BS 8568:2013

BSI Standards Publication

# Cleanroom energy – Code of practice for improving energy efficiency in cleanrooms and clean air devices

bsi.

...making excellence a habit.™

## Publishing and copyright information



Published by BSI Standards Limited 2013

ISBN 978 0 580 74267 5

ICS 13.040.35

The following BSI references relate to the work on this document:
Committee reference LBI/30
Draft for comment 12/30240811 DC

## Publication history

First published March 2013

## Amendments issued since publication

| Date | Text affected |
| --- | --- |

# Contents



**Summary of pages**

This document comprises a front cover, an inside front cover, pages i to ii, pages 1 to 30, an inside back cover and a back cover.

# Foreword

## Publishing information

This British Standard is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 31 March 2013. It was prepared by Technical Committee LBI/30, *Cleanroom technology*. A list of organizations represented on this committee can be obtained on request to its secretary.

## Use of this document

As a code of practice, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

Any user claiming compliance with this British Standard is expected to be able to justify any course of action that deviates from its recommendations.

## Presentational conventions

The provisions in this standard are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is "should".

*Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.*

## Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

**Compliance with a British Standard cannot confer immunity from legal obligations.**

# Introduction

Cleanroom cleanliness can be classified by the concentration of specific contaminants in the air or on surfaces in the cleanroom. Cleanrooms use a considerable amount of energy to provide large amounts of filtered and conditioned air to achieve the specified levels of cleanliness. A considerable amount of energy is also used to achieve:

a) the necessary temperature and relative humidity for the process in the cleanroom and for personnel comfort;

b) the necessary pressurization of the space; and

c) in some cases, the necessary airflow volume flow rate for unidirectional airflow and to a reduced extent non-unidirectional airflow.

Some firms using cleanrooms report that heating and ventilating systems consume up to 80% of the total energy used in their manufacturing facility simply to deliver clean, conditioned air to critical operations. This energy is consumed by heating, cooling, humidification and fan power. Of this, fans required to move air can account for 35% to 50%, much of this being due to the extra energy required to overcome the high pressure differential required for the high efficiency filters and other ventilation components used in cleanrooms. There is therefore a significant potential for energy saving by diligent design in the installation of new cleanrooms, and by retrofit improvements and upgrades to existing facilities.

This British Standard lists and explains measures that can be taken to reduce energy consumption in cleanrooms and applies to the whole range of "cleanroom technology", from cleanrooms to clean air devices, including isolators, glove boxes and mini-environments as described in BS EN 14644-7. Cleanroom technology is used by organizations within the life-sciences, micro-electronics, aerospace and nuclear fields. The life-sciences sector includes hospital, pharmaceutical and medical device activities.

This British Standard does not address related production processes such as water treatment, oven, autoclave and stress cycling operations that can also create significant energy demands.

# 1 Scope

This British Standard gives recommendations on reducing energy consumption and maintaining energy efficiency in new and existing cleanrooms and clean air devices, classified by BS EN ISO 14644-1.

The standard is not applicable to the energy efficiency of process equipment, except where it affects the cleanroom environment.

*NOTE 1 Further guidance on the use of energy management systems is given in BS EN ISO 50001.*

*NOTE 2 Energy saving opportunities are listed in Annex A and detailed in Annex B.*

# 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS EN 1886, *Ventilation for buildings – Air handling units – Mechanical performance*

BS EN 14799, *Air filters for general air cleaning – Terminology*

BS EN ISO 14644-4, *Cleanrooms and associated controlled environments – Part 4: Design, construction and start-up*

BS EN ISO 14644-5:2004, *Cleanrooms and associated controlled environments – Part 5: Cleanroom operations*

BS EN ISO 14644-6:2007*, Cleanrooms and associated environments – Part 6: Vocabulary*

BS EN ISO 50001, *Energy management systems – Requirements with guidance for use*

**Other publications**

[N1] HEATING AND VENTILATING CONTRACTORS' ASSOCATION. *Specification for sheet metal ductwork: low, medium and high pressure/velocity air systems*. DW144. Cumbria, 1998. ISBN: 0 903783 27 4.

# 3 Terms and definitions

For the purposes of this British Standard, the following terms and definitions apply.

**3.1 air handling unit (AHU)**
unit or plant, comprising fan, filtration, heating, cooling and mixing of fresh air and recirculated air, that delivers conditioned air to a room or facility

**3.2 clean air device**
stand-alone equipment for treating and distributing clean air to achieve defined environmental conditions

[SOURCE: BS EN ISO 14644-6:2007, **2.31**]

*NOTE Clean air devices include certain separative devices as defined in BS EN ISO 14644-7, for example, clean air hoods, containment enclosures, gloveboxes, isolators and mini-environments.*

**3.3 cleanroom**
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

[SOURCE: BS EN ISO 14644-6:2007, **2.33**]

**3.4 colony forming units (CFUs)**
single micro-organism or a single small mass of micro-organisms that when deposited on a microbiological growth medium grows to form a single visible colony that can be counted

*NOTE One colony forming unit is expressed as 1 CFU.*

**3.5 combined heat and power**
electrical generation by internal combustion engine or gas turbine with the waste heat from this process being used to generate hot water or steam

**3.6 controlled environment**
defined zone in which sources of contamination are controlled by specified means

[SOURCE: BS EN ISO 14644-6:2007, **2.45**]

**3.7 critical zone**
area where the product is exposed to the potential deposition of airborne contamination

**3.8 final filter**
last high efficiency filter in the system before the air enters the cleanroom

*NOTE This may be in the AHU or it may be a terminal filter (see **3.12**).*

**3.9 high efficiency air filter**
air filter conforming to BS EN 1822 (all parts), covering the range of efficient particulate air filters (EPA): E 10 – E 12, high efficiency particulate air filters (HEPA): H 13 – H 14 and ultra low penetration air filters (ULPA): U 15 – U 17

**3.10 microbe-carrying particle (MCP)**
particle on which a micro-organism is carried; it is normally dispersed into room air by personnel as a skin cell, or fragment of skin cell, on which a skin microbe(s) is carried

**3.11 non-unidirectional airflow (non-UDAF)**
air distribution where the supply air entering the clean zone mixes with the internal air by means of induction

[SOURCE: BS EN ISO 14644-6:2007, **2.95**]

**3.12 terminal filter**
high efficiency air filter located at the point where the air enters the cleanroom

**3.13 tri-generation**
electrical generation that is integrated with both heat and chilled water generation

**3.14 turn down**
controlled reduction of airflow velocity in UDAF cleanrooms and clean air devices and airflow rates in non-UDAF cleanrooms in order to save energy during periods when the cleanroom is not in operation

**3.15 unidirectional airflow (UDAF)**
controlled airflow through the entire cross-section of a clean zone with a steady velocity and approximately parallel airstreams

*NOTE This type of airflow results in a directed transport of particles from the clean zone.*

[SOURCE: BS EN ISO 14644-6:2007, **2.138**, modified - Note 2 has been deleted.]

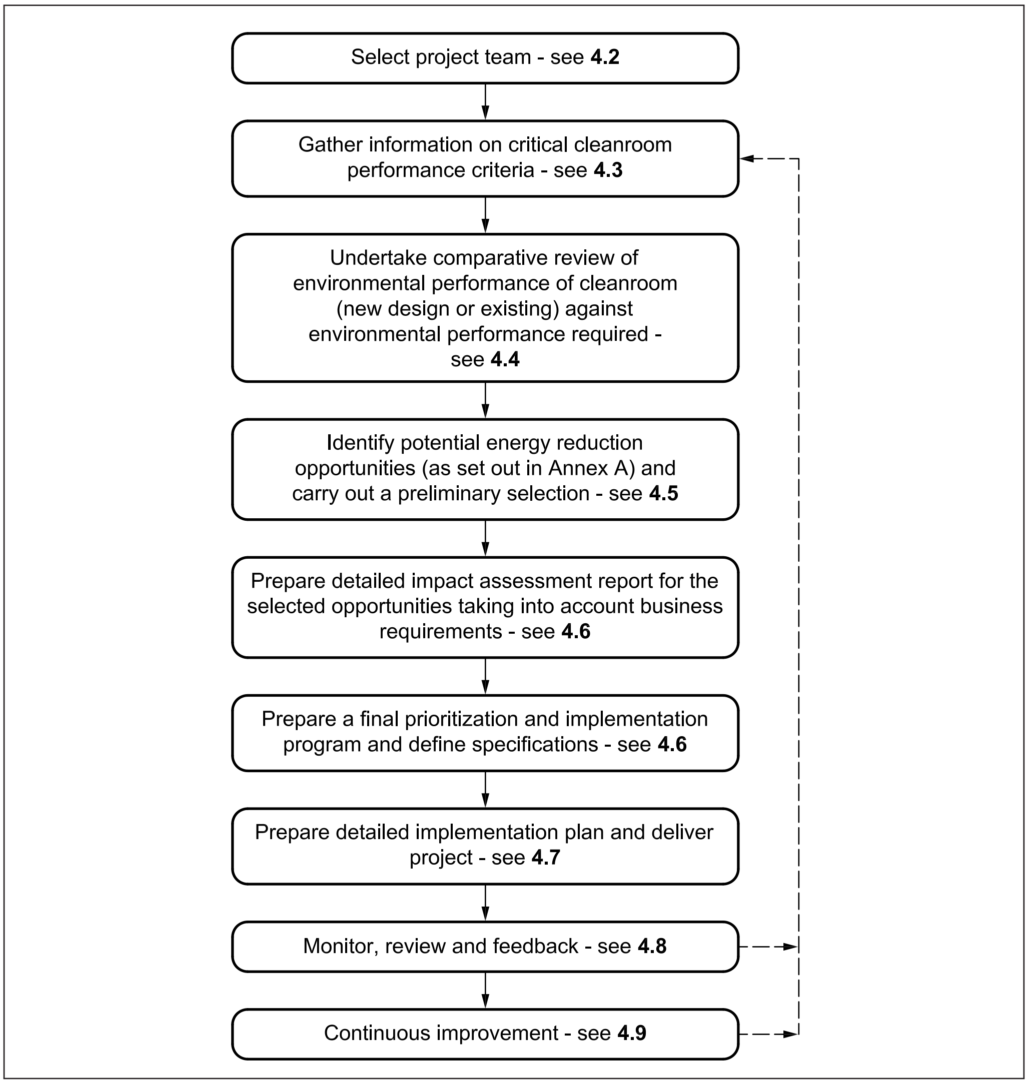
# 4 The energy evaluation and implementation process

## 4.1 General

Energy reduction in new and existing cleanrooms and separative devices should be carried out in accordance with the process described in this clause and summarized as a flowchart in Figure 1.

*NOTE Attention is drawn to the European Commission Energy Performance of the Buildings Directive [1], the Energy Act 2011 [2] and the Building Regulations 2010 [3].*

Figure 1 **Process flowchart**




## 4.2 Selecting a project team

A project team should be set up to include representatives from the key business functions such as quality, validation, production, planning, finance, engineering, maintenance and cleanroom energy experts.

*NOTE Additional expertise can be provided by internal or external consultants.*

## 4.3 Gathering information

### 4.3.1 General

Documents, including drawings and specifications, and information that define the cleanroom performance criteria should be collated; this might take the form of existing quality risk assessments or facility operational assessments.

*NOTE The objective is to identify criteria that affect performance and to consider the direct and indirect impacts of possible energy reduction actions.*

A survey of the facilities should be carried out and reviewed to identify all the energy saving opportunities, see Annex A.

### 4.3.2 Existing cleanrooms

For existing cleanrooms the survey should include:

a) identifying the cleanroom performance criteria to meet the requirements of the process, the products and personnel comfort;

b) a profile of energy use; this should cover lighting, air handling, comfort heating, cooling and any other significant energy use. The information should come from monitoring or, where this is not possible, from professionally derived estimates;

c) the current cleanliness performance (from classification and monitoring – particles, chemical species, micro-organisms);

d) airflow volume flow rate, airflow velocity and pressurization;

e) practical issues related to onsite operations, e.g. reliability and control, layout, age, condition, function, maintenance;

f) the results of any benchmarking exercise; this should compare the existing design with best practice energy use with respect to energy cost and carbon emissions;

g) life cycle costs and optimization studies if possible.

### 4.3.3 New cleanrooms

For new cleanrooms the survey should include:

a) identifying the cleanroom performance criteria to meet the requirements of the process, the products and personnel comfort;

b) the best estimates of projected energy use; this should cover lighting, air handling, heating, cooling and any other significant energy use;

c) the design performance (in classification terms: cleanliness, microbial, etc.);

d) the results of any benchmarking exercise; this should confirm that the new design complies with best practice energy use with respect to energy cost and carbon emissions.

*NOTE The consideration of life cycle costs and optimization studies can also be included in the exercise.*

## 4.4 Comparative review

A comparative review should be undertaken, to compare the environmental performance of the designed (new) cleanroom or redesigned (existing) cleanroom with the environmental performance requirements (of the process, the products and personnel comfort), to avoid overdesigning, e.g. specifying cleanliness classifications that are lower (cleaner) than necessary or clean spaces that are larger than necessary.

*NOTE Significant energy savings can be identified by carrying out such a review.*

## 4.5 Improvement opportunities

The project team should analyse the results of the comparative review, identify potential energy reduction opportunities and carry out a preliminary selection; this can be done using the checklist given in Annex A, Table A.1. Once the preliminary selection has been made using Table A.1, the selection should be assessed and documented as part of the decision-making process, and the reasons why an opportunity is chosen, or not, should be recorded.

## 4.6 Impact assessment and prioritization

Once the potential energy saving opportunities have been identified from Table A.1 and a preliminary selection carried out, a detailed impact assessment report should be produced, covering all of the potential opportunities identified and taking into account the corresponding recommendations given in Annex B as well as the following business requirements:

- feasibility;
- process compatibility;
- risk;
- safety;
- cost;
- return on investment;
- incentives (e.g. government);
- implementation timeline/programme;
- implementation resources;
- business continuity.

This report identifies which energy reduction opportunities have become less viable or more challenging; these should be reprioritized behind those that can be easily and effectively delivered. A final prioritization and implementation programme should then be prepared.

Specifications and scopes of work should be defined for those opportunities that are to be implemented.

Where industries have standards or guidelines that specify performance requirements, all the situations where one or more performance requirements are in conflict with a particular proposed energy reduction measure should be identified.

*NOTE Such performance requirements might include air quality (in terms of particle and microbial concentration), filter efficiency, unidirectional airflow velocity, room air change rate (by varying the air supply rate), recovery time and pressure differentials between adjacent rooms of different grades.*

When these situations have been identified, the project team (see **4.2**) should formulate a detailed justification to demonstrate that product quality is not affected by the proposed measure. Agreement from any authority concerned prior to implementation should then be obtained.

## 4.7 Implementation

The project team, now including the selected contractors and suppliers, should produce a detailed implementation plan and undertake the work. The implementation plan should include the expected outcomes for all the selected elements.

## 4.8 Monitor, review and feedback

On completion of the project and thereafter at regular intervals, for each selected element, the expected outcome defined in the implementation plan should be monitored and reviewed to ensure that the changes remain effective. The associated energy reductions should be monitored, recorded and analysed. The information gathered should be used as feedback for continuous improvement.

## 4.9 Continuous improvement

Using the feedback, it should be determined if any further changes are needed and then these should be implemented.

Where improvements might be applicable to other similar facilities in the organization, they should be assessed and applied.

## Annex A (informative) Energy saving opportunities checklist

Table A.1 lists elements of a cleanroom or clean air device that present opportunities for energy reduction. All these opportunities exist at the design stage of a new facility and some of them are available when an existing facility is being re-evaluated. Table A.1 may be used as a pro-forma to identify and prioritize energy reduction opportunities; a column is provided for this. Greater detail on how to achieve a worthwhile energy reduction for each element is given in Annex B and the references in column 3 refer to the relevant clauses in Annex B.

Table A.1 **Energy reduction opportunities in cleanrooms**

| **Element** | **Opportunity** | **Impact on energy use** | | **Opportunity for energy reduction** | |
|---|---|---|---|---|---|
| | | **Clause number** | **Consideration** | **Area** [A)] | **Possible adverse impact subject to impact assessment (see 4.6)** |
| Performance requirements | Avoid overdesigning | **B.2** | Ensure that operational parameters are not excessive for the process | | Limitation for future development, potential for conflict with internal or external quality auditors |
| Facilities design/redesign | Optimize energy consumption | **B.3** | See BS EN 14644-4 | | Loss of spare capacity |
| Airflow: UDAF | Reduce air velocity | **B.4.2** | Displacement effectiveness | | Increased ingress and reduced removal of particles |
| Airflow: non-UDAF | Reduce airflow volume flow rate | **B.4.3** | Airflow volume flow rate reduction and mixing effectiveness | | Insufficient particulate dilution and temperature control |
| Make-up air use | Use less fresh air | **B.4.4.1** | Health and safety (sufficient fresh air for occupancy), optimization of room pressure | | Operator fatigue and discomfort, pressure control |
| Room pressure | Reduce pressure | **B.4.4.2** | Particle ingress or loss of containment | | Potential for conflict with internal or external quality auditors |
| Leakage: leak paths/pressure leaks | Reduce conditioned air | **B.4.4.3** | Fix all uncontrolled leak paths, e.g. poorly fitting doors and loose ceiling tiles, ducting | | A lack of controlled leak paths can result in pressure stability problems |
| Equipment extract systems | Reduce air extraction | **B.4.4.4** | Fresh air reduction | | None |
| Recirculated air | Maximize recirculation | **B.4.4.5** | Optimize fresh air consumption | | Room pressure control |
| Occupancy levels | Minimize people numbers | **B.5** | Reduced particles and MCPs | | Cross contamination exposure due to multitasking |
| Garment requirements | Maximize containment of people emissions | **B.6** | Correct specification of garments to meet process requirements | | Increased cost and personnel discomfort |

Table A.1 **Energy reduction opportunities in cleanrooms**

| Element | Opportunity | Impact on energy use | | Opportunity for energy reduction | |
|---|---|---|---|---|---|
| | | Clause number | Consideration | Area [A)] | Possible adverse impact subject to impact assessment (see 4.6) |
| Operator competence | Ensure people are trained to operate in cleanrooms | **B.7** | Operators trained to work in a cleanroom, i.e. generate fewer particles to be removed by not being overactive | | None |
| Air handling units | Use the most efficient equipment and optimize performance | **B.8** | Efficient motors/high efficiency fans/clean coils/low energy filtration; fan, motor and drive selection for optimum efficiency; component selection to minimize pressure drops; power factor correction to minimize power consumption | | Cost (installation and capital) |
| Air filters | Reduce excessive pressure drops | **B.9** | Pre-filter and final filter selection including the use of the “Air Filter Life Cycle Costing” model | | None |
| Cooling | Maximize efficiency of chilled water system | **B.10** | Inclusion of heat recovery | | None |
| Building management system (BMS) | Optimize and improve energy management | **B.11** | Avoid conflicting energy demands between heating/cooling, humidifying/ dehumidifying | | None |
| Environmental monitoring systems (EMS) | Monitor environmental parameters to support energy reduction measures | **B.12** | Ensure environmental parameters are maintained when airflow is reduced | | None |
| Lighting levels | Use high efficiency localized LED lighting where possible | **B.13** | Use high efficiency localized LED equipment | | Operator fatigue |
| Heat gains/losses | Minimize heat gains and maximize recirculation | **B.14** | Consider how to minimize all equipment and structural heat gains | | Maintenance access for equipment relocated to have heat source (e.g. motors) outside cleanroom |

Table A.1 **Energy reduction opportunities in cleanrooms**

| **Element** | **Opportunity** | **Impact on energy use** | | **Opportunity for energy reduction** | |
|---|---|---|---|---|---|
| | | **Clause number** | **Consideration** | **Area** [A)] | **Possible adverse impact subject to impact assessment (see 4.6)** |
| Turn down | Run HVAC at reduced rate when not in operation | **B.15** | Maintain minimum classification during turn down | | Unauthorized room entry, e.g. maintenance and cleaning personnel |
| Turn off | Switch off HVAC when cleanroom not operational | **B.16** | Risk assessments required, take great care on start-up | | Risk of overall contamination, particulate displacement from filters on restart |
| Use of clean air and containment devices | Minimize high classification areas | **B.17** | Ensure that high classification areas are no larger than necessary | | Might complicate material flow and storage |
| Maintenance regimes | Ensure filters and motors are not overloaded | **B.18** | Good maintenance minimizes excessive pressure drops, air loss through leakage and maximizes fan drive efficiencies | | None |
| Monitoring | Record improvements | **B.19** | Track changes | | None |
| Energy supply | To examine alternative forms of energy generation | **B.20** | Capital and running cost, maintenance and fuel supply | | Possible long payback on investment |

[A)] This column is used to identify and prioritize energy reduction opportunities.

# Annex B (normative) Energy reduction opportunities in cleanrooms

*COMMENTARY ON ANNEX B*

*Annex B sets out energy reduction opportunities that can be applied to the design of new cleanrooms. Many of these can also be applied retrospectively to existing cleanrooms.*

## B.1 General

To decide whether the energy saving for each opportunity in Annex B is worth implementing, the energy savings should be first estimated. Once a decision has been made, the opportunity should be implemented in accordance with the relevant subclause.

Where specific energy saving measures are identified, the cleanroom operator should ensure that the cleanroom control parameters are not reduced to a level beyond which there is an adverse threat to the quality of materials produced or the integrity of operations in the cleanroom.

When a cleanroom is operated with energy saving attributes, the performance parameters should be monitored to provide assurance that adequate levels of control are achieved during normal and turn down modes. The following parameters should be taken into account:

a) room or device pressure differential compared with less clean adjacent areas/rooms;

b) room or space temperature and relative humidity;

c) airflow velocity for unidirectional airflow systems;

d) airflow volume flow rate for non-unidirectional airflow systems.

Where energy saving features are included within the original design or as a retrospective modification, they should be specifically designed, effectively documented, correctly installed and accurately commissioned.

Where system complexity is increased as a result of incorporating energy efficiency features into the design of the cleanroom or its air handling system, the increased risk resulting from the increased complexity should be assessed as part of the decision-making process (see **4.4** and **4.5**) required when selecting energy saving measures.

*NOTE BS EN ISO 50001 specifies that energy saving targets are ambitious, realistic, specific and measurable, and use the Best Available Technology (BAT).*

The viability of any proposed energy saving measures for a cleanroom should be assessed in accordance with BS EN ISO 50001.

## B.2 Performance requirements

### B.2.1 General

Overspecification of performance requirements and overdesigning should be avoided as part of any energy reduction campaign.

*NOTE Performance requirements include values for primary parameters such as air cleanliness by particle concentration, and for secondary parameters that contribute to delivering the cleanliness, such as unidirectional airflow velocity (UDAF), airflow volume flow rate (non-UDAF) or room pressure differentials.*

The project team should leave sufficient capacity and flexibility in the design to accommodate future developments, changes or expansions of the activity to be carried out in the cleanroom, if this is considered necessary.

For existing operational cleanrooms, documented performance specifications, alert levels, alarm levels and action levels should be examined to see if the performance requirements are overstated, e.g. with excessive safety margins, and can be reduced with consequent energy savings. Any reductions identified should then be implemented.

Before finalizing the design for new cleanrooms or implementing energy saving measures for existing cleanrooms, the project team should assess whether the values of any of the cleanroom control parameters are in conflict with standards or guidelines that are specific to the particular industry. If there is a conflict, agreement should be obtained from internal and external quality auditors in accordance with **4.6**.

### B.2.2 Contamination source strength

The contamination source strength in the cleanroom should be evaluated and minimized by good cleanroom practice, including gowning, layout, process localization and process design in order to minimize the supply of clean air required and thus the energy required.

The airborne cleanliness condition should be no more than is required by the manufacturing process carried out in the room.

The supply airflow volume flow rate should be no greater than is required to give the airborne cleanliness required for the manufacturing process carried out in the room.

*NOTE 1 For some types of cleanrooms the airborne concentrations are set by regulatory authorities.*

*NOTE 2 Equation B.1 is a useful guide to the number of airborne particles that deposit onto a product during a manufacturing process in a cleanroom:*

Number of airborne contaminants deposited on a product = $C \times A \times T \times S$ *(B.1)*

*where:*

- $C$ is airborne concentration of particulate contaminants, in numbers per cubic metre (no./$m^3$);
- $A$ is the area of product exposed to contamination, in squared metres ($m^2$);
- $T$ is the time the product is open to airborne contamination, in seconds (s);
- $S$ is sedimentation velocity of airborne particles onto product, in metres per second (m/s).

*NOTE 3 S is used for particles ≥0.3 µm typically $3 \times 10^{-5}$ m/s [4] and for MCPs $4.5 \times 10^{-3}$ m/s [5].*

Equation B.1 should be used, along with a rationalized assessment of the proportion of product that can be contaminated, to obtain information on the required airborne concentration of particulate contamination in the cleanroom and hence the required air supply.

## B.3 Facilities design/redesign

The cleanroom environment should be sized to match the operational needs within the facility in accordance with BS EN ISO 14644-4 wherein the process air becomes cleaner as one moves towards the core of the facility.

The cleanliness class level should be designed to not overexceed the current or planned product requirement. Since the airflow volume flow rate requirement for a unidirectional airflow cleanroom is much higher than a non-unidirectional airflow room, the decision of which of these airflow systems to use is the first decision that should be made when considering energy reduction measures.

*NOTE 1 BS EN ISO 14644-1 requires that the "considered particle size" is always specified when a classification level is specified.*

*NOTE 2 For activities that require a small amount of space, clean air devices with the necessary classification level can be used (see also **B.17**).*

## B.4 Airflow

### B.4.1 General

When calculating the air supply to a cleanroom, it should be determined, whether the air supply requirement is dominated by:

a) the need to control high heat gains from machinery; or

b) the need to achieve low concentrations of airborne contamination.

If the dominant requirement is to control heat gains, then a conventional heating and ventilation (H&V) design approach should be used, although the use of local heat containment and removal (see **B.14**) should also be evaluated.

The required supply airflow volume flow rate for a cleanroom to produce the specified level of airborne particle or MCP concentration should be calculated according to whether the airflow in the cleanroom is unidirectional or non-unidirectional.

*NOTE 1 Unidirectional airflow cleanrooms give much cleaner conditions than non-UDAF cleanrooms. This is because the clean air is supplied from a complete wall or ceiling of high efficiency filters, passes through the room in a piston-like manner and leaves through the opposite wall or floor. Unidirectional airflow is also used in many clean air devices.*

*NOTE 2 Non-unidirectional airflow works on the principle of removal of airborne contamination by mixing and dilution; ventilation effectiveness is a measure of the effectiveness of the mixing and dilution.*

*NOTE 3 The supply airflow volume flow rate in unidirectional airflow systems can be calculated from the airflow velocity. Guidance values for airflow velocities in UDAF systems are given in **B.4.2**.*

*NOTE 4 The calculation for supply airflow volume flow rate in non-UDAF systems is given in **B.4.3**.*

*NOTE 5 Unidirectional airflow always requires a much larger airflow volume flow rate for the same space than non-unidirectional airflow.*

Since the amount of air in circulation depends on the room volume and the airflow volume flow rate, the room volume should be minimized by means of an efficient layout. Tall equipment should be located along the room walls to allow the ceiling height to be reduced in the rest of the area.

Wherever possible, in order to help minimize the heat gain in the cleanroom, processing equipment should be mounted through the cleanroom wall so that only the loading aperture is in the cleanroom.

The (UDAF and non-UDAF) terminal filter air velocities for supply air should be capable of being controlled for normal and turn down operations.

The energy efficiency of air curtains to segregate zones should be evaluated before they are considered for use.

The balancing of all the supply air ducts and all the return air ducts and exhausts is carried out at commissioning after installation and should not be changed without management approval to ensure that energy efficient operation of the air system is maintained. Likewise low level return intakes should not be blocked by equipment or furniture.

*NOTE 6 Computational fluid dynamics (CFD) can be used to simulate and predict the effectiveness of air movement within a cleanroom. CFD is used primarily at the design stage to investigate the interaction between cleanroom and process layout, air diffuser type and location, supply air volume flow rate and room extract location so as to achieve a theoretically optimized design with particular emphasis on removal of airborne particles. CFD can also identify likely dead spots and short circuits of airflow.*

*NOTE 7 Systems are available that vary the air volume supply rate according to the level of contamination that is measured in the room.*

### B.4.2 Unidirectional airflow

To reduce the supply airflow volume flow rate, and thus energy consumption, a decision should be made on whether low concentrations of contamination obtained by unidirectional airflow systems are really required or whether a non-unidirectional system would be adequate.

Where unidirectional airflow is provided, the size of the unidirectional area should be minimized to cover only the critical zones where it is required; this may be obtained by use of clean air devices (see **B.17**).

When the unidirectional airflow velocity is reduced, the specified particle or MCP concentration limits should continue to be maintained and monitored.

The lower the air velocity, the higher the concentration of airborne contamination; it has been shown that velocities of 0.3 m/s provide sufficiently low concentrations of airborne contamination in normal levels of occupancy and activity but should not exceed 0.5 m/s in order to conserve energy. The following variables should take into account the amounts of contamination dispersed by:

a) personnel;

b) machinery;

c) other sources of airborne contamination.

In the case of personnel [a)], the following variables should be taken into account:

1) the number of personnel present;

2) the proportion of their bodies within the unidirectional airflow;

3) the proportion of time they are within the unidirectional airflow;

4) how close they are to the exposed product.

Disturbance of the airflow by people and machinery increases the contamination concentration in the critical zone and should also be evaluated. In the case of personnel their movement should be taken into account, and in the case of machinery its movement, thermal emission and obstruction to airflow should be taken into account.

In areas where there is little or no activity, e.g. during the night when no production occurs or in isolators where automatic production occurs, the airflow velocity should be reduced to below 0.3 m/s. The effectiveness of low velocity should be validated (see **B.15** for details on turn down).

The effectiveness of the reduced air velocity to control particulate ingress and removal should be confirmed by particle counting in operation and also by airflow visualization (see BS EN ISO 14644-3).

### B.4.3 Non-unidirectional airflow

Dispersion rates for airborne contamination should be minimized because the supply airflow volume flow rate is directly proportional to the dispersion rate; this can be calculated using Equation B.2.

$$Q = D/C \tag{B.2}$$

where:

$Q$ is the minimum supply airflow volume flow rate to the cleanroom, in cubic metres per second ($m^3/s$).

$D$ is the dispersion rate of airborne contamination, i.e. source strength, in numbers per second (no./s);

$C$ is the maximum concentration of airborne contamination per cubic metre (for the cleanroom classification).

*NOTE 1 The use of Equation B.2 assumes that an insignificant amount of particles or MCPs come from the filtered air supply. This is a reasonable assumption, provided that the recommendations regarding filters (see **B.9**) have been observed. Equation B.2 also assumes that the cleanroom air is well mixed. It can therefore only be accurately applied to non-unidirectional cleanrooms where the air supply inlets are fitted with diffusers and low-level extracts to achieve good mixing.*

The required supply airflow volume flow rate should be estimated using the magnitude of the contamination source strength taking into account variations. Information about contamination dispersion rates from personnel and machinery should be obtained from reports (or documentation) of previous measurements or by average measurements of particle counts at the extracts in a non-unidirectional cleanroom when the source to be measured is in the cleanroom and the particle concentration is in a steady-state condition. Equation B.2 should then be applied. If the source strength is not available, the following risk factors should be evaluated and the supply airflow volume flow rate should be estimated from the information gathered for:

a) people: the fewer the people in the cleanroom the lower the airborne dispersion;

   *NOTE 2 The more effective the cleanroom clothing fabric in preventing dispersion, and the more it envelopes the person, the lower the dispersion rate.*

b) machinery and ancillary equipment: the presence, or not, of machinery and whether the type of machinery present is likely to disperse a large number of particles.

   *NOTE 3 The airborne dispersion may be reduced by removal of equipment that emits contamination and placing it outside the cleanroom, and bulkhead fitting of equipment so that the particle emission occurs behind the cleanroom wall.*

Dispersion rates are often available as averages, but dispersion does vary and this leads to variations in airborne concentration in the cleanroom; the air supply rate should be sufficient to deal with these variations.

When clean air devices are used in cleanrooms, the air in the room is filtered by the device and this additional air flow should be taken into account when calculating the required air supply rate.

The use of clean air devices, such as unidirectional workstations and isolators, should be evaluated as they enable the product to be exposed in much cleaner conditions and the rest of the cleanroom to be run with a higher concentration of airborne contamination.

Where a non-unidirectional airflow system is to be installed, ceiling diffusers and the placement of extract grilles that greatly improve airflow mixing and the dilution of contaminants should be chosen; good ventilation effectiveness can be provided at a lower air supply.

Where appropriate, computational fluid dynamics should be used to ascertain the effectiveness of the airflow design (see **B.4.1**, Note 6).

In large installations, the use of multiple air-handling units, or a combination of fan-filter units should be evaluated; this allows zoning, enabling various parts of the area to be put into standby mode, when not in use.

The location and style of supply air grilles and the location of return air grilles should be determined to ensure optimal mixing of air for clean up and avoidance of dead airflow zones.

The supply airflow volume flow rate chosen should be adequate to maintain appropriate levels of cleanliness and heat removal and the performance should be validated by "in operation" cleanroom classification.

## B.4.4 Make-up air use

### B.4.4.1 General

*NOTE 1 Make-up air is required in all cleanrooms to ensure that the facility maintains an overpressure for successful contamination control. Fresh air is also required to ensure operator comfort. The percentage of make-up air introduced into a handling system has a significant impact on energy consumption, and air recirculated from a classified cleanroom is significantly cleaner than make up air drawn from outside or from within the building envelope.*

The percentage of make-up air should therefore be as low as possible consistent with contamination control and operator comfort, but sufficient to provide for ventilation requirements, pressurization of cleanroom areas and to compensate for any process exhaust air drawn from the cleanroom.

The following configuration of systems (only applicable to new designs) should be examined.

a) Enthalpy control systems: this design concept utilizes variable outside and make-up airflow volume flow rates. The control system maximizes free cooling and minimizes heating and cooling loads required for the make-up air. To achieve this, the system includes automated control dampers that can vary the outside air make up from 100% to the minimum required for pressurization and ventilation requirements. Enthalpy control systems are unusual in cleanroom applications due to the nature of the internal heat gains, but more importantly because varying the make-up air percentage makes it more difficult to maintain steady room pressure differentials.

b) Use of conditioned recirculated air, where possible, mixed with fresh air treated as necessary: this design concept uses separate air handling systems to pre-treat the make-up air and then inject this preconditioned air into an air handling system, providing the controlled conditions for a zone, group of rooms or suite of rooms with similar performance characteristics.

*NOTE 2 In addition it might be necessary to replace air lost by leakage or through equipment extract systems.*

*NOTE 3 There are some applications where a much higher percentage of fresh air/extract air is required to reduce the concentration of toxic, sensitizing or other chemical substances in the air to safe or cleanliness levels (see BS EN ISO 14644-8).*

#### B.4.4.2 Room pressure

As detailed in BS EN ISO 14644-4, the cleanroom facility should show progressive improvements in air cleanliness while moving to the process core of the operation. This should be achieved by maintaining a pressure differential between each sector of the facility in the progression.

A positive pressure differential between the outside environment and the changing room, then the gowning room and finally the cleanroom should be established. A reduction in operational pressure reduces the fan loadings and can contribute to considerable energy savings, thus pressure differentials should not normally exceed 10 Pa.

In applications where toxic containment is required, one or more negative pressure sectors might be needed between the process core and the outside environment in order to achieve the necessary level of containment required for safety; in such situations the pressure differentials should be kept as low as possible to be consistent with the necessary level of containment.

#### B.4.4.3 Leakage: leak paths/pressure leaks

For existing cleanrooms, air loss by leakage [from ill-fitting doors, duct leakage, loss of sealant, open ducts (access panels accidentally left off), or holes in the ceiling and other similar flaws] should be minimized by rectification or sealing in order to minimize the provision of additional compensating air.

Usually the worst leaks are detected by pressure alarms and supervisors should make regular checks to ensure that alarm settings are in accordance with the specification and have not been subjected to unauthorized adjustment.

During the design of new cleanrooms, the number of doors and other access apertures, such as hatches and communication flaps, should be minimized and interlocked air locks for equipment and product movement should be provided. Easily accessible telephone links or intercoms should be specified for operator communication.

Structural (envelope) air losses should be reduced by appropriate design, including sealing, to ensure structural integrity or, in the case of existing cleanrooms, by sealing; this applies to:

- ceiling leakage;
- wall leakage;
- door leakage;
- hatch leakage.

All ductwork and incorporated components should be specified and installed to minimize system air leakage. Ductwork should be installed and tested to DW144 [N1] as a minimum requirement.

*NOTE A lack of adequate controlled leak paths can result in pressure stability problems.*

#### B.4.4.4 Equipment extract systems

Air exhausted by equipment extract systems should be minimized by appropriate design; this applies to:

- isolator extract systems;
- safety cabinet extract systems;
- fume cupboard extract systems;
- process equipment extract systems.

The airflow volume flow rate extracted by these extract systems should be taken into account as part of the room extract in the system design calculations.

#### B.4.4.5 Recirculated air

The maximum possible percentage of room air should be recirculated back through the air handling system to reduce fresh air consumption. Where some or all of the air needs to be directly extracted from the room, a heat reclaim system should be incorporated that best matches the psychometric condition of the extract and supply air.

*NOTE Recirculated air has already been heated, cooled and filtered to the requirements of the cleanroom and its maximum use represents a valuable saving in energy that would otherwise be used in bringing fresh air up to the specified conditions.*

All recirculated air should only be filtered to the extent necessary to achieve the room conditions required, taking note of the fact that it has been air conditioned and filtered previously (see **B.9** for guidance on filter selection for energy reduction).

## B.5 Occupancy levels

Skin particles, including MCPs, and general clothing fibres dispersed from personnel might present the largest contribution to cleanroom contamination and, therefore, occupancy levels should be minimized and taken into account during the calculation of the air supply rate. Occupancy levels should be taken into account at design and stated during annual room validation.

The process design should allow for maximum airflow around the operator and should not permit shoulder-to-shoulder working arrangements. If the decision is made to reduce the numbers by increasing the workload assigned to each operator, the effect of cross contamination as a result of operators moving between workstations should be assessed.

## B.6 Garment requirements

Cleanroom garments for personnel should be selected for the type of product and the specified airborne classification of the cleanroom. In addition, they should also be selected for their effectiveness in lowering the emission of airborne contamination in order to provide an energy saving by enabling the air supply volume for the same standard of air cleanliness to be reduced.

*NOTE 1 Cleanroom garments are available in different designs ranging from a smock to a suit that fully envelopes a person (see BS EN ISO 14644-5:2004, Annex B). In addition, clothing is made from fabrics with different degrees of effectiveness in filtering body emissions.*

*NOTE 2 A compromise has to be made between clothing designed purely for personnel comfort and more occlusive clothing to reduce emissions; the more occlusive the clothing is, the less the air exchange between personnel and the room, which adversely affects personnel comfort.*

To additionally minimize dispersion from personnel, linting or fluffy clothing should not be worn under the cleanroom garments.

Control of contamination from mouth, nose, beards and long hair should be achieved by selecting suitable face masks, beard masks and head-covers for the situation.

A strict shoe changing, storage and wiping policy to control particulate ingress should be defined in the standard operating procedure.

The energy balance between disposable and reusable (laundered) garments should be taken into account.

## B.7 Operator competence

In order to minimize emissions of particles during operations and make airflow reduction possible and therefore save energy, operators should be trained in all aspects of working in a cleanroom, especially in personal hygiene, gowning procedures and the performance of all the required tasks in a controlled and deliberate manner so as to avoid generating airborne contamination (see BS EN ISO 14644-5:2004, Annex C).

## B.8 Air handling units (AHUs)

Where conditioned air is required for a cleanroom, a central AHU should be used as it is the most energy efficient solution. It should be positioned as close to the cleanroom as practical to minimize the length of duct runs and associated energy losses.

*NOTE 1 The use of terminal fan filter units can simplify the zoning of the cleanroom so that certain areas can be shut down to conserve energy while others continue to receive their full airflow volume flow rate. A further advantage is that the air velocity to individual processes can be fine-tuned.*

As the type and nature of the AHU is critical to the energy efficiency of the cleanroom, the AHU should be sized to match the volume of the room it is serving and the room classification required for the process. The components incorporated in the AHU should be configured to reduce resistance, improve efficiencies and reduce contamination distribution. Internal coils and filters should be sized to minimize pressure drops and maximize efficiency.

Fans should be selected based on how they achieve the best balance between energy and air delivery, taking into account fan efficiency, drive efficiency and fan characteristics that deal with increased filter loading.

Fan efficiencies can have a wide range; therefore fans that operate at high efficiency should be selected as a major means of reducing energy usage.

*NOTE 2 The energy (E) used in supplying air to a cleanroom is determined by:*

$$E = \frac{q_v \Delta pt}{\eta_{fan} 1000} \tag{B.3}$$

*where:*

- $E$ is electrical energy, in kilowatts per hour (kW/h);
- $t$ is time, in hours (h);
- $q_v$ is airflow volume flow rate through fan, in cubic metres per hour ($m^3/h$);
- $\Delta p$ is total pressure rise from the fan inlet to the outlet, in pascals (Pa);
- $\eta_{fan}$ is overall efficiency of the fan and motor system, as a factor of 1.

*NOTE 3 As can be seen from equation B.3, E is greatly influenced by the fan efficiency, which can vary from 20% to 80% depending on the design of the fan blades casing, the type of drive from the motor, the type of motor and the fan speed.*

*NOTE 4 Motor classes have recently been changed to take account of improving efficiencies (see BS EN 60034-30). IE3 is the high efficiency motor class, IE2 mid efficiency and IE1 low efficiency. Changing to IE3 motors at the same duty can save up to 4% to 5% energy. The payback time for implementing such an action is short enough to be attractive for implementation.*

*NOTE 5 Direct drive fans with integral motor are the most energy efficient and the latest generation of direct drive fans using EC motors can achieve 80% efficiency.*

Existing fan systems with a motor separate from the fan should either have a belt upgrade or be replaced by a direct drive fan with a high efficiency motor.

*NOTE 6 The belt drive between the motor and the fan can typically consume 10% to 15% of the motor energy before it reaches the fan. Therefore direct drive fans with an integral motor can save this lost energy. The use of low friction belts and toothed belts can minimize energy losses where belts have to be used.*

Speed controllers provide adjustment of the supply airflow volume flow rate and energy efficient types should be used.

All fan motors should be fitted with inverters to give efficient control and future flexibility.

The fan manufacturer should be consulted in order to select a fan that is quiet in operation and has the lowest energy consumption.

Specific fan power is a key parameter in the design of energy efficient fan systems and should always be kept to a minimum that is consistent with the application.

*NOTE 7 Specific fan power is defined as a parameter that quantifies the energy-efficiency of fan air movement systems. It is a measure of the electric power that is needed to drive a fan (or collection of fans), relative to the amount of air that is circulated through the fan(s). It is not constant for a given fan, but changes with both air flow rate and fan pressure rise.*

*NOTE 8 Guidelines on specific power in a range of different applications are given in the Non-Domestic Building Services Guidelines [6].*

*NOTE 9 Useful information on the energy characteristics of AHUs is given in BS EN 13053.*

Power factor correction packs consisting of capacitors or inductors should be added to all electric motors, including those used to drive cleanroom fans in order to achieve maximum energy saving, reduced heat emissions, reduced power transmission losses and lower periodic tariffs from the utility supplier on their periodic system charges

*NOTE 10 The power factor is the ratio between the true and apparent electrical power of an alternating power circuit and varies between 0.6 and 1.0. While a purely resistive load such as a heating element operates at the ultimate power factor of 1.0, the inductive and capacitive loads of electric motors vary dependent on the design of the motor windings and the way they are connected to the electrical circuits.*

## B.9 Selection of air filters

The filtration system in cleanrooms requires the use of high pressure fans, which are major consumers of energy; therefore measures should be taken to minimize the airflow resistance of the filtration system in order to minimize the energy requirement of the fans.

The removal efficiency of final filters in relation to particle size efficiency of the final filter should be no more than is required to give the specified particulate cleanliness level in the cleanroom.

Final filters should be selected with the minimum pressure drop for the required particle removal efficiency; filters with a greater amount of filter media have a lower pressure drop than those with a minimal amount.

*NOTE 1 If the media pack depth of a high efficiency air filter panel is increased from 66 mm to 110 mm, the pressure drop can be reduced by approximately 40% and life increased by 2.5 times.*

The final filters should be protected against too frequent renewal by the use of pre-filters. There should be a robust cleaning or replacement protocol for the pre-filters in the return or recirculated air to ensure that they do not become excessively loaded, causing excessive pressure drops in the system and an increase in particle concentration in the cleanroom.

Energy efficient pre-filters should be chosen with the assistance of an energy classification method, such as given in Eurovent 4/11 [7].

An energy-saving feature that should be examined is the use of a two-stage pre-filter system.

*NOTE 2 For example, if two low energy filters are placed in series, the particulate removal efficiency of an F7 fine filter can increase to an efficiency of an F9. Typical pressure drop reductions from adopting this technique are 40% to 60%. If these filters have a high dust holding capacity then at filter renewal the second stage filter can be refitted into the primary stage position and a new filter fitted in the second stage position.*

A life cycle costing (LCC) model should be used at the design stage to assist in obtaining an informed selection of air filters; such a model is provided by Eurovent [8] and covers filter purchase, energy use and the cost of installation, maintenance and disposal. The model should be applied to reduce costs in both existing and planned facilities.

## B.10 Cooling

The provision of cooling for air conditioning systems, whether by chilled water systems or by direct expansion (DX) systems, is a major part of energy consumption in a cleanroom; therefore the cooling load should be reduced as far as possible and the most efficient cooling plant should be selected.

Cooling is required to both remove heat gains in the cleanroom (sensible cooling) and to control humidity levels (latent cooling), which is the greater cooling duty in a cleanroom; therefore it should be assessed whether or not controlling the humidity level is necessary, if it is not necessary, then a major energy saving can be achieved.

As chilled water cooling plants have become more efficient, existing installations should be upgraded by replacing them with more efficient systems in order to save energy.

For larger installations separate chilled water circuits should be provided for latent cooling and sensible cooling so that latent cooling is minimized by only providing it for those areas that require it and sensible cooling is maximized by using it wherever possible.

*NOTE 1 The sensible cooling chilled water circuit operates at higher flow and return temperatures than the latent cooling chilled water circuit. Dehumidification by latent cooling is typically applied to fresh air systems. The cooling coils have to achieve dew point to condense the moisture out of the air and to do this the chilled water temperatures are low, e.g. 6 °C on to the coil and 12 °C off. Cooling by sensible cooling is typically applied to recirculated air as it has already been conditioned and there is no need to condense any moisture from it so the cooling coils can be run at higher temperatures, e.g. 12 °C on and 16 °C off. The higher the temperature of the cooling coils, the higher the refrigerant condensing and evaporation temperatures and the higher the refrigeration performance efficiency. Thus the overall coefficient of performance (CoP) of the refrigeration equipment can be optimized and energy usage reduced by minimizing latent cooling and maximizing sensible cooling.*

Chilled water flow should be reduced during non-peak cooling requirements by means of chilled water distribution and control systems.

Where air cooled water chillers are installed, they should be fitted with a double heat exchanger configuration to provide free cooling by allowing the refrigerant cooling system to be bypassed when the ambient air temperature is low enough.

*NOTE 2 Heat recovery from condenser water systems can be used for air conditioning system, reheat, space heating or pre-heating domestic water services.*

Where cooling is required for smaller cleanrooms, refrigerant-based DX systems should be assessed as an alternative to water cooled systems for use in new designs or as replacements for small rooms being upgraded because they provide significant energy reductions over the lifetime of the cleanroom.

DX systems utilizing modern variable speed screw compressors with close controls should be used as they provide lower energy usage during low heat load periods while maintaining good controlled conditions.

*NOTE 3 There are four basic components in a DX system: an evaporator, compressor, condenser and thermal expansion control device. The evaporator (located inside the supply air ductwork) absorbs heat through the process of evaporating the refrigerant flowing within it. The refrigerant then flows to a compressor, which compresses it causing it to condense in the condenser and release the heat it removed from the supply air. The condensed liquid refrigerant then flows through the thermal expansion control device, which controls the flow and pressure of the refrigerant back into the evaporator.*

## B.11 Building management system (BMS)

*NOTE The BMS for the cleanroom allows the key data from the operation of the cleanroom facility to be displayed and logged, with actions recorded, for external examination. The BMS is linked to a system of alarms designed to alert the engineers, technicians and control personnel to abnormal situations.*

Where such a system is installed, energy management should be added to the control and alarm criteria. This should include the following:

- energy consumption display showing kilowatt hours and trends for all major components;
- a visual indication of turn down periods, parameter reductions and alarm levels, as agreed with quality control;
- prevention of conflicting energy demands by heating/cooling, humidifying/dehumidifying, for example during turn down;
- pressure monitoring during turn down;
- feedback from online particulate counting, if installed;
- door interlocking or remote locking during turn down periods;
- air speed monitoring at crucial workstations;
- phased motor start up following turn down periods;
- demand control of the lighting system;
- shut down dates and times.

## B.12 Environmental monitoring systems

An environmental monitoring system should be used to collect and record data to demonstrate continued conformity to the designed environmental parameters, especially particle concentrations.

*NOTE 1 It operates independently of the BMS.*

*NOTE 2 The environmental monitoring system can support energy saving initiatives. In a facility where temporary or even permanent changes are made (to the HVAC settings) in order to save energy, suitable environmental sensors can continuously monitor the environment to demonstrate that the facility remains in control, and the environment continues to perform as originally designed.*

## B.13 Lighting levels

The lighting within the cleanroom should be within operator control or governed by the use of demand control devices so that the lights can be turned off when the room is not occupied. The use of local LED lighting should be used for intricate work and allows the background lighting to be reduced. The work station lighting should be optimized to facilitate work and minimize operator fatigue.

## B.14 Heat gains/losses

The cleanroom environment is designed to provide a controlled environment as well as to contain the required process equipment; the relative humidity and temperature control specification should not be controlled within a tighter range than is necessary as this can have a great effect on energy consumption.

*NOTE 1 Controlling relative humidity to levels of less than 50% can lead to high energy consumption.*

In situations where there is no specific requirement for tightly controlled temperature and/or relative humidity conditions, the temperature should not normally be controlled tighter than (20 ±3) °C and relative humidity (RH) should be allowed to float according to ambient conditions within the range 30% to 70% to satisfy operator comfort.

*NOTE 2 Temperature and humidity control is provided to:*

*a) give comfort conditions for the operators working within the cleanroom;*

*b) give dry conditions for hygroscopic products;*

*c) maintain product control over dimensional tolerances;*

*d) minimize the effect of electrostatic build up.*

An energy efficient cleanroom HVAC system should utilize a recirculation air design principle. To minimize the cooling load in the HVAC design, all heat sources (heat gains) that contribute to the cooling load of the HVAC system should be reviewed.

Heat gains into the cleanroom should be treated by a cooling system within the HVAC system serving the cleanroom (see **B.10**) and can come from the following sources:

1) structural heat gains through the cleanroom fabric (floors, partitions and ceilings);
2) solar heat gains through any windows that are directly or indirectly in the external building structure;
3) equipment heat gains from any items located inside the cleanroom;
4) lighting heat gains from the lighting used within the cleanroom;
5) sensible and latent heat gains from the operators working within the cleanroom;
6) fresh air load (see **B.4.4**).

Heat losses from the cleanroom should be treated by a heating system within the HVAC serving the cleanroom and can come from the following sources:

i) structural heat losses through the cleanroom fabric (floors, partitions and ceilings);

ii) extract air;

iii) fresh air load (see **B.4.4)**.

The following elements of a cleanroom design can be a source of opportunity and support for energy savings; the design review should include the following:

- insulation of the cleanroom structure where appropriate;
- eliminate windows that give rise to solar heat gains or, if they cannot be eliminated, they should be treated with a solar reflective film;
- a review of the operating requirements of all items of process equipment that act as a heat source and determine if these items of equipment can be installed, wholly or partially, outside of the cleanroom or contained within a mini or dedicated control zone that provides locally controlled environmental conditions. If items of process equipment are to be located within the cleanroom, they should be correctly installed and vented if appropriate to do so;
- ensure that the background lighting design is appropriate for the activities being carried out and that localized task lighting is used where possible;
- ensure that personnel levels are set at the design stage to be appropriate for the production process and are kept to a minimum in practice;
- ensure that the fresh airflow volume flow rate is kept to a minimum (see **B.4.4**).

## B.15 Turn down

An essential technique that should be assessed for energy saving is to turn down the airflow volume flow rate and allow the range of temperature and RH to widen accordingly when the cleanroom or clean air device is in the "at-rest" or "unoccupied" state. Where possible variable speed fans should be used to control the air velocity and reduce the energy load.

*NOTE 1 Air volume is proportional to the cube of the fan power, i.e. a halving of the air volume reduces the fan power to one eighth.*

All new installations should be capable of having their supply air velocity for UDAF and supply airflow rate for non-UDAF controlled down to an idling level for weekend or overnight use in a non 24 h facility (see **B.4.1** and **B.4.2**).

Motorized dampers should be fitted to the main branches of the ductwork, which in conjunction with the fan motor inverter, facilitates a night turn down during non-operational hours and lower pressure differentials during periods when the facility is not occupied.

*NOTE 2 Under turn down conditions, i.e. unmanned and not in operation, the contamination source strength and heat gains in the controlled space are substantially less than during operational design conditions. Under these circumstances a turn down condition can be estimated at the design stage, and confirmed during commissioning or qualification.*

When setting back performance parameters, a positive cleanroom pressure should be maintained that prevents ingress of contamination from the surrounding area into the cleanroom or clean zone. The appropriate visible notices that the zone is in a turn down situation should be displayed and all personnel, including maintenance and janitorial staff, should be correctly trained with respect to their movement through and around this zone during turn down.

Access and entry points should be closed during turn down to control unauthorized entry that might introduce contamination.

Filter units should not be switched to maximum when the zone is reactivated but allowed to ramp up gradually; this operation should be externally controlled and monitored by computer.

The specified operating conditions should be re-established prior to commencing or recommencing normal operations.

All turn downs should be measured and controlled and, during commissioning, validated. In addition to all the standard tests, including particle counting, airflow visualization might also be found to be useful during the validation process.

## B.16 Turn off

Systems should not be turned off unless a detailed risk assessment has been carried out, agreed by quality control and included in the standard operating procedure; turn off is the simplest method of saving energy.

*NOTE 1 The configuration of the cleanroom has a major impact on what can be turned off: for example turning off a unidirectional airflow clean air device located within a less clean cleanroom, or turning off some of the fan filter modules within a large cleanroom using multiple modules. This could include heating and cooling systems while maintaining the normal or turned down airflow.*

In order to assess whether turn off is acceptable to product quality, the following risks should be taken into account:

a) ingress of airborne contamination due to loss of pressurization in the classified space;

b) depositions of contamination shaken from the clean side of terminal high efficiency air filters;

c) the ability to restore the required cleanliness conditions upon restarting the system within a determined recovery time.

Access and entry points should be sealed during turn off to control unauthorized entry that might introduce contamination.

*NOTE 2 Tests to verify air cleanliness at critical zones can provide the basis for determining the necessary recovery time before recommencing operations.*

## B.17 Use of clean air and containment devices

The use of clean air devices should be incorporated into the facility design to provide a localized clean air environment, reducing the airflow volume flow rate delivered by the HVAC and filtration system, thus reducing the amount of energy required.

*NOTE 1 These devices include unidirectional airflow clean air work stations and enclosures, microbiological safety cabinets, restricted access barrier systems (RABS), isolators, high integrity containment barrier isolators and mini-environments.*

The following aspects of a facility design should be evaluated for energy savings.

- Can any part(s) of the process operations be contained within an independent clean air work station or localized fan filter unit?
- How are components and materials moved between workstations and how are they stored?
- Can the independent clean air device recirculate air back to the cleanroom, rather than exhaust to outside so that its air changes can be added to the cleanroom air changes to give the required cleanliness classification?
- When the facility is not in operation, can the independent clean air device be turned off leaving the HVAC system to maintain the cleanroom background environment at a lower level in a turn down mode?
- Does the reduction of the cleanroom air supply rate, by inclusion of the air supply rate of the independent clean air device, result in reduced control of temperature and relative humidity in the cleanroom?
- Can any part of the process operations be contained within containment barrier isolators?
- Does the extract airflow volume flow rate required by the isolator require a significant increase in the make up air being drawn into the HVAC system to maintain room overpressure and if so check the design?

A risk assessment should be carried out to ensure that the use of independent clean air or containment devices is appropriate for the process and also to identify whether the air cleaning effect can be safely added to the air cleaning of the cleanroom without compromise to the other environmental control conditions.

*NOTE 2 The use of clean air devices that include high efficiency air filters can allow a lowering of the surrounding cleanroom cleanliness classification and thus, potentially, the energy requirement.*

*NOTE 3 Where the clean air device acts as a physical barrier between the operator in the cleanroom background and the product environment within, and access into the clean air device is provided through glove ports, this effectively creates a closely controlled environment required by the product and process on a small scale. This is an energy efficient alternative to having the entire cleanroom to maintain these high levels of environmental control.*

## B.18 Maintenance regimes

Effective maintenance of cleanroom engineering systems should be part of the energy saving programme; the following should be addressed:

a) timely replacement of dirty filters prevents excessive pressure drops that could result in airflow reduction and/or excessive fan power consumption (see **B.9**, Note 2). Filters should be replaced when the operating pressure drop across them reaches two times the initial pressure drop at installation;

b) elimination of excessive leakage from air handling units and distribution ductwork prevents airflow reduction and/or excessive fan power consumption. The leakage limits for these components, including the filter mountings, should be in accordance with BS EN 1886;

   *NOTE 1 This is particularly important for cleanroom air handling systems where frequently quite high static pressures are required to deliver the air through the air distribution and filtration system.*

c) calibration of measurement instruments ensures correct set points and optimal performance;

*NOTE 2 Incorrectly calibrated and tuned control systems can result in excessive energy consumption due to heating and cooling overlap, and sub optimal performance of control loop feedback systems.*

d) regular maintenance of fan drive lines prevents energy loss due to excessive friction and belt slip.

## B.19 Monitoring

### B.19.1 Monitoring of energy saving measures

Monitoring should be carried out to ensure that after modification of an existing installation or after completion of a new installation, the energy saving objectives (as set out in **4.8**) have been met and continue to be met. In the case of an existing installation, pre-modification monitoring should also be carried out in order that a comparison can be made.

*NOTE The objective of this monitoring is to collect data, verify assumptions, check key performance parameters, note the energy usage of key components and review the return on investment.*

The energy usage of the following main components of the facility should be recorded and reviewed at regular intervals to identify energy usage trends against predicted performance:

a) individual fans;

b) chillers;

c) heating/cooling;

d) pumps;

e) lighting;

f) humidifiers.

Each of these major components within the air delivery system should have its own individual energy meter to allow ongoing monitoring for each component.

### B.19.2 Monitoring of environmental performance

Before operations commence, and at regular intervals thereafter, the environmental performance of each cleanroom in the facility should be measured and recorded, utilizing calibrated test equipment. This should be part of a normal routine in every cleanroom but is particularly important when energy saving measures have been implemented to ensure that they have not had an adverse effect on the environmental conditions required by the process. The results should always be recorded for future reference and benchmarking. The measuring and recording should be done on the following test parameters:

a) particle counts and, where applicable, colony forming units (CFUs) in the as built, at rest and operational cleanroom;

b) room air supply rates;

c) pressure differentials;

d) room recovery rates;

e) temperature, humidity and their stability.

All sensors within the air delivery system should be calibrated in situ to verify accuracy of outputs.

The modification of temperature or humidity set points and operational times should be carried out by the cleanroom manager; controlled access should be provided for this to prevent unauthorized adjustment.

## B.20 Energy supply

*NOTE 1 The utilities that provide electrical power, heating and cooling all have an important and significant impact on the energy consumption of a cleanroom. While these utilities do not have a direct impact on the control of cleanliness or temperature and relative humidity conditions, they provide the energy source that enables the air handling systems to work effectively.*

On larger sites, one of the available decentralized energy generation technologies should be evaluated and utilized.

Where standby electrical generation is required for a facility, one of the decentralized energy generation technologies should be evaluated as a replacement so that the decentralized energy generation is always active and the grid becomes the standby provider.

*NOTE 2 Available decentralized energy generation technologies include:*

*a) combined heat and power (CHP):*

*b) solar photovoltaics: power;*

*c) wind: power;*

*d) solar thermal: heat;*

*e) heat pumps: heat;*

*f) biomass boilers: heat.*

*NOTE 3 CHP utilizes a primary fossil energy source, such as oil or gas, to generate electrical power directly. Waste heat from the power generation system is utilized to provide the energy for heating. Cooling can also be provided at the same time via absorption chilling equipment. This is then called tri-generation. The principal advantage of this technique, from an energy perspective, is that many of the losses associated with grid power generation are obviated. This technique can also be advantageous where a plant requires a degree of autonomy and resilience against grid power failure. This might be seen to be an advantage in an environment where electrical supplies are discontinuous or becoming fragile.*

*NOTE 4 Currently, some of the decentralized energy generation technologies (see Note 2) are classed as low and zero carbon (LZC) technology options, which are incentivized by the UK Government [1].*

---

[1] See www.ofgem.gov.uk for FIT (feed in tariff) and RHI (renewable heat initiatives) [viewed 07.03.2013].

# Bibliography

## Standards publications

For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS EN 779:2012, *Particulate air filters for general ventilation – Determination of the filtration performance*

BS EN 1822 (all parts), *High efficiency air filters (EPA, HEPA and ULPA)*

BS EN 13053, *Ventilation for buildings – Air handling units – Rating and performance for units, components and sections*

BS EN 60034-30, *Rotating electrical machines – Part 30: Efficiency classes of single-speed, three-phase, cage-induction motors (IE-code)*

BS EN ISO 14644-1, *Cleanrooms and associated controlled environments – Part 1: Classification of air cleanliness*

BS EN ISO 14644-3, *Cleanrooms and associated controlled environments – Part 3: Test methods*

BS EN ISO 14644-7:2004*, Cleanrooms and associated environments – Part 7: Separative devices (clean air hoods, gloveboxes, isolators and mini-environments)*

BS EN ISO 14644-8, *Cleanrooms and associated environments – Part 8: Classification of airborne molecular contamination*

PD 6609, *Environmental cleanliness in enclosed spaces – Guide to in situ high efficiency filter leak testing*

## Other publications

[1] EUROPEAN COMMUNITIES. 2010/31/EU. Council Directive 2012/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings. Luxembourg: Office for Official Publications of the European Communities, 2010.

[2] GREAT BRITAIN. The Energy Act 2011. London: The Stationary Office.

[3] GREAT BRITAIN. The Building Regulations 2010. London: The Stationary Office.

[4] CARR, P.E., RAPA, A.C., FOSNIGHT, W.J., BASEMAN, R.J., and COOPER, D.W. *Measured effects of reduced flow velocity in a laminar flow cleanroom*. Journal of Institute Environmental Science, May/June 1994: 41-46.

[5] WHYTE W. *Sterility assurance and models for assessing airborne bacterial contamination*. Journal of Pharmaceutical Science and Technology, 1986, 40(5): 188-197.

[6] DEPARTMENT FOR COMMUNITIES AND LOCAL GOVERNMENT. *Non-domestic building services compliance guide*. London: National Building Specification (NBS), part of RIBA Enterprises Ltd. ISBN: 978 1 85946 376 5.

[7] EUROVENT. *Energy efficiency classification of air filters for general ventilation purposes*. Eurovent 4/11. Paris, 2011.

[8] EUROVENT. *Recommendation concerning calculating of life cycle cost for air filters*. Paris, 2005.

## Further reading

BS EN 15053, *Ventilation for buildings – Air handling units – Rating and performance for units, components and sections*

BS EN 13779, *Ventilation for non-residential buildings – Performance requirements for ventilation and room-conditioning systems*

*This page deliberately left blank*

# British Standards Institution (BSI)

BSI is the national body responsible for preparing British Standards and other standards-related publications, information and services.

BSI is incorporated by Royal Charter. British Standards and other standardization products are published by BSI Standards Limited.

## About us

We bring together business, industry, government, consumers, innovators and others to shape their combined experience and expertise into standards -based solutions.

The knowledge embodied in our standards has been carefully assembled in a dependable format and refined through our open consultation process. Organizations of all sizes and across all sectors choose standards to help them achieve their goals.

## Information on standards

We can provide you with the knowledge that your organization needs to succeed. Find out more about British Standards by visiting our website at bsigroup.com/standards or contacting our Customer Services team or Knowledge Centre.

## Buying standards

You can buy and download PDF versions of BSI publications, including British and adopted European and international standards, through our website at bsigroup.com/shop, where hard copies can also be purchased.

If you need international and foreign standards from other Standards Development Organizations, hard copies can be ordered from our Customer Services team.

## Subscriptions

Our range of subscription services are designed to make using standards easier for you. For further information on our subscription products go to bsigroup.com/subscriptions.

With **British Standards Online (BSOL)** you'll have instant access to over 55,000 British and adopted European and international standards from your desktop. It's available 24/7 and is refreshed daily so you'll always be up to date.

You can keep in touch with standards developments and receive substantial discounts on the purchase price of standards, both in single copy and subscription format, by becoming a **BSI Subscribing Member**.

**PLUS** is an updating service exclusive to BSI Subscribing Members. You will automatically receive the latest hard copy of your standards when they're revised or replaced.

To find out more about becoming a BSI Subscribing Member and the benefits of membership, please visit bsigroup.com/shop.

With a **Multi-User Network Licence (MUNL)** you are able to host standards publications on your intranet. Licences can cover as few or as many users as you wish. With updates supplied as soon as they're available, you can be sure your documentation is current. For further information, email bsmusales@bsigroup.com.

## Revisions

Our British Standards and other publications are updated by amendment or revision.

We continually improve the quality of our products and services to benefit your business. If you find an inaccuracy or ambiguity within a British Standard or other BSI publication please inform the Knowledge Centre.

## Copyright



## Useful Contacts:

**Customer Services**
**Tel:** +44 845 086 9001
**Email (orders):** orders@bsigroup.com
**Email (enquiries):** cservices@bsigroup.com

**Subscriptions**
**Tel:** +44 845 086 9001
**Email:** subscriptions@bsigroup.com

**Knowledge Centre**
**Tel:** +44 20 8996 7004
**Email:** knowledgecentre@bsigroup.com

**Copyright & Licensing**
**Tel:** +44 20 8996 7070
**Email:** copyright@bsigroup.com

**BSI Group Headquarters**

389 Chiswick High Road London W4 4AL UK

bsi.

...making excellence a habit.™