International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Review Article

Air Conditioning for Cleanroom Applications-A Review

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Accepted 12 March 2017, Available online 16 March 2017, **Special Issue-7 (March 2017)**

Abstract

Cleanroom air conditioning plays a significant role in applications starting from food and beverages, health care, pharmaceutical, optics, bio safety, semiconductor and electronics applications. It also plays a key role in special applications for sector like defense, research and space technology. The present paper discusses the important aspects to be taken into considerations during air conditioning for cleanrooms. In addition to control of temperature and humidity, cleanroom air conditioning also involves control of air borne particles, air flow pattern, room pressurization, etc. The paper also addresses important issues such as energy conservation and cleanroom performance testing. The present study gives an insight towards efficient designing of cleanroom air conditioning.

Keywords: *Cleanroom, air conditioning, air borne particles, energy conservation*

1. Introduction

Design of clean spaces or cleanrooms covers much more than traditional temperature and humidity control. Other factors may include control of particle, microbial, electrostatic discharge molecular, and gaseous contamination; airflow pattern control; pressurization; sound and vibration control; industrial engineering aspects; and manufacturing equipment layout. The objective of good cleanroom design is to control these variables while maintaining reasonable installation and operating costs(ASHRAE Clean spaces, 2007). Cleanroom is a room in which the concentration of airborne particles is controlled, and which is constructed and used in a manner to minimize the introduction, generation and retention of particles inside the room, and in which other relevant parameters, e.g. temperature, humidity and pressure, are controlled as necessary (ISO 14644 – 3, 2005). The information on the historical developments in air cleaning and cleanrooms has been compiled by Bhattacharjee (B. Bhattacharjee, 2003). Building a cleanroom is a complex exercise carried out in order to assure the product quality, within the overall guidelines of good manufacturing practices in the pharmaceutical industry(Pradeep Shankar, 2001). The trend in cleanroom guidelines is to cast the designer inthe role of expert "generalist" able to fulfill the wishes of the client, once those wishes are known. The guidelines typically use words such as "subject to agreement between buyer and seller" to draw the client into the decision-making processsince there are as many variations on cleanroom design asthere are designers that create them(Raymond Schneider, 2001).D. Nirmal Ram (2007) investigated the HVAC systems for R&D laboratories. The personal training and discipline are the key factors in the sustenance of cleanroom conditions (Rashmi Nagabhushan, 2001). The key metrics and benchmarks that facility managers can use to assess, track, and manage their cleanroom energy efficiency or to set energy-efficiency targets for new construction was investigated by Mathew et al. (2010).The critical elements of cleanroom design that would significantly impact the costs of itsconstruction were studied by Yang and Gan (2007). The authors developed a cost model that can be applied to small cleanrooms,which has an increasing demand from entrepreneurs and small and medium enterprises. Such small, standard and modular cleanroomsare suitable for individual inventors, small high-tech manufacturers and school laboratories.

The present paper discusses the important aspects to be taken into considerations during air conditioning for cleanrooms.

2. Cleanroom air conditioning

Table 1 defines the various classes of cleanrooms as per ISO 14644(ASHRAE Clean spaces, 2007).

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Table 1 Comparison of Airborne Particle Concentration Limits from ISO14644-1(ASHRAE Clean spaces, 2007)

ISO 14644 Class	0.1 µm	0.2 µm	0.3 µm	0.5 µm	1.0 µm	5.0 µm
	ISO 14644					
	Particles per m^3					
1	10	2				
2	100	24	10	4		
3	1000	237	102	35	8	
4	10000	2370	1020	352	83	
5	100000	23700	10000	3520	832	29
6	1000000	237000	102000	35200	8320	293
7				352000	83 200	2930
8				3 520000	832000	29300
9				35200000	8320000	293000

Note: Values shown are the concentration limits for particles equal to and larger than the sizes shown.
$C_n = 10^N(0.1/D)^{2.08}$ where C_n = concentration limits in particles/m^3, N = ISO class, and D = particle diameter in µm

3. Cleanroom applications

Use of clean space environments in manufacturing, packaging,and research continues to grow as technology advances and the need for cleaner work environments increases. The following major industries use clean spaces for their products:

*3.1Pharmaceuticals/Biotechnology:*Preparation of pharmaceutical, biological, and medical products requires clean spaces to control viable (living) particles that would produce undesirable bacterial growth and other contaminants.

*3.2 Microelectronics/Semiconductor:*Advances in semiconductor microelectronics drive cleanroom design. Semiconductor facilities are a significant percentage of all cleanrooms in operation in the United States, with most newer semiconductor cleanrooms being ISO 14644-1 Class 5 or cleaner.

*3.3 Aerospace:*Cleanrooms were first developed for aerospace applications to manufacture and assemble satellites, missiles, and aerospace electronics. Most applications involve large-volume spaces with cleanliness levels of ISO 14644-1 Class 8 or cleaner.

3.4 Miscellaneous Applications: Cleanrooms are also used in aseptic food processing and packaging; manufacture of artificial limbs and joints; automotive paint booths; crystal; laser/optic industries; and advanced materials research.

Hospital operating rooms may be classified as cleanrooms, but their primary function is to limit particular types of contamination rather than the quantity of particles present. Cleanrooms are used in patient isolation and surgery where risks of infection exist.

4. Important Consideration in Clean Room Air Conditioning

4.1 Air changes per hour (ACPH)

Table 2 provides the guidelines for ACPH for different class of cleanrooms. Careful selection of ACPH helps in reducing the energy requirements for cleanroom air conditioning. A study on ACPH for cleanroom air conditioning was conducted by Zhang (2004). The author investigated the parameters affecting ACPH such as room pressurization and recovery time.

Table 2 Air changes per hour versus vertical airflow velocities, room heights and cleanliness classes(ASHRAE Clean spaces, 2007)

ISO Class	Velocity, m/s	Air Changes per Hour for ceiling Height, m							
		2.2	15.2	18.4	24.4	30.5	36.6	42.7	48.8
2	0.43 to 0.50	128 to 150	102 to 120	85 to 100					
3	0.35 to 0.43	105 to 128	84 to 102	70 to 85	52 to 64				
4	0.30 to 0.35	90 to 105	72 to 84	60 to 70	45 to 52	36 to 42			
5	0.23 to 0.28	68 to 83	54 to 66	45 to 55	34 to 41	27 to 33	22 to 27		
6	0.12 to 0.18	38 to 53	30 to 42	25 to 35	19 to 26	15 to 21	12 to 18	10 to 15	
7	0.04 to 0.08	12 to 24	10 to 19	8 to 16	6 to 12	5 to 10	4 to 8	3 to 6	3 to 2
8	0.02 to 0.03	8 to 10	5 to 7	4 to 6	3 to 4	2 to 3	2 to 3	2	2
9	0.01 to 0.015	3 to 5	2 to 3	2 to 3	2	1 to 2	1 to 2	1	1

4.2 Air flow pattern

Airflow direction and its control is a challenging but necessary task to prevent the cross contamination of airborne particles. Numerous air pattern configurations are used, but they fall intotwo general categories: unidirectional airflow and non-unidirectional airflow.

Figure 1 and 2 shows the air flow patterns in a cleanroom. Cleanroom air flow modeling can be done by computer simulation as shown in Fig. 3 and 4.
Efficient, optimally sized airflow systems can, in practice, reduce initial costs andhelp cleanrooms achieve high performance that can benefit productivity(TengfangXu, 2004).

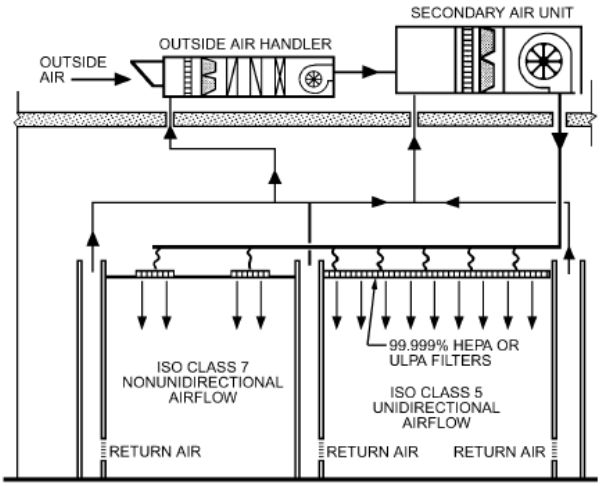

Fig.1 ISO Class 7 Non unidirectional Cleanroom with Ducted HEPA Filter Supply Element and ISO Class 5 Unidirectional Cleanroom with Ducted HEPA or ULPA Filter Ceiling (ASHRAE Clean spaces, 2007)

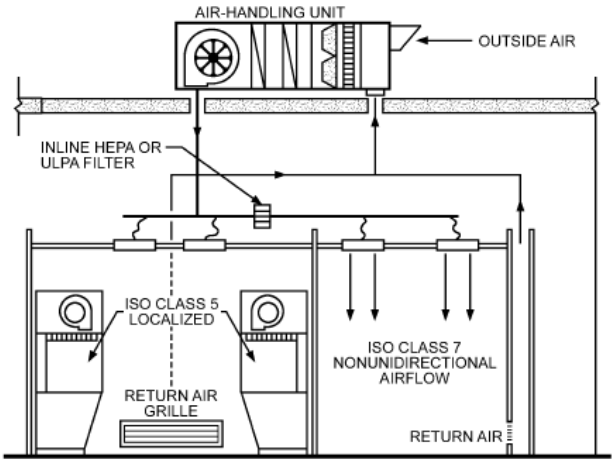

Fig.2 ISO Class 7 Non unidirectional Cleanroom with HEPA Filters Located in Supply Duct and ISO Class 5 Local Workstations (ASHRAE Clean spaces, 2007)

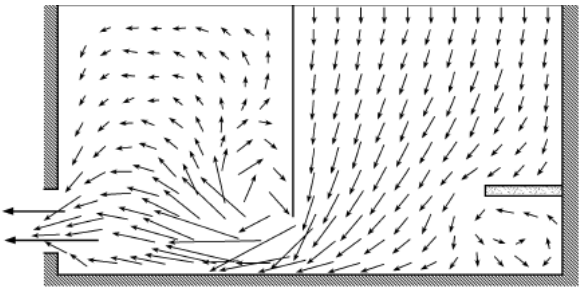

Fig.3 Cleanroom Airflow Velocity Vectors Generated by Computer Simulation (ASHRAE Clean spaces, 2007)

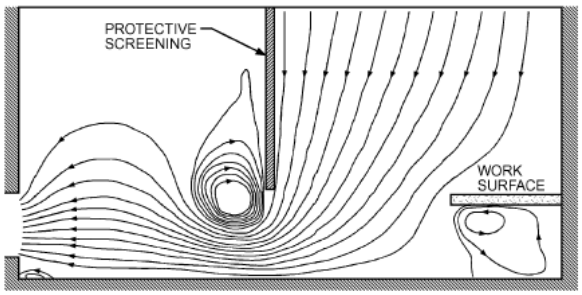

Fig. 4 Computer Modeling of CleanroomAirflow Streamlines (ASHRAE Clean spaces, 2007)

4.3 Room pressurization

Differential pressure between any two rooms is normally designed at 12.5 Pa or less. Controlling contaminants in cleanrooms requires controlling the direction of airflow between adjacent spaces with various levels of cleanliness. This is equivalent to controlling the relative pressures between the spaces. Room airtightness is the key element in the relationship between the room's flow offset value and the resulting pressure differential, and each room airtightness is unique and unknown unless tested.

4.4 Filtration

Proper air filtration prevents most externally generated particles from entering the cleanroom. High-efficiency air filters come in two types: high-efficiency particulate air (HEPA) filters and ultralow penetration air (ULPA) filters. HEPA and ULPA filters use glass fiber paper technology; laminates and non glass media for special applications also have been developed. The efficiency of the filter as well as the effect on the energy consumption (the pressure drop during the entire operation) are the critical factors to be taken into consideration during filter selection.

4.5 Energy conservation in cleanrooms

The major operating costs associated with a cleanroom include conditioning the air, fan energy for air movement in the cleanroom and process exhaust.

Energy conservation plays a significant role in cleanroom air conditioning due to intake of more air for better filtration. Several investigations are made by researchers on use of energy saving techniques for cleanroom air conditioning (Mao, 2006)(T.S Jadhav et al.,2015)(Tsao et al., 2010).

4.6 Cleanroom performance testing

The validation of cleanroom is performed as per ISO 14644-3. The various cleanroom performance testing are summarized below.

4.6.1 Required test for installation

- Airborne particles count for classification and test measurement of cleanrooms and clean air devices

4.6.2 Optional tests for installation

- Airborne particle count for ultrafine particles
- Airborne particle count for macro particle
- Airflow test
- Air pressure difference test
- Installed filter system leakage test
- Airflow direction test and visualization
- Temperature test
- Humidity test
- Electrostatic and ion generator test
- Particle deposition test
- Recovery test
- Containment leak test

The guidelines for conducting the above tests are specified in ISO 14644 -3 (2005).

Conclusions

Cleanroom air conditioning is comparatively more complex and challenging than comfort air conditioning. It is implicit that the higher filtration requirement makes cleanroom air conditioning more energy intensive.

There is a need to perform comprehensive analysis of energy recovery devices for cleanroom air conditioning. Extensive research is needed on optimization of crucial factors such as air changes per hour, room pressurization, etc. for achieving energy efficient cleanroom air conditioning.

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