Energy efficiency in cleanrooms and separative devices: ISO 14644-16, outreach article

Dick Gibbons, Convenor, ISO/TC 209 Working Group 13; May 6, 2020

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Keywords

ISO, TC 209, 14644, cleanrooms, standards, energy efficiency, processes, monitoring, clean air devices, cleanroom energy use

Abstract

The ISO 14644 family of cleanroom standards has been at the center of international cleanroom standards development for many years and covers most facets of cleanroom activity and cleanroom types from large ballroom cleanrooms to isolators and clean tunnels. The series is under constant review and is still expanding.

Recent documents that have been released concern the quantification of airborne and surface chemical concentrations, nanoparticles and the selection and testing of equipment used within these rooms. However, apart from some misleading information in the original Part 4 design document, questions concerning the energy demands from air purification processing have been overlooked. Nationally, institutions such as the BSI in UK, DIN- VDI in Germany and IEST in the USA have produced limited information on the topic, but Part 16 is the first standard to be internationally agreed upon.

The key new features of the standard are a) the preparation of an accurate User Requirement Specification (URS), b) a practical method for estimating the volume of supply air needed to maintain the specified ISO room classifications in operation, c) tuning and d) benchmarking. An informative annex develops three useful metrics for benchmarking: power intensity for contamination removal (PICR), fan energy intensity for contamination removal (EICR) and energy intensity (EI).

14644 Part 16: Energy efficiency in cleanrooms and clean air devices[i]

The new standard was proposed and convened by the UK as a progression of their 2013 cleanroom energy management document, BS 8568[ii]. It reinforces the principal established in that guide, that airflow preparation and circulation are the main contributors to cleanroom energy use, demanding up to 80% of total energy in some facilities. While much of its original advice in BS 8568 on basics such as over-engineering, leak prevention, filter selection, management and maintenance is retained in the new standard, the content is expanded and airflow volume assessments replace air change rate calculations. All this has been achieved by the formation of ISO Working Group 13 with cleanroom experts from Australia, China, Europe, Russia, Scandinavia and the USA to share their experience in this field. The working group also agreed that an energy comparison scheme should be part of the new standard, using terminology and metrics developed for ISO 50001, the international energy management systems standard. Experts from France, Holland, and the USA have produced a comprehensive Annex to explain the mathematics of this difficult area which should enable its use worldwide.

Technically the new document focuses on 4 new features:

1. The preparation of an accurate User Requirement Specification (URS) to establish the precise user requirement.

This is normal procedure in the pharmaceutical and medical device fields but seems lacking within the mechanical and microelectronic world. Effective design requires an accurate estimation of how many people will work in the room, what type of garments will be worn, the type of materials being processed, the tooling used and the final air and product quality levels to be maintained. Due regard should also be made for the environmental situation outside the facility and seasonal digressions. These considerations should be detailed in the design brief.

2. A practical method for estimating the volume of supply air needed to maintain the specified ISO room classifications in operation.

This requires estimates to be made for the contamination load from the process, from cleanroom people and their garment shedding, and from tooling, in order to factor the contamination load into the new air volume formula. Investigations into particle concentrations, such as those carried out by Ljungqvist and Reinmüller in Sweden and the International Camfil Farr group are listed for reference in the bibliography.

The design of a non-unidirectional airflow cleanroom requires effective airflow design for good performance. Traditional air volume calculations can be improved by the inclusion of a ventilation effectiveness (VE) index in their data. This index is influenced by the placement of ceiling diffusers and exhaust vents. Part 16 gives two options for its estimation, namely Air Change Effectiveness (ACE**)** and Contaminant Removal Effectiveness (CRE). The ACE index compares how much clean air a test location receives relative to the average in the cleanroom, whereas CRE, used by the European Heating, Ventilation and Air-conditioning Association (REHVA) and parts of the USA, derives this by comparing the average particle count per cubic metre in the cleanroom and in the exhaust duct.

The ACE theory and the new equations have been developed and production tested by Dr. Whyte and colleagues in the UK. Wei Sun's ASHRAE experiments and research work in the US reinforced much of the thinking and introduction of CRE. Several of their papers on the airflow topic are listed in the bibliography.

Note that these indices are not suitable for unidirectional airflow (UDAF) cleanrooms with total ceiling HEPA coverage. Those rooms require optimisation of airflow speeds, controlled idling set back periods and strict cleanroom discipline, addressed in document sections on adaptive control, education, training and maintenance.

3. Tuning

In non-unidirectional airflow rooms, the air volume flow rate can only be estimated at the design stage since only approximate data on particle generation are available, and a compensation factor is normally applied. Computational Fluid Dynamics (CFD) can be useful in determining the size and positioning of the supply air points and the location(s) of the air extract points. Alexander Fedotov's progressive testing system, developed in Russia, is a pragmatic way of testing the completed cleanroom and ensuring that the compensation factor is not excessive. The process involves progressive testing and relaxation of the air volume until the correct cleanliness level is reliably maintained. This can normally be achieved within 2 or 3 iterations of the test cycle giving rise to the concept of a tuneable process.

A worked example including all the above theory is included in the airflow Annex.

4. Benchmarking

Designated as environmental management tools, the Energy Management Systems standards, especially ISO 50001[iii] and ISO 50006[iv], contain a wealth of useful information with terminology designed to define the contributing elements of an energy load. They provide ideal tools for comparative process analysis, and the experts on the working group reported on how these were adopted and developed in Holland, the USA and France for comparative analysis of process fan power between shifts. Additionally, an engineering team from ASPEC-ADEME in France worked with the EDF power company to study consumption within their national clean process industries. The study, published in December 2016, compared the annual facility consumption by process, using measurement metrics such as Specific Fan Power (SFP). The study, presented by EDF team and working group member Jean Paul Rignac, makes very interesting reading and shows that these methods can be an excellent indicator of energy power management. Jean Paul was able to share his experience, helping Peter Bertrand and Norman Goldsmith to complete their work on the complex benchmarking Annex for Part 16.

This Annex develops the baseline energy performance indicators (EnPIs), used by the Laurence Berkeley National Laboratory with comprehensive formulae to define three main cleanroom related metrics:

1. **Power intensity for contamination removal (PICR)** giving the instantaneous power consumption per square meter of floor surface for the air-handling system to remove contamination. PICR can also be determined from the product of two sub-metrics:
   a) The specific fan power (SFP): the total energy power in kj/m^3 with which the air is moved through all the air handling units serving the cleanroom. This can be calculated by dividing the total electrical power in kW of all the fans by the total airflow rate in m^3/s.
   b) The normalized air volume flow rate: the amount of air per square meter in [(m^3/s)/m^2] being used to dilute and displace contaminates in the cleanroom. This can be calculated by dividing the total volume airflow rate in m^3/s by the floor surface area of the cleanroom in m^2.
2. **Fan energy intensity for contamination removal (EICR)** is a similar metric to PICR but takes into account energy reduction that occurs during times when the cleanroom is not in operation or in adaptive control mode where the airflow varies according to how much contamination is being generated at the time. This metric is calculated by totaling the energy use of all the fan systems serving a cleanroom, for a period of a year, and dividing by the floor area of the cleanroom.

3. **Energy intensity (EI)** is a basic design metric that is calculated by totaling all annual energy flows to condition the cleanroom in question and dividing by the floor area served. These data are then sorted according to ISO class so that comparisons can be made between facilities, environments, companies and industries for classes 3 to 9 in operation.

We consider that these three metrics establish a host of techniques enabling engineers to compare and optimize energy usage within the cleanroom industry.

The new document also covers the significance of correct gowning, education and training in energy conservation and carries forward the maintenance, leak prevention, filter and motor selection material used in BS 8568. The reduction technique selection tables from 8568 have also been improved to illustrate the benefits or dangers of certain reduction techniques.

Acknowledgement

Finally, I would pay tribute to all our working group members and their professional bodies in China, Germany, Holland, Italy, UK and the US who supported this work by hosting our preparatory meetings. While at 43 pages it is a large document, it is well indexed and provides much new and useful information.

About ISO/TC 209

The use of cleanrooms and associated controlled environments is becoming more and more common and a key enabling technology for production. In response, ISO/TC 209 working groups (WGs) have contributed standards for design, testing and use of cleanrooms and associated controlled environments to aid in the acceptance of this beneficial technology by different user groups and regions.

There are currently 24 participating member (P members) countries, which are eligible to nominate experts for WGs and vote on standards in development or systematic review. There are currently 21 countries (O members) that can observe the work of ISO/TC 209.

ISO/TC 209 standards are written generically in that they can be applied for testing and monitoring, or in a broader sense to control cleanliness in various industries such as

- automotive,
- aerospace,
- electronics,
- semiconductors,
- food,
- life sciences (e.g. pharmaceuticals, health care, hospitals),
- scientific research.

In addition, industry or national standards and guidelines are sometimes used to provide deviating or more specific requirements and aspects.

ISO/TC 209 has established formal liaisons with five other ISO TCs and the International Confederation of Contamination Control Societies (ICCCS) to ensure transparency and consistency in its standardization efforts. In 2017, ISO/TC 209 revised its business plan and scope to capture and address current and future standardization needs of consumers, regulators, and industry regarding cleanrooms. The revised scope reflects technical progress and the recognition that cleanroom technology has become more widely applied in various industries and the applications have become more diverse.

Bibliography

[i] ISO14644-16:2019 - Cleanrooms and associated controlled environments - Part 16: Energy efficiency in cleanrooms and separative devices (ISO 14644-16:2019)

[ii] BS 8568:2013, Cleanroom energy — Code of practice for improving energy efficiency in cleanrooms and clean air devices

[iii] ISO 50001:2018, Energy management systems — Requirements with guidance for use

[iv] ISO 50006:2014, Energy management systems — Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI) — General principles and guidance

About the Author

Dick Gibbons, CEng, IMechE, FSEE, has an extensive career in contamination control and processing of cleanroom product. He has been a major contributor to the work of BSI LBI/30 for many years and is currently convenor of ISO TC 209 Working Group 8 that has produced both ISO 14644-8:2013 - Part 8: Classification of air cleanliness by chemical concentration (ACC) and ISO 14644-10:2013 - Part 10: Classification of surface cleanliness by chemical concentration. He was also the UK technical expert on ISO TC 209 Working Group 9 which produced ISO 14644-9:2012 - Part 9: classification of surface cleanliness by particle concentration. Having chaired the sub-committee of LBI/30 which produced BS 8568:2013 on cleanroom energy efficiency, he was appointed convenor of ISO Working Group 13 that wrote ISO 14644-16: 2019 on cleanroom energy reduction.

IEST is the leading global nonprofit contamination control society and Secretariat for ISO Technical Committee 209 (ISO/TC 209), the committee developing the ISO 14644 Standards. IEST has served as the Secretariat for ISO/TC 209 for more than 25 years with an established international leadership role based on more than 45 years of expertise in cleanrooms and controlled environments.