Reduction of temperature influence in temperature-controlled rooms in the engineering industries

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Abstract. Typical air conditioning and ventilation systems are used to create and maintain microclimate parameters. Analytical studies have shown that the existing ventilation systems do not provide proper maintenance of the required parameters of the environment, since the influence of the temperature of the enclosing structures is not taken into account. Thus, the paper proposes the structure of the air conditioning System (ventilation), which provides a sufficiently high degree of air purity and excludes temperature increase on the enclosing structures of the thermoconstant room. The technical result is achieved due to the fact that the air conditioning system additionally contains air distributors for supplying air that adheres to the enclosing structures along the perimeter of the clean zone, and devices for removing this air, connected to exhaust air ducts located along the perimeter of the zone at certain intervals. The application of numerical simulation of air parameters in a thermoconstant room was also analyzed using cleanroom software that allows evaluating the degree of temperature impact from enclosing structures.

1. Introduction

New types of high precision processing machines have been created and tighter requirements for the conditions of their operation, as a result, have been formed due to the development of the equipment and technologies, and newly appeared materials, including nanomaterials.

Stricter requirements for stability of temperature, humidity, and cleanliness of air shall be met for the rooms, where the equipment is fabricated and operated [1]. Hence, it is recommended to maintain the following parameters of medium in the facility for assembling: dimensions of dust particles - 2.0 μm; air temperature - 17-19°C (20-22°C) with not more than 5% deviation; air humidity - 40-60%; air velocity – 0.2 m/sec.

In the central regions of Russia, when facilities are operated on a year-round basis, the parameters of external air, which may change from -30°C during cold season to +30°C in the warm period, affect microclimate parameters. The humidity rate and relative humidity of air also greatly vary [2].

The systems of air ventilation and conditioning, which ensure microclimate and cleanliness in the thermoconstant rooms, are crucial in maintaining normal conditions [3-7].

Generally, to carry out maintenance of thermoconstant rooms, typical schemes of air conditioning systems are utilized, namely, through-flow air conditioning system[8] with low costs in terms of capital expenditures and simplicity as an advantage, and lack of economy as a shortcoming; and a system with primary recirculation [9] advantages – power saving, disadvantage – greater dimensions of installation.
However, it is impossible to assess the efficiency of choosing the equipment with no analysing the distribution of air flows and the content of particles therein. The support systems are required that facilitate viewing the system operation visually [10, 11].

Method of supplying and removing air substantially influences distribution of air across the room and air parameters, creation and distribution of temperature fields, relative humidities, velocities and concentrations.

The following schemes of supplying air are usually utilized in the thermoconstant rooms: with air diffusers [14], static pressure chambers [13], with filter-ventilator [16] and ventilator [15] units. Exhaust grilles and perforated flooring panels are used for removal of air. However, it doesn’t allow to identify the entire package of measures to ensure necessary characteristics of a room.

Thus, for instance, in flexible systems of Deutsche Babcock AG, similar problems to solve have substantial shortcomings. Ceiling chamber is under negative-pressure, and infiltration of foreign microflora, low-degree cleanout of filter-ventilator units from microorganisms and solid particles, ingress of heat inside the clean area from actuators of ventilation systems, and so on shall occur through the enclosing structures.

Technical solutions for the systems in question have to a greater or lesser extent both advantages, and disadvantages, and the degree of their impact may play a significant role in decreasing the stability of the parameters of a clean room, and this is unacceptable. The enclosing surfaces often stay beyond vision when designing ventilation systems.

In this regard, it is necessary to create such systems of air ventilation and conditioning, which will solve an additional problem, alongside the basic one, of regulating heat transfer from enclosing structures.

2. A method of reducing the temperature

The resultant temperature of air in the thermoconstant room is under the significant influence of the temperature of internal surfaces of walls, partitions, and flooring.

The authors have analysed the existing plans of air distribution and removal [16, 17], and a plan is suggested [18], which, at the expense of changing air temperature in the supply adhering jet of air, will allow to control the temperature in the internal enclosing structures and hence, affect the resultant temperature of air in the room.

Figure 1 presents a suggested ventilation plan of isolated clean thermoconstant room. The system of ventilation includes enclosing structures 1, plenum 2 and exhaust ventilation system 3 with fine filters 4. In grey (service) area 5 raised perforated flooring 6 and enclosing demountable structures 7 are mounted. Transition portal 8 with thickened doors 9 is utilized to isolate interconnected rooms.

Clean area 10 has perforated ceiling 11 with ceiling chamber 12, shutoff and control air diffuser 13 and overflow channel 14 with fine mesh filter 15. Air diffusers 16 create adhering jet to the enclosing structures of isolated clean room. Tapered (funnel) shaped appliance 17 is used to remove air, adhering to enclosing structures.

Exhaust ventilation 3 creates underpressure in grey area 5 around clean area 10, simultaneously removing air from the clean area through perforated flooring 6, and clean air, adhering to the enclosing structures of the room is removed through appliances 17. Sterile air is supplied to clean area through perforated ceiling 11 from ceiling chamber 12. Due to the fact that perforated ceiling 11 and perforated flooring 6 have a rated value of air flow resistance, during the operation of the systems of plenum 2 and exhaust 3 ventilation that service this room, an excess pressure is maintained in ceiling chamber 12, which is sufficient for forming laminar flow in clean area 10 and which blocks an ingress of uncleaned ambient air inside chamber 12. In addition, the specified resistance to air flow of the raised floor allows to maintain in clean area 10 an excess pressure with respect to grey area 5: underpressure, maintained in grey area 5 by the system of exhaust ventilation 3, does not enable the process air, removable from the clean area, to flow beyond the boundaries of the enclosing structures 1. Shutoff and control air diffuser 13 functions as: air diffuser, uniformly distributing air throughout the entire volume of ceiling chamber 12, stabilizer of pressure in ceiling chamber 12; back pressure valve
in emergency conditions in the systems of plenum 2 and exhaust ventilation 3. To create an air barrier, which prevents process air from leaving clean area 10, transition to portal 8 through looseness of door 9, overflow channel 14 is provided for with filter 15 that connects a hollow space of transition.

Figure 1. Ventilation plan of clean room:
1 – enclosing structures of the existing room; 2 – plenum system; 3 – exhaust ventilation system; 4 – fine filters; 5 – grey (service) area; 6 – raised perforated flooring; 7 – enclosing demountable structures; 8 – transition portal; 9 – thickened doors; 10 – clean area; 11 – perforated ceiling; 12 – ceiling chamber; 13 – shutoff and control air diffuser; 14 – overflow channel; 15 – fine mesh filter; 16 – air diffuser; 17 – tapered (funnel) shaped appliances portal 8 with plenum air duct 2.

Figure 2. Scenario of using CAD components.
1) Designer develops 3D model of the production room with the equipment placed therein.
2) Designer creates a model of boundary conditions.
3) Designer initiates development of the models of hydrodynamics and heat exchange.
4) Designer introduces changes into 3D-model.
5) Designer import sit into the documentation preparation system.
6) If the cost of creating a clean room is out of compliance with the requirements, a designer performs a trial design, starting from item 1 of this scenario.

Here, a rather high degree of cleanliness of air mixture is provided due to removing dust from enclosing structures and since there is no rise in temperature over the internal surfaces in the clean isolated room, through supplying adhering jet of air to the enclosing structures and removing this air through the funnel-shaped appliances, connected with the exhaust system and located at the specified interval along the perimeter of the clean area.

3. Simulation of a clean room
Mathematical simulation as a tool for forecasting and describing physical processes is used for analysing air distribution in a thermoconstant room. Numerical simulation of air parameters in the thermoconstant room shall be considered using Clearoom® software.

Cleanroom software system is intended for modelling aerodynamic, thermal, and the process of transporting dust in a clean room in order to choose a climate control system that ensures a specified cleanliness class of the room.

The software automatizes the process of calculating the cleanliness class of a room, drawing the field of air temperature and vector field of the air flow velocity, and may be effectively used as a part of the software system that involves the components shown in the figure 2.

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* CAD is designed by Inteco Company with the participation of Vladimir State University.
Clean room simulation. The state of air in the clean room shall be identified by the interaction between air and internal surfaces of the room and exterior surfaces of the components placed (equipment, appliances, etc.). The temperature of surfaces and the flow of air through them specify boundary conditions for the process of changing temperature and velocity of air in the room. Changes in the state of air shall be described using the Navier-Stokes system of differential equations.

Oberbeck - Boussinesq approximation shall be used in the software for the system of equations in question. The software numerically solves the system of differential equations by finite element method. To this effect, the inner space of the room is divided into finite elements in the form of tetrahedrons. As a result of solving, there are obtained values of air velocity vectors and the values of temperature in the vertices of finite elements.

Determining the class of the room cleanliness comes down to determining concentration of particles in the air pursuant to the Gustaffson method for each rating of particles. This concentration depends on the degree of dust emission from the equipment and other surfaces in contact with the room air. It also depends on the concentration of particles in the plenum air and velocity of withdrawing air from the room. These indicators shall be specified by the software user.

Absolute system of coordinates is tied to the room, for which simulation is performed. The origin of coordinates is located in the lower-left far corner of the room when looking through its front plan view (front view, figure 3a).

Each element of placement shall be tied to the relative system of coordinates, the origin of which is located in the lower-left far corner of the placement element, when looking through its front plan view (figure 3a).

Each panel shall be tied to the relative system of coordinates. The origin of this system of coordinates is located in the lower-left corner of the panel, when viewing it on the side of the room air medium (figure 3b). Positive direction of the Z axis shall be towards the room air medium.

Figure 2. CAD components
Figure 3. System of coordinates for a room and relative coordinate system for a panel: (A) – panel on the room surface; (B) – panel on the surface of the element for placement.

Physical parameters for surface planes and panels shall be specified similarly. It enables a user to obtain all six views (front, top, left-side, back, bottom, right-side) of the room and their respective sections.

To display physical fields in the simulated processes, a plan for laying out the elements in the room is also utilised. Here, the section of the room shall be superimposed with the section of the physical field. Scalar field of temperature and concentration is displayed with the lines of equal values on the cutting plane. Vector field is displayed as a graphic image of vectors, the length of which is defined by the projection of the vector of velocity on the cutting plane.

When choosing a display mode of temperature, temperature isolines are displayed on the forms of sections (figure 4). It provides a designer with ample opportunities for identifying visually temperature characteristics of the thermoconstant room. A certain colour corresponds to each level of isoline. Here, a minimum and a maximum value of temperature in a room are displayed.

When choosing a display mode of air velocity, the direction of air movement in the room is displayed on the forms of sections (Figure 4). The vectors shown have equal length and indicate the direction of movement in the section plane. The colour of vector corresponds to the value of air velocity.

Visual displaying of finite elements allows to assess a detail degree of partitioning air space of the room into elements and select a proper ratio between the accuracy of solution and the time for solving. Here, the number of finite elements and the total number of vertices of finite elements are displayed. The sections of finite elements are shown in the room sections.

Of special note is the potential simultaneous displaying the temperature, velocity of air and finite elements. Such form of indicating data makes the software very effective as a tool for designing, since it enables to visually assess propagation of heat and air flows in the room and its specific parts. If needed, free combinations of temperature, velocity of air and finite elements may be chosen (Figure 5).
Figure 4. Displaying temperature field

Figure 5. Simultaneous displaying temperature, velocity of air and finite elements
4. Conclusion
A new solution has been obtained, calculations and local tests have been carried out, which have shown that the above solution provides the supply of adhering air jets to the enclosing structures, which allows maintaining a constant temperature of the enclosing structures. Thus, the expected decrease in the temperature of enclosing structures will amount to about 3-5%. Such a structural concept also makes it possible to remove dust from enclosures with no special equipment required.

Mathematical simulation of physical processes in the analysed design concept using Cleanroom software principally confirmed the results of the computations and allowed to choose ventilation equipment, which maintains the specified class of the room cleanliness.

The paper materials are of practical value for the purposes of designing ventilation and air conditioning systems for thermoconstant rooms. Further research is aimed at analytical description of the process and conducting research in real production conditions.

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