paper, the problem of computer-aided design of cleanroom VACS based on: the type of technological process, providing the necessary purity class, specified geometric dimensions of premises. To do this, it's necessary to determine the basic initial data for cleanroom VACS calculation:

– planning decisions with purity and pressure drop indication;

– appointment of cleanroom (clean areas): product and process protection, protection of workers and the environment;

– the release of harmful substances;

– heat and moisture from the equipment;

– numbers of employers;

– construction area climate characteristic.

Using the VACS computer-aided design system provides the reduction of project development time, improving the system quality, execution of greater number of projects per unit time, improving the quality of working documentation and competitiveness of projects. Block diagram of VACS computer-aided design system is presented in Fig. 3.

Consider software for each system presented in Fig. 3.

V. COMPUTER-AIDED DESIGN SUBSYSTEM OF DUCTS NETWORK SOFTWARE

Computer-aided design subsystem of ducts network software includes: calculation of air exchange, ducts aerodynamic calculation. Initial data for type, speed of air flow and air exchange rates determination are taken from Table 2.

TABLE 2

Example indicators of air for microelectronics (GOST R ISO 14644-4)

Class clean room in the operational state	**Type air flow**	**Average air velocity, m / s**	**Air flow rate in m^3 per 1 m^2 of floor space in 1 hour**	**Examples of application**
ISO 2	U	0,3–0,5	Notapplicable	Photolithography and other critical areas
ISO 3	U	0,3–0,5	Same	Working areas
ISO 4	U	0,3–0,5	–	Work areas. Production of masks with several substrates, the production of compact discs, the service areas and the auxiliary areas
ISO 5	U(T, C)	0,2–0,5	Notapplicable	Work areas. Production of masks with several substrates, the production of compact discs, the service areas and the auxiliary areas
ISO 6	T/M	Notapplicable	70–160	Service areas, auxiliary areas
ISO 7	T/M	Same	30–70	Service areas, the auxiliary areas, surface machining
ISO 8	T/M	–	10–20	Service areas, auxiliary areas

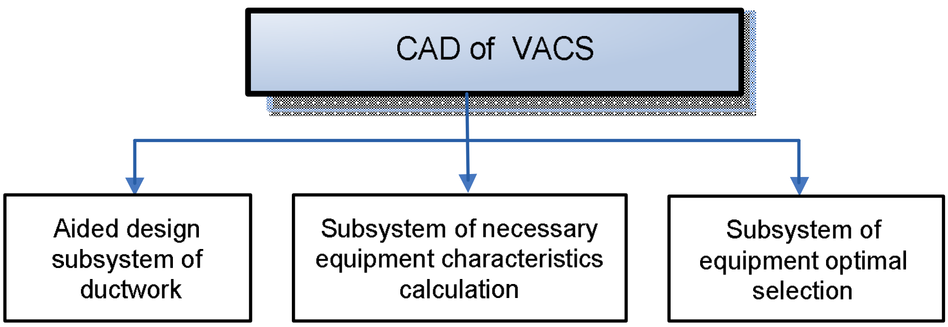


Fig. 3. Block diagram of VACS computer-aided design system

Algorithm for calculating the duct system has the form.

1. Calculation of air exchange in the premise (ventilation capacity) – amount of air (m^3), which comes inside:

– *in a turbulent flow*:

$$L = WV_{room},$$

where L is supplied air volume to the room, m^3/hr; W is multiplicity of air exchange, hr^{-1}; V_{room} is room volume, m^3.

– *at unidirectional flow:*

$$V = V_{air} S \cdot 3600,$$

where S is area of the room, m^2; V_{air} is average air velocity, m/s.

2. Ducts aerodynamic calculation.

Ducts aerodynamic calculation reduces to determining the size of their cross-section, and the pressure loss in separate zones, the overall system.

Total pressure losses, Pa, in ducts network for standard air is determined by the formula:

$$P = (Rl + Z), \quad (1)$$

where R is pressure loss for friction on the calculated network zone, Pa at 1m; l is duct zone length, m; Z is pressure loss due to local resistance on the calculated network zone, Pa.

To determine R it is compiled tables and nomograms for ducts of circular section made of sheet steel with absolute equivalent roughness $k_e = 0.1$ mm. For ducts made of other materials with an absolute roughness $k_e > 0,1$, the value R is excepted with correction coefficient n for pressure loss from friction.

For rectangular ducts for the calculated value of the diameter it is accepted the diameter d_e, at which the pressure loss in the circular duct at the same air velocity is equal to losses in a rectangular duct.

The values of equivalent diameters, m, is determined by:

$$d_e = \frac{2ab}{a+b},$$

where a and b is sides sizes of the rectangular duct, m.

The pressure loss Z, Pa, for local resistances, it is determined by formula:

$$Z = \sum \xi \frac{W^2 P}{2}, \quad (2)$$

where $\sum \xi$ is sum of the coefficients of local resistances; $\frac{W^2 P}{2}$ is velocity (dynamic) pressure, Pa.

The coefficient of local resistances at the border of two zones is necessary to apply to the zone with less air flow.

V. Calculation algorithm

1. Draw an axonometric diagram of the ventilation system.

2. It is selected the design direction in the system. In systems with a mechanical drive it is taken the longest and having the greater load on zones calculated direction.

3. Divide the system into calculated zones, and enumerate them, specify the load. Firstly, it is successively numbered the calculated direction zones, and then all the others.

4. At each zone of the design direction for the required air flow rate and taking into account the allowable velocity according to the tables for the ducts calculation it is necessary to choose the duct diameter and calculate the values R and $\frac{W^2 P}{2}$.

5. Calculate the sum of coefficients of local resistances $\sum \xi$ and by formula (2) find the pressure loss at local resistances.

6. By formula (1) to find the total loss of pressure at all zones of design directions and summing them to find pressure loss in ducts network P_{net}.

7. Similarly, find pressure loss at all zones (branches).

8. Link the pressure loss in branches with design direction. When it is impossible to link the pressure loss by ducts branches within 10 % it is necessary to install the diaphragms primarily on vertical zones.

9. Determine the pressure loss in the ventilation system:

$$P_{syst} = R_{net} + R_{eq}, \quad (4)$$

where $R_{eq.}$ is pressure losses in the equipment available in the system. For example: in the supply air system – it is the equipment of plenum chamber, exhaust – cleaning equipment etc.

VI. The ducts network computer-aided design subsystem software

The ducts network computer-aided design subsystem software includes: fan design, cleaning distributors design, selection of other elements.

The algorithm for calculating the characteristics of the necessary equipment is of the form:

1. Fan design includes the determining:

– fan air supply:

$$L_{fan} = 1,1\, L_{sys},$$

where L_{sys} is load system m^3/hour;

– fan design pressure:

$$\Delta p_{fan} = 1,1(\Delta p_{aer} + \Delta p_{val} + \Delta p_{fil} + \Delta p_{c.a.c.} + \Delta p_{lat} + \Delta p_{att}),$$

where Δp_{aer} is pressure loss in the ducts network; Δp_{val} is pressure loss of air valve; Δp_{fil} is pressure loss of filters; $\Delta p_{c.a.c}$ is pressure loss of central air conditioner; Δp_{lat} is pressure loss of noise suppresser; Δp_{att} is pressure loss attenuator;

– motor power by formula

$$N = \frac{L_{fan} \Delta p_{fan}}{3600 \cdot 1000 \cdot \eta_{fan}},$$

where L_{fan} is supply fan; Δp_{fan} is the design pressure of the fan; η_{fan} is overall efficiency of aerodynamic characteristics fan.

2. Design of distributors:

– select the scheme of product supply air from distributors (Fig. 4):

• at the distribution of fan-jets:

$$\sqrt{F_{rz}} = (1.23 \ldots 3.3)(h - h_{rz}),$$

where F_{rz} is working zone square per one air distributor; h is installation height of air distributor; h_{rz} is working height;

• in the distribution of compact axisymmetric jets:

$$\sqrt{F_{rz}} = (1.23 \ldots 2)(h - h_{rz});$$

– according to the selected value of F_{rz} it is determined the smallest number of air distributors

$$N = \frac{F_{\text{room}}}{F_{rz}},$$

where F_{room} is horse premises;

– determine the air supply for one air distributor

$$L_0 = \frac{L_{syst}}{N},$$

where L_{syst} is intake air supplied to the space.

3. Other elements selection:

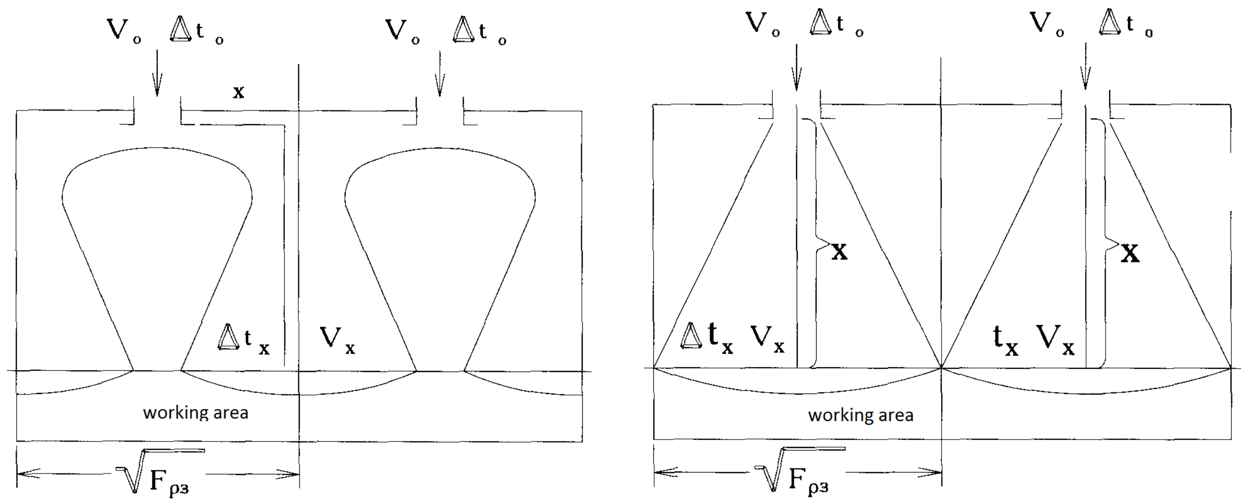
– intake grille is chosen depending on the ducts network;

– filter and noise suppresser are chosen by catalog, where, besides the overall dimensions and the nominal flow, it is given their aerodynamic resistance ΔpH;

– blocks of the heat exchange and mass exchange at now are chosen by the methodic developed by the companies manufactures and the pressure loss in them are given just below the stated supply.

VII. Subsystem of Equipment Optimal Selection

Subsystem of equipment optimal selection permits the necessary equipment from database according to the Table 3.



a b

Fig. 4. Lay fan jet (premises for 2.5–6 m height) (a); compact axisymmetric jet (premises for 4–12 m height) (b)

Table 3

The list of equipment VACS

No	Equipment Type	Key Features	Manufacturer
1	Air exit grille	- the performance of air - material - dimensions - pressure loss	- LLC «Alvent» (Russia) - LLC «SPS» (Russia) - «Liag Technic Service Ukraine» (Ukraine) - «MAICO ventilatoren» (Germany)
2	Ductwork	- material - pressure loss - resistance - dimensions - air flow rate	- VTS Clima (Poland) - «Systemair» (Sweden) - «Ostberg» (Sweden) - «Remak» (Czech Republic)
3	Air valve	- working pressure (network) - class level of leakage	- «VENTSIS» (Ukraine) - «SIGMA» (Ukraine) - «Progress» (Russia) - «ScanAir BV» (Netherlands)

ENDING OF THE TABLE 3

No	Equipment Type	Key Features	Manufacturer
4	Filter	- air capacity - pressure loss - the degree of purification - the degree of dust collection $\eta = (G2 - G1) / G1 \times 100$ - aerodynamic drag - regenerability	- JSC «Multifilter» (Russia) - NPP «Folter» (Russia) - GK «Air filters» (Russia) - «EGIDA^{TM}» (Ukraine)
5	Central air conditioner	- air capacity - performance at cold and heat - external static pressure is developed by the fan	- LLC «VKTehnologiya» (Russia) - LLC «industrial air conditioning plan» (Russia)
6	Fan	- productivity (air flow) - maximum static pressure - supply voltage - maximum current - maximum electric power - speed for maximum efficiency - dimensions - sound pressure level	- «Ostberg» (Sweden) - PJSC «Ventilation systems» (Ukraine) - «AERMEC» (Russia)
7	Noise suppresser	- a specific range of sound insulation - material - dimensions	- PJSC «Interconditioner» (Ukraine) - «VentKlimatStroy» (Ukraine) - «Systemair» (Kanalflakt) - «WOLF» (Germany)
8	Cleaning distributors	- air flow rate - dimensions, cross-sectional area - weight - aerodynamic drag - material - jet ejection angle to the horizon	- «DOSPEL» (Moldova) - «Ventindustriya» (Russia) - «Hidria» (Slovenia)
4	Filter	- air capacity - pressure loss - the degree of purification - the degree of dust collection $\eta = (G2 - G1) / G1 \times 100$ - aerodynamic drag - regenerability	- JSC «Multifilter» (Russia) - NPP «Folter» (Russia) - GK «Air filters» (Russia) - «EGIDATM» (Ukraine)

VIII. CONCLUSIONS

The necessities of use computer-aided design system of clean rooms VACS. It is shown that the fundamental sources of data are: the type of technological process, cleanliness class and geometrical sizes of premises.

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В. М. Синєглазов, В. Н. Федосенко, Є. І. Андрієнко. Автоматизоване проектування системи вентиляції та кондиціонування чистих приміщень

Запропоновано структуру системи автоматизованого проектування вентиляції та кондиціонування чистих приміщень. Розроблено алгоритми проектування повітроводів і оптимального вибору вентиляційного обладнання.

Ключові слова: чисті приміщення; система автоматизованого проектування; система вентиляції та кондиціонування; повітроводи; вентилятор; фільтр; повітророзподільні решітки.

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В. М. Синеглазов, В. Н. Федосенко, Е. И. Андриенко. Автоматизированное проектирование системы вентиляции и кондиционирования чистых помещений

Предложена структура системы автоматизированного проектирования вентиляции и кондиционирования чистых помещений. Разработаны алгоритмы проектирования воздуховодов и оптимального выбора вентиляционного оборудования.

Ключевые слова: чистые помещения; система автоматизированного проектирования; система вентиляции и кондиционирования; воздуховоды; вентилятор; фильтр; воздухораспределительные решетки.

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