

CLEANROOM CONTROL SYSTEM AND METHOD

TECHNICAL FIELD OF THE INVENTION

5 This invention relates to a cleanroom control system and method. In particular, this invention relates to a cleanroom control system which maintains the strict air cleanliness requirements of cleanrooms, whilst optimising energy performance of the equipment necessary for operations, which primarily includes the cleanroom's heating, ventilation and air conditioning (HVAC) system.

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BACKGROUND

A cleanroom is an environment, typically used in manufacturing or scientific research, that has a low level of environmental pollutants such as dust, airborne microbes, aerosol particles and chemical vapours for critical environment applications and research. More specifically, a cleanroom has a controlled level of contamination that is specified by the number of particles per cubic metre at a specified particle size. To put this in some perspective, the ambient outside air in a typical urban environment contains 35,000,000 particles per cubic metre having a particle diameter greater than 0.5 μ m. This would be classified as an International Standards Organization (ISO) 14644-1 Class 9 cleanroom.

15 For the most critical environment applications, an ISO Class 1 cleanroom is defined as allowing not more than 10 particles of 0.1 μ m diameter and greater per cubic metre.

The majority of cleanrooms that have been designed since the 1950s are based on a fixed air volume system that are generally over-designed to supply more air than is required to meet the relevant classification and cover the risk of not maintaining the classification due to lack of continuous information. Whilst cleanroom clothing and standard operating procedures have improved greatly since the inception of cleanrooms, comparable advances in control systems have hitherto not been made.

25 This results in much higher energy costs than is actually needed for operating the cleanroom. There is a strong commercial need for a control system which maintains the strict air cleanliness requirements of the cleanroom, whilst optimising the energy performance of the cleanroom's HVAC system. Any such control system which addresses this problem serves two major purposes: firstly, helping to reduce the energy

costs of the cleanroom, and secondly helping companies adopt a more sustainable stance boosting their public image.

5 Energy efficiency activities are rare in cleanrooms, however they present a very real opportunity in terms of energy savings. The energy requirements of cleanrooms are immense: in some cases, up to 80% of the energy consumed is required by the HVAC system to control temperature and humidity as well as to filter out particles and maintain pressure control. The integrity of the cleanroom environment is also dependent upon maintaining a positive or negative pressure, created by the HVAC system.

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Until recently, energy efficiency has been of little concern to cleanroom operations as energy prices were low. As Good Manufacturing Practice (GMP) compliance is of the utmost importance in the manufacture of food and pharmaceutical products, for example, most companies in these sectors had been willing to accept whatever energy is required to maintain the HVAC system performance and ensure resulting compliance. This has made it hitherto difficult for cleanroom operators to reduce energy costs in HVAC systems.

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It is estimated that high technology manufacturers in the UK alone spend £200 million on energy for their cleanroom operations and very few pharmaceutical cleanroom operations have any mitigation in place to reduce HVAC energy consumption. However, with rising energy prices, and a desire for more sustainable products, plant operators are very keen on finding ways to reduce energy consumption without sacrificing plant performance.

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Several strategies have already been proposed for the control of HVAC cleanroom systems. Existing control systems are frequently independent of each other and are dedicated to subsystems or groups of subsystems for example: ventilation, heating and cooling, humidification and pressurisation.

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One of the HVAC control systems available in the art is described in US 2013/0324026 A1. US 2013/0324026 A1 provides a cleanroom control system and method that reduces the energy consumed by the air handling system of the cleanroom at times when the cleanroom was not in use. It also provides a cleanroom control system and method that

enables the air handling system of the cleanroom to return to an operation state (where the air handling system operates at full capacity) from a low or reduced state upon demand or at predetermined times.

- 5 There are still problems with known control systems of this type. They do not provide the aforementioned control and flexibility to maintain cleanroom integrity and significantly reduce energy costs.

10 It is an object of the present invention to provide a cleanroom control system and its method of use which overcomes or reduces the drawbacks associated with known products of this type. The present invention provides cleanroom control system that can be used with, or retrofitted to, a HVAC cleanroom system, which can save 50% or more of a cleanroom's energy costs whilst maintaining the desired air quality levels. It is an object of the present invention to provide a control system that integrates all of the
15 cleanroom's operations, including ventilation, heating, cooling, room pressure, filtration and occupancy. Complex algorithms have been developed to take into account cleanroom usage, demand and user activities and/or energy prices. The present invention being able to self-adapt to maintain the area or zone of the cleanroom in the required condition in the most energy efficient and cost effective manner. It is a further object of
20 the present invention to provide a cleanroom control system that will continuously capture, and act upon, data from airborne particle counters, temperature/humidity sensors, differential pressure sensors, occupancy sensors, room pressure sensors, airborne molecular contamination (AMC) sensors, particle deposition sensors and microbiological sensors. Use of the present invention enabling communication,
25 integration and/or interoperability with other third party products, including existing building management systems (BMS). The present invention using open standards and application programming interfaces (API) for communication. By using model predictive control, variables such as occupancy, energy costs, past monitoring and usage data can be utilised to create usage patterns and forecasts for predictive control. This is key to
30 accelerate the system response time and guarantee air cleanliness and quality. Use of the present invention provides a flexible, modular and scalable system which can be suitable for retrofit and stand-alone installations. The control system being flexible enough to be expanded upon or altered as the cleanroom environment changes.

SUMMARY OF THE INVENTION

The present invention is described herein and in the claims.

According to the present invention there is provided a control system for controlling air
5 volume to maintain a desired concentration of airborne contamination in a cleanroom
supplied by a HVAC system being operative to supply treated air to the cleanroom,
comprising:

- sensing means for sensing a concentration of non-viable particles and/or viable
particles in real time or near real time; and
- 10 processing means for comparing the sensed concentration of non-viable particles
and/or viable particles against the desired concentration of airborne contamination and
outputting at least one control signal to the HVAC system based on the comparison.

An advantage of the present invention is that it can be used to maintain the cleanroom in
15 the required condition in the most energy efficient and cost effective manner both in-
operation and at rest. The control system can vary the control parameters based on a
proportion of the desired classification, as determined by a level of acceptable risk.

Preferably, the cleanroom further comprises one or more zones or rooms, each of the
20 zones or rooms having a respective desired concentration of airborne contamination.

Further preferably, the desired concentration of airborne contamination is specified by
the number of non-viable particles per cubic meter having a particle size of equal to or
greater than 0.1 μ m, 0.2 μ m, 0.3 μ m, 0.5 μ m, 1 μ m and 5 μ m in diameter.

25 In use, the cleanroom can be classified by particle size concentration as defined in ISO
14644-1 or any other classification standard related to particle size concentration as
determined by the cleanroom user.

30 Further preferably, the control system will detect movement and automatically change
from an “at rest” to an “in-operation” classification or mode of operation automatically.

Preferably, the HVAC system comprises at least one HVAC air handling unit (AHU)
supplying treated air through a ducting system, and one or more constant air volume

devices and/or one or more variable air volume devices positioned in the ducting and generally associated with each respective zone or room of the cleanroom.

Further preferably, the air treatment is selected from the group consisting, but not limited to, any one of the following: filtration, ventilation, heating, cooling, humidification, pressurisation, occupancy, and combinations thereof.

In use, the sensing means may comprise one or more ISO 14644-1 calibrated laser particle counters and/or viable particulate air monitoring sensors positioned in the cleanroom or the ducting of the HVAC system.

Preferably, the control system further comprising one or more secondary sensing means for sensing an environmental condition and/or process condition and/or HVAC system condition in real time or near real time.

Further preferably, the secondary sensing means further comprises one or more sensors selected from the group consisting, but not limited to, any one of the following: temperature sensor, humidity sensor, pressure sensor, differential pressure sensor, airborne molecular contamination sensor, contaminant deposition sensor, air flow sensor, proximity sensor, and combinations thereof.

In use, the processing means may receive energy price data and/or usage data.

Preferably, the processing means receiving the sensed environmental condition and/or process condition and/or HVAC system condition and/or energy price data and/or usage data and outputting one or more secondary control signals to the HVAC system.

Further preferably, the one or more secondary control signals are outputted without causing the sensed concentration of particles to depart from the desired concentration of airborne contamination.

In use, the desired concentration of airborne contamination and/or energy price data and/or usage data may be initially user configurable.

Preferably, the at least one control signal to the HVAC system controlling the air volume supplied to the cleanroom.

Further preferably, the one or more secondary control signals controlling the filtration,
5 ventilation, heating, cooling, humidification, pressurisation, occupancy, and combinations thereof supplied to the cleanroom.

Preferably, indication will be provided within the cleanroom through a visual indication system to indicate status. A graphical user interface may also be provided.

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In use, the processing means may comprise a model predictive control (MPC) algorithm.

Preferably, the model predictive control algorithm being able to self-adapt.

15 Further preferably, the control system further comprising:

a model component that receives a HVAC system operating condition from extrinsic data analysis and which models HVAC system behaviour; and

means for receiving the modelled HVAC system behaviour and issuing a control action based on the modelled HVAC system behaviour and a cost minimizing function
20 and constraints.

Preferably, the control system is implemented in a programmable logic controller (PLC).

Further preferably, the control system further comprising display means.

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In use, the control system may further comprise means for enabling communication and/or integration and/or interoperability with third party building management systems (BMSs).

30 Preferably, the control system further comprising monitoring the energy performance of the cleanroom and/or performance to the particle contamination concentration within the cleanroom.

Also according to the present invention there is provided a method of controlling air volume to maintain a desired concentration of airborne contamination in a cleanroom supplied by a HVAC system being operative to supply treated air to the cleanroom, comprising the steps of:

- 5 sensing a concentration of non-viable particles and/or viable particles in real time or near real time;
- comparing the sensed concentration of non-viable particles and/or viable particles against the desired concentration of airborne contamination; and
- outputting at least one control signal to the HVAC system based on the
- 10 comparison.

Further according to the present invention there is provided a computer program product for controlling air volume to maintain a desired concentration of airborne contamination in a cleanroom supplied by a HVAC system being operative to supply treated air to the

15 cleanroom, comprising:

- computer program means for sensing a concentration of non-viable particles and/or viable particles in real time or near real time;
- computer program means for comparing the sensed concentration of non-viable particles and/or viable particles against the desired concentration of airborne
- 20 contamination; and
- computer program means for outputting at least one control signal to the HVAC system based on the comparison.

It is believed that a cleanroom control system and its method of use in accordance with

25 the present invention at least addresses the problems outlined above.

It will be obvious to those skilled in the art that variations of the present invention are possible and it is intended that the present invention may be used other than as specifically described herein.

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BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be described by way of example only, and with reference to the accompanying drawings, in which:

Figure 1 is a schematic illustration of a typical cleanroom in which the control system of the present invention is used to monitor and maintain the air cleanliness and other controlled variables including temperature, humidity, occupancy, pressure etc.;

- 5 Figure 2 shows a schematic illustration of how the control system of the present invention can be utilised to maintain the required air cleanliness of a cleanroom;

Figure 3 is a high level flow diagram showing the multivariable inputs and outputs of the control system of the present invention;

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Figure 4 illustrates a block diagram of a model predictive controller (MPC) for a cleanroom HVAC system of the present invention;

- 15 Figure 5 shows a flow diagram illustrating how the system model for the MPC controller of the present invention is obtained;

Figure 6 is a schematic illustration of a typical cleanroom supplied by two separate HVAC air handling units and controlled by the MPC controller of the present invention;

- 20 Figures 7 and 8 show comparative data obtained from the cleanroom of Figure 6 and shows particle concentrations measured in various zones of the cleanroom to the experimental test defined in Table 1, the test data showing the response of a known BMS control system which is based on a Proportional-Integral (PI) control algorithm;

- 25 Figure 9 shows the dynamic response of the cleanroom control system of the present invention in response to the same experimental test of Figures 7 and 8, based on a first optimal setting value;

- 30 Figure 10 shows the dynamic response of the cleanroom control system of the present invention in response to the same experimental test of Figure 7 and 8, based on a second optimal setting value; and

Figure 11 shows the power consumed by a known BMS system at various air change rates obtained from the cleanroom of Figure 6 as well as comparative dynamic power

measurements obtained by the cleanroom control system of the present invention and shows that model predictive control significantly reduces the power consumption of the cleanroom HVAC system.

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DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention has adopted the approach of utilising a cleanroom control system that can be used with, or retrofitted to, a HVAC cleanroom system, which can save 50% or more of a cleanroom's energy costs whilst maintaining the desired air quality levels. Advantageously, the present invention provides a control system that integrates all of the
10 cleanroom's operations, including ventilation, heating, cooling, room pressure, filtration and occupancy. Complex algorithms have been developed to take into account cleanroom usage, demand and user activities and/or energy prices. The present invention being able to self-adapt to maintain the area or zone of the cleanroom in the required condition in the most energy efficient and cost effective manner. Further advantageously,
15 the present invention provides a cleanroom control system that will continuously capture, and act upon, data from airborne particle counters, temperature/humidity sensors, differential pressure sensors, occupancy sensors, room pressure sensors, airborne molecular contamination (AMC) sensors, particle deposition sensors and microbiological sensors. Use of the present invention enabling communication, integration and/or
20 interoperability with other third party products, including existing building management systems (BMS). The present invention using open standards and application programming interfaces (API) for communication. Further advantageously, by using predictive control, variables such as occupancy, energy costs, past monitoring and usage data can be utilised to create usage patterns and forecasts for predictive control. This is
25 key to accelerate the system response time and guarantee air cleanliness and quality. Further advantageously, use of the present invention provides a flexible, modular and scalable system which can be suitable for retrofit and stand-alone installation. The control system being flexible enough to be expanded upon or altered as the cleanroom environment changes.

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Referring now to the drawings, Figure 1 is illustrative of a typical cleanroom 100 for which the control system 10 of the present invention can be utilised to maintain the required air cleanliness. The cleanroom 100 shown in Figure 1 is for illustrative purposes

only and the control system 10 of the present invention can be used to control multiple zones or rooms in multiple configurations according to the requirements of the facility.

As can be seen a typical cleanroom 100 comprises a number of zones or rooms usually of varying cleanliness ISO classifications, or other as required. The cleanroom 100 in the example of Figure 1 has its highest rated zone or room, in this case zone 108, which is an ISO Class 5 cleanroom at the furthest point from the main door entry 110. It is adjoined to a “dirtier” less clean cleanliness classification room or zone 104, which in this example is an ISO Class 7 cleanroom, via a gown/ungown room 106. Entry to room 104 being made through airlock entry 102.

The skilled person will appreciate that the ISO Class 5 cleanroom is kept at a higher air pressure (known as a “pressure cascade”) to prevent contaminants from, say, the adjacent ISO Class 7 cleanroom 104 entering through the gown/ungown room 106. This pressure differential is maintained by the supply of filtered and conditioned air, which flows through the inflows 112. Exfiltration/exhaust air is taken from outflows 114. The inflows 112 and outflows 114 are controlled by the HVAC cleanroom control system 10, as described in more detail below.

Figure 2 shows how a HVAC cleanroom system can be controlled utilising the control unit or system 10 of the present invention. In order to aid clarification, only a single central HVAC air handling unit (AHU) 12 is depicted, although the skilled person will appreciate that any number of such HVAC air handling units 12 can be controlled by the control unit 10 according to the size, capacity and/or cleanliness requirements of the cleanroom 100.

As shown in Figure 2, fresh air is drawn through the inlet 14 of the air handling unit 12. This is controlled by a series of baffles 16. The incoming air can be mixed with the air returning from the cleanroom 100 generally in the mixing area 18 behind the baffles 16. If needed, returning air from the cleanroom 100 can be directly vented outside of the air handling unit 12 via discharge outlet 20.

The air is then filtered, firstly through a pre-filter 22a and a secondary filter 22b before passing through a series of heating and cooling elements 24, 26 being drawn by the main

air blower 28. The output of the main air blower 28 passes through the main high-efficiency particulate air (HEPA) filter element 30 before being transferred through ducting 32 to a series of proprietary constant air volume (CAV) devices 36. It is necessary to regulate the pressure variations in the air duct system 36 in order to achieve
5 the desired airflow in the room or zones 102, 104, 106, 108. The outflow of the air into the room or zones 102, 104, 106, 108 is through distribution grilles 38.

The air to be recirculated is drawn through grilles 40 and the control unit 10 modulates a plurality of variable air volume (VAV) devices 42 before returning the exhaust air
10 through ducting 44 and return or check valve 46.

The control unit 10 of the present invention is used to monitor and control each and every operation of the HVAC cleanroom system. As shown in Figure 2, the control unit 10, which is typically implemented as microcontroller, receives a number of sensor
15 inputs 48 indicated generally at the left hand side of the control unit 10. The microcontroller 100 can be considered a self-contained system with a processor, memory and peripherals and can be used to control all of the cleanroom's 100 operations, including ventilation, heating, cooling, filtration via a number of outputs indicated generally at the right hand side of the control unit 10.

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For reasons of clarity in Figure 2, the skilled person will appreciate that there are a significant number of sensors and transducers which are inputted to the control unit 10. These have been shown schematically as sensor inputs 48 in Figure 2. This drawing is a schematic diagram and, in order to aid clarification, many other circuit elements are not
25 shown. For example, although not shown in Figure 2, the analogue signal received from any one or more of the sensors is first converted to a digital form by any suitable type of analogue-to-digital convertor (ADC) available in the art. Equally, one or more of the digital outputs of the microprocessor 100 can be converted to analogue form using any form of digital-to-analogue convertor (DAC) available in the art. For example, such an
30 analogue output signal could be used to energise the heating element 24. In operation, a set of instructions or algorithm written in software in the microcontroller is configured to program the control unit 10. The control unit 10 processes the input signals using complex algorithms to provide control outputs to multiple HVAC devices, including the central HVAC air handling unit 12, constant air volume devices 36 and variable air

volume 42 devices to maintain a supply of filtered and conditioned air within the cleanroom 100, whilst taking into account cleanroom classification, usage and occupancy, and other activities within the cleanroom 100 environment.

- 5 The control unit 10 provides predictive sensor-based dynamic control of the HVAC cleanroom system to maintain the required air cleanliness while maximising energy efficiency. The unit 10 is a modular, retrofit control solution, easily expanded as the cleanroom 100 environment changes. It is able to communicate with third-party products for complete integration with, for example, a building energy management system.
- 10 Bespoke control algorithms have been developed based on real-world cleanroom applications in the applicant's own HVAC cleanroom test facility.

The present invention at its core intelligently handles particulate levels in the cleanroom 100 by monitoring viable and/or non-viable particles of varying sizes. The control
15 system 10 controls air volume to maintain below a desired concentration of both viable (particles containing living micro-organisms) and non-viable (particles that do not contain living micro-organisms but acts as transportation for viable particles) particles using real time or near real time viable and non-viable particle counters, and other sensors and transducers inputted to the control system. The control system 10 being able
20 to vary the control signal outputted to the HVAC cleanroom system as a percentage under the desired class limit as a variable set point or weighting. The control system 10 will also detect occupancy within the cleanroom 100 environment to determine the particulate limit being controlled between an "at rest" or "in-operation" mode of operation and bring the system out of the "at rest" state to aid speed of response, as
25 required.

Figure 3 shows systematically how the control steps of the unit 10 are followed using the logic flow shown in Figure 3. In the following description each step of Figure 3 will be referred to as "S" followed by a step number, e.g. S52, S54 etc.

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Figure 3 also shows that the control unit 10 can be implemented as part of, or integrated within, a building management system 50 which is computer-based control system installed in buildings that controls and monitors the building's mechanical and electrical

equipment such as ventilation, lighting, power systems, fire systems, and security systems.

In its broadest sense the control system 10 of the present invention will monitor, process
5 and control all variables, including particulate sensors, on a continuous real time basis to ensure the HVAC equipment responds to demands, occupancy and changes within the cleanroom 100 environment and other associated areas served by the HVAC cleanroom system. The control system 10 will either control the air volume as a secondary function to maintain a correct air temperature and/or humidity directly or send and receive data to
10 the existing BMS system 50, as required.

The sensor and control arrangement of the present invention is such that it provides a level of redundancy to ensure fail safe operation of HVAC equipment in the event of sensor failure or control system failure. In use, the sensor arrangement continuously
15 captures data from the cleanroom 100 environment (including particulate count, temperature, humidity, occupancy, pressure) and sends that data in real time to the control unit 10 for processing. These “fail safe” modes of operation will ensure that the control unit 10 maximises the risk to the product in the cleanroom 100.

In a preferred embodiment, the control system 10 will be installed with a control panel (not shown) local to the cleanroom 100. There will be an option for a touchscreen graphical user interface on the control panel. The external devices, such as the various sensors, CAVs 36, VAVs 42 and AHUs 12 will be hardwired directly to the control system 10, although the system 10 will be able to control existing HVAC equipment via
25 an Open Platform Communications (OPC) server in an existing BMS system 50. In addition, one or more of the various sensor inputs 48 which are remote to the control unit 10 can be inputted via wireless communication protocols, such as, for example, Wi-Fi (IEEE 802.11 standard), Bluetooth or a cellular telecommunications network would also be appropriate.

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The BMS 50 or control panel of the control unit 10 can be used to set the reference inputs for the rooms or zones of the cleanroom 100. These will include the temperature and humidity and the desired cleanroom classification for the various zones. The cleanroom classifications for particulates are defined in ISO 14644-1, or equivalent, but

the skilled person will understand that all classifications will be selectable or programmable in the software. The amount of air supplied to meet the cleanroom classification within a desired level of margin or comfort is also a selectable parameter, and will need to be a risk-based decision by each particular cleanroom facility operator.

In addition to the particulate contamination level or class, the pressure cascade within the cleanroom 100 needs to be maintained to achieve the desired cascade based on the room classifications and adjacent rooms. This will be a selectable and controllable parameter as part of the control system 10.

Once the various input variables have been initially set, the cleanroom control system 10 will continuously capture, and act upon, data from airborne counters, temperature/humidity sensors etc. and be able to self-adapt to maintain the area or zone of the cleanroom 100 in the required condition in the most energy efficient and cost effective manner.

At S52, the primary sensor input inputted to the control system 10 to maintain the area or zone of the cleanroom 100 in the required condition or class is the real time continuous monitoring of non-viable particles detected in the various rooms or zones of the cleanroom 100 or the extraction ducting 44. The particles that will primarily be the control measure will be non-viable, in the size range of 0.1 μm , 0.2 μm , 0.3 μm , 0.5 μm , 1 μm and 5 μm diameter, but any particle size measurable by a particle counter could be selected as the primary control measure. Non-viable particles in the size range of 0.5 μm and 5 μm are the preferred particulates used for pharmaceutical cleanrooms 100.

The control system 10 will also be able to monitor viable particulates using one or more viable particulate counting devices. The non-viable and viable particle counters are positioned in the room space or within the extraction ductwork 44 serving the controlled zone in the cleanroom 100.

The predictive control algorithm will follow the required particle counting methodology defined by ISO 14644, but will also be configurable to other standards and requirements. The measuring device will be a calibrated instrument, as defined in ISO 14644.

Non-viable particles are inert particles of varying sizes. Particle sizes for classifying cleanrooms are 0.1 μm , 0.2 μm , 0.3 μm , 0.5 μm , 1 μm to 5 μm . The measurement of these non-viable particles in the size range 0.5 μm to 5 μm will be the primary control measure
5 of the control system 10. Other particle sizes can be selectable should they be required.

Viable particles are those that could carry pathogens and bacteria. The control system 10 is capable of controlling the ventilation rates to viable counts utilising appropriate viable particle counting equipment. This will be the secondary control function or measure for
10 the control of the cleanroom 100.

The control system 100 will also need to be capable of controlling the air volume as a secondary function to maintain a correct air temperature and/or humidity. This could be measured via a connected temperature/humidity sensor, but could also be via the remote
15 BMS 50. As mentioned, temperature and humidity are a secondary control function either measured via connected sensors or via the external BMS 50 input.

At S52, the AHU 12 also can be monitored with equipment sensors measuring pressure, temperature, humidity, power, filter pressure etc. and which are all measured as
20 secondary input parameters but that are still part of the control unit sensor input. Each of these variables forming a part of the multivariable control system.

At S54, the various input sensors are continuously interrogated to ensure that the rooms or zone of the cleanroom 100 are within the bounds initially set by operator or as
25 modified by the predictive control algorithm. As mentioned, the system 10 will be capable of controlling directly or interfacing with the BMS 50 for the following additional parameters: fan static pressure control, temperature and/or humidity.

In addition, pressure cascade between areas or zones of differing classification are a key
30 requirement for cleanrooms 100. The control system 10 will maintain a pressure set point for each room or zone being controlled to either absolute pressure or differential pressure to the adjacent rooms. The pressure control, at S58, will be achieved with suitable proprietary pressure sensors and mechanical dampers capable of acting and stabilising quickly.

What is key to the present invention that provides advances over other continuously based sensor control of cleanrooms is that integrates all cleanroom 100 operations (ventilation, heating, cooling, filtration, pressure) in a complex control algorithm or multiple control algorithms that takes into account cleanroom usage, occupancy and/or user activities. The number and complexity of the variables to monitor and control, and their constant evolution, means that the algorithm must self-adapt to keep the area in the required condition in the most energy efficient and cost effective manner.

10 The output response of the control system 10 is determined by the predictive control algorithm at S56. The algorithm is automatically and continuously adaptive and self-learning in that it will process and analyse to make a predictive control action based on past environment conditions and equipment operation, in order to approach optimum cleanliness conditions and equipment performance according to the criteria defined by the facility operator.

The control algorithms embedded in the control unit 10 utilises a model predictive control (MPC) algorithm to maximise the control of the inputs and outputs. As mentioned, the control system 10 receives the data from the particle counters, pressure sensors, temperature sensors and/or any external BMS signals. It is envisaged that energy prices and the data collected can also be used to create usage patterns and forecasts for predictive control. The MPC algorithm will process all parameters to provide the optimal control output whilst optimising energy performance of the equipment necessary for HVAC operations.

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At S58, the air volume will be controlled utilising proprietary CAV devices 36 and VAV devices 42 readily available in the marketplace with the required capabilities. The central HVAC air handling unit 12 can also be controlled directly from the control system 10 if required to optimise the system energy consumption and control.

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The control system 10 can modulate the CAV 36, VAV 42 and AHU 12 to achieve the optimal air volumes and minimise energy consumption and will maintain the desired margin to the cleanroom 100 classification. The controller outputs at S58 alter the

conditions in the cleanroom 100 and these are again continually monitored at S60, as described above.

The skilled person will appreciate that the control system 10 can also provide out of
5 condition alarming and reporting. This can be via traffic light signals within the cleanroom 100, or local to control panel, e-mail, cellular messaging or via a remote web dashboard.

Offsite monitoring and alarming will also be available to allow the system 10 be
10 monitored remotely. The cleanroom 100 and its energy performance can be monitored by the use of the applicant's GSM-based remote energy monitoring systems under the trade mark MEMUTM. These remote monitoring units feed information back to a dashboard and can include monitored variables such as temperature, airflow velocities, fan speeds, energy drawn, filter pressures etc. Predictive and planned maintenance and alarm
15 conditions can all be set and accessed on the dashboard by the plant operator.

The software embedded in the control system 10 of the present invention is capable of being CRF11 Part 2 compliant. The system will be supplied complete and with a standard validation protocol to ensure that.

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As mentioned, the control algorithms embedded in the control unit 10 utilise a model predictive control (MPC) algorithm to exploit the control of the inputs and outputs. Figure 4 shows a block diagram of an illustrative model predictive controller (MPC) 10 for a cleanroom HVAC system. In essence, model predictive control is a multivariable
25 control algorithm that uses a dynamic model 62 to predict future process outputs, based on the past and current values and on proposed optimal future control actions. These actions are calculated by an optimizer 64 that takes into account a cost minimizing function 66 as well as various constraints 68.

30 As shown in Figure 4, the main values the MPC controller 10 uses are sensors 70 and drivers 71. In the illustrative embodiment of Figure 4, the MPC controller 10 controlling a cleanroom 100 HVAC system receives the sensed 70 airflow rate, air pressure, concentration of non-viable and viable particles, temperature, humidity and occupancy. These give the past outputs of the model 62.

The other main values the MPC controller 10 refers to are drivers 70. The drivers 70 are devices used to implement or manipulate the control action, e.g. blowers 28 to achieve a particular fan speed, and/or CAVs 36 and VAVs 42 set to various damper positions and/or cooling 26 or heating coils 24 to deliver a proper air temperature, and/or humidifiers to humidify the air, if necessary. These give the past inputs to the model 62.

The model 62 uses these past inputs and outputs, and future inputs from the optimizer 64 to predict the future outputs. Known control algorithms, such as Proportional Integral (PI) control, do not have this predictive ability. The difference 74 between the predicted future outputs and a reference trajectory 72, is defined as future errors which are inputted to the optimizer 62. The optimizer 62 limits the inputs and outputs using the constraints 68. It minimises the cost function 66 to make the output approach the set-point (target), the input to achieve a particular value, and the increment rate of the input to the calculated level.

The cost functions 66 are the sum of the difference between the current and past measured output and the desired set-point, w_y is a weighting coefficient; the sum of the increment of the inputs, $w_{\Delta u}$ is a weighting coefficient; and the sum of the input and a particular value, w_u is a weighting coefficient.

The constraints 68 are the upper limit and lower limits of the input u , the output y and the increment rate of the input.

The skilled person will understand that the process model 62 plays a crucial role in the realisation of the MPC controller 10. The chosen model must be able to capture the process dynamics to precisely predict the future outputs and be simple to implement and understand. As model predictive control is not a “one size fits all” approach, but rather a set of different methodologies, and there are many types of models that could be used to predict the system behaviour.

The optimizer 64 is a fundamental part of the control strategy as it provides the control actions. If the cost function 66 is quadratic, its minimum can be obtained as an explicit function (linear) of past inputs and outputs and the future reference trajectory. In the

presence of inequality constraints, the solution must be obtained by more complex numerical algorithms. The size of the optimisation problems depends on the number of variables and the prediction horizons used, and which usually turns out to be a relatively modest optimisation problem which does not require solving by sophisticated computer programs.

Figure 5 is a flow diagram illustrating how the system model 62 for a MPC controller 10 of the present invention can be obtained for the particular typical cleanroom 100 shown in Figure 6. In the following description each step of Figure 5 will be referred to as “S” followed by a step number, e.g. S76, S78 etc.

To determine an appropriate mathematical model of the cleanroom 100 of Figure 6, the process involves, at S76, running a series of operational measurements from the HVAC equipment of the cleanroom 100 under the control of the existing BMS system 50. These operational measurements of the cleanroom 100 can be collected via the Open Platform Communications (OPC) server on the existing BMS system 50 which operates using several single-input single-output (SISO) PI controllers. Data is collected at S78 from the OPC server from the results of these several experimental tests to derive the inputs and outputs of the model. As noted below, the measured data for model identification can be collected in a variety of ways, such as open-loop testing by applying a step signal (or other kind of signal) input and collecting the measured output, or closed-loop testing by PI or other control methods, etc. In essence, any sets of input and output data can be used to identify the mathematical model.

The skilled person appreciates that whilst a closed-loop measurement of the system has been described, it is also possible for the model structure and parameters to be obtained in open-loop systems without having any feedback. For the present invention, since the HVAC system can be operated by BMS 50 with PI control, closed-loop data is easier to collect.

Disturbances affecting the process will highly influence the modelling and therefore a priori assumptions on the noise are required to describe the process. The main disturbance of this system is the disturbance affecting the process internally, such as the air leakage, the distribution of the hardware, hysteresis and time delay of the sensors 70

etc. A white noise signal is therefore generated and integrated in the input to overcome such uncertainties.

At S80, the model is then determined using a variety of techniques available in the art.

5 This step involves applying methodologies for computationally modelling the structure and parameterisation. This skilled person will understand that various sets of software tools and applications can be utilised to systematically analyse and design the system model. For the MPC control of the typical cleanroom 100 shown in Figure 6 a black-box modelling approach was applied to allow a judicious selection from three model
10 structures: including Auto-Regressive with eXogenous input (ARX) models, State Space (SS) model and Transfer Function (TF) models. A criterion function is specified to measure the fitness between the outputs of the identified model and the operational measurements.

15 The estimated model is evaluated at S82 to decide if the resulting model is accurate enough to be used in MPC controller 10. It is possible to adjust the performance of the controller 10 as it runs by tuning disturbance models, horizons, constraints, and weights. In the preferred embodiment, these steps were undertaken using the Model Predictive Control ToolboxTM and Simulink[®] blocks of Matlab[®].

20

After the evaluation, at S84, the robust mathematical model can be used to support the design of the MPC controller 10 and the system model design can be embedded in a programmable logic controller (PLC).

25 Figure 6 is illustrative of a typical cleanroom 100 supplied by two separate HVAC air handling units 12a, 12b and controlled by the MPC controller 10, and which has been used to develop the methodology of the present invention. Unlike Figure 2, the cleanroom 100 of Figure 6 has two separate AHUs 12a, 12b which allow a wide variety of performance testing options. The testing experiments are taken in the cleanroom 100
30 via the HVAC system. The HVAC system cleans and circulates the air drawn from outside of the cleanroom 100, the functionality of which is achieved by the operation of hardware including AHUs 12a, 12b, VAVs 42, extract ductwork 44, sensors, grilles 38 and diffusers 40, as described previously.

This typical cleanroom 100 is configured having an entrance 120 which leads into an ISO Class 7 change room 122. From the change room 122 is a zone or small room 124 which is an ISO Class 7 cleanroom 124. Between the Class 7 cleanroom 124 and a larger ISO Class 5 cleanroom 130 are a series of material pass rooms and airlock 126 and a large lab change room 128 which is a Class 5 change room. As with Figure 2, the Class 5 cleanroom 130 is operated at higher pressure than the Class 7 cleanroom 124. The cleanroom 100 in the example of Figure 6 has its highest rated room, in this case the larger room 130, at the furthest point from the main door entry 110. It is adjoined to the “dirtier” cleanliness classification smaller room 124, via a change room 122.

10

The skilled person will appreciate that the Class 5 cleanroom 130 is kept at a higher air pressure (known as a “pressure cascade”) to prevent contaminants from, say, the adjacent Class 7 cleanroom 124. Such a configuration has been used to validate the model 62 and gives significant improvement in terms of dynamic response and efficiency, as described and shown in Figures 7 to 11.

15

A simple test was devised to challenge the standard BMS 50 cleanroom control against the particle-based MPC based control system 10. All the following dynamic test results are obtained following the same test protocol as set out in Table 1.

20

Timeline (minutes)	Behaviour	No. of personnel
0	Class 7 level guard up and enter the room 124, stay and walk around. Note: hair and, where relevant beard and moustache, should be covered. A two-piece trouser suit, gathered at the wrists and with high neck and appropriate overshoes should be worn. They should shed virtually no fibres or particulate matter.	3
15	Class 5 level guard up and enter the room 130, stay and walk around. Note: headgear should totally	2

	enclose hair and, where relevant, beard and moustache. A boiler suit is worn with face mask to prevent the shedding of droplets. Appropriate sterilized, non-powdered rubber or plastic gloves should be worn. Bootees should be worn with the trouser leg tucked in. Garment sleeves should be tucked into the gloves. The protective clothing should shed virtually no fibres or particulate matter and retain particles shed by the body.	
	Stay in room 124, walk around	1
30	Leave the cleanroom	3

Table 1 – Experimental test protocol; personnel donning cleanroom garb

Figure 7 shows comparative data obtained from the cleanroom of Figure 6, and shows particle concentrations measured in various rooms of the cleanroom 100 in accordance with the experimental test defined in Table 1, the test data showing the response of a known BMS 50 control system which is based on a Proportional-Integral (PI) control algorithm.

The PI controllers implemented in the BMS 50 maintain the air change rate (ACR) for each room 124, 130 at a steady state. The ACR rates were fixed at 17 ACR/h for the ISO 7 room 124, and 40 ACR/h for the ISO 5 room 130 (and termed ACR1 in Table 2). At same time, the air pressure in each lab is kept constant at 15 Pa in the ISO 7 room 124, and 30 Pa in the ISO 5 room 130.

Two particle sizes are analysed: 0.5 μm and 5 μm . Room 124 has one particle counter, and room 130 has two particle counters, PC2 and PC3.

Figures 7 to 10 also make reference to interval data and rolling data. This is obtained as described below: The particle counters continuously sample air at a fixed sampling rate.

The size of the air sample is therefore determined by the length of the measurement interval. The standard flow rate is 1.0 cubic feet per minute, which limits the allowable concentration of particles to 1 million per cubic foot (CF) or 35.3 million per cubic meter (CM). The sample volume can be collected in CF mode or CM mode. The sample time
5 for the CF mode is 1 minute whereas the sample time for the CM mode is 35.3 minutes, such that in Figures 7 to 10:

- Interval data – 60 times more frequently than the full sample volume, based on 1/60 of the total sample volume, updated every 35.3s; and
10 Rolling data – the totalized counts, particle concentration over a continuous sample volume, not an increasing number of particles for the current sample, updated every 35.3s.

Figure 7(a) shows the ISO 7 room 124 0.5 μm particle concentration; Figure 7(b) shows
15 the ISO 7 room 124 5 μm particle concentration; Figure 7(c) shows the ISO 5 room 130 0.5 μm particle concentration; and Figure 7(d) shows the ISO 5 room 130 5 μm particle concentration. It can be clearly seen that the known BMS 50 control system, which is based on a Proportional-Integral (PI) control algorithm, takes a significant time lag to bring the particle count down in the various rooms 124, 130.

20 Figure 8 shows the same BMS 50 control system operating at another ACR (termed ACR4 in Table 2) and being fixed at 3 ACR/h for the ISO 7 room 124 and 10 ACR/h for the ISO 5 room 130. Again, the Proportional-Integral (PI) control algorithm takes a significant time to reduce the particle count down in rooms 124, 130.

25 Figures 9 and 10 show the dynamic response of the MPC controller 10 of the present invention to the same experimental test protocol as set out in Table 1, when the desired particle concentration set-points are set at 20% and 50%, respectively. These dynamic test results were obtained with the MPC controller 10 implemented in a PLC platform.
30 The measured values from the particle counters are transferred into percentage values which is calculated against the particle limitations defined in the classifications. Room 124, which is designed as a class 7 cleanroom, has a limitation of 3,520,000 0.5 μm particles and 29,000 5 μm particles per cubic meter. Room 130, which is designed as a

class 5 cleanroom, has a limitation of 352,000 0.5 μm particles and 2,900 5 μm particles per cubic meter.

Figures 9(a) and 10(a) show the ISO 7 room 124 0.5 μm and 5 μm particle concentrations; and Figures 9(b) and 10(b) show the ISO 5 room 130 0.5 μm and 5 μm particle concentrations, and it is clear from both that an improved dynamic response is obtained.

Figures 9(c) and 10(c) show the dynamic control of the air change rates in the ISO 7 room 124 and ISO 5 room 130, and again it can be seen that the ACR ramp ups rapidly when there are particles in the rooms 124, 130, as expected.

Figures 9(d) and 10(d) show the static room pressure for the ISO 7 room 124 (15 Pa) and the ISO 5 room 130 (30 Pa). The pressures are controlled within the process range ± 5 Pa, except when the door 110 is open and close. The minimum differential pressure (DP) is monitored and alarmed in this system 10 and is determined to be 5 Pa for the ISO 7 room 124 and 15 Pa for the ISO 5 room 130, separated with airlocks 126, 128 to maintain DP during personal and material transitions. DP values higher than 5 Pa provide sufficient overflow on one side. The static pressure set-points of the cleanrooms are designed as 15 Pa in the ISO 7 room 124 and 30 Pa in the ISO 5 room 130. The system recovers from the peak to steady state in a very short time.

Figures 9(e) and 10(e) show dynamic control of the AHU 12a (AHU1) supply fan and the supply VAV 42 of each room 124, 130 and shows a good dynamic response when the particle concentration is higher than the set-point.

The dynamic response of the MPC controller (Figures 9 and 10) is much better that is obtained from the known BMS 50 control system (Figures 7 and 8).

Figure 11 shows the power consumed by a known BMS 50 system at various air change rates (ACR) obtained from the typical cleanroom 100 of Figure 6, as set out in Table 2.

No.	ISO 7 room ACR (/h)	ISO 5 room ACR (/h)
ACR1	17	40
ACR2	13	30
ACR3	8	20
ACR4	3	10

Table 2 – Air change rates of typical cleanroom 100 as depicted in Figure 11

All the fans are controlled in steady state which give steady powers, and the figures demonstrate the average power consumed at each ACR of the known BMS 50 system.

5

The right hand portion of Figure 11 is comparative dynamic power measurements obtained by the MPC controller 10 of the present invention and shows that model predictive control significantly reduces the power consumption of the cleanroom HVAC system. It can be clearly seen that the power drawn by the MPC controller 10 is significantly less the steady state ACR of the known BMS 50 system.

10

	20%, Set-point	50%, Set-point
Duration (hours)	2.27	2.43
Dynamic Energy (KWh)	2.82	3.14
ACR1 energy (KWh)	8.52	9.14
ACR2 energy (KWh)	5.38	5.78
ACR3 energy (KWh)	3.98	4.27
ACR4 energy (KWh)	3.03	3.25

Table 3 – Consumed energy for MPC and BMS 50 control, as depicted in Figure 11

The consumed energy for each test is calculated as shown in Table 3. The energy consumption of the dynamic control is calculated by the integral of power (from the power curve in Figure 11) against time. Since the BMS 50 system operates in steady state, the power is assumed to be static. The energy consumption of the known BMS 50 system is calculated by the multiplication of the static power and the time duration of the dynamic control. As shown in Table 3, the dynamic control consumes lower energy than the known BMS 50 system whatever the air change rate (ACR) the system maintains.

The system of the present invention is flexible enough to be expanded, and/or altered as the cleanroom 100 requirements change. The control system 10 is completely scalable for a single cleanroom 100 to multiple rooms or zones within multiple cleanrooms 100. Furthermore, no use of a system of this nature has ever been produced or hinted at in any printed publication of a system of the purpose generally for industrial use within existing cleanrooms or bespoke cleanrooms and which provides advances in continuously based sensor control of cleanrooms.

The use of the letters HVAC (heating, ventilation and air conditioning) are intended to be used with their ordinary English language meaning and this is generally speaking accepted as the words heating, ventilation and air conditioning, as used previously in the document.

The invention is not intended to be limited to the details of the embodiments described herein, which are described by way of example only. Various additions and alternations may be made to the present invention without departing from the scope of the invention. For example, although particular embodiments refer to implementing the present invention as a HVAC cleanroom control system this is in no way intended to be limiting as, in use, the present invention can be used with many types of industrial environments. It will be understood that features described in relation to any particular embodiment can be featured in combination with other embodiments.

30

When used in this specification and claims, the terms “comprises” and “comprising” and variations thereof mean that the specified features, steps or integers are included. The terms are not to be interpreted to exclude the presence of other features, steps or components.

The features disclosed in the foregoing description, or the following claims, or the accompanying drawings, expressed in their specific forms or in the terms of a means for performing the disclosed function, or a method or process for attaining the disclosed
5 result, as appropriate, separately, or in any combination of such features, can be utilised for realising the invention in diverse forms thereof.

CLAIMS

1. A control system for controlling air volume to maintain a desired concentration of
5 airborne contamination in a cleanroom supplied by a HVAC system being operative to
supply treated air to the cleanroom which comprises one or more zones or rooms, each of
the zones or rooms having a respective desired concentration of airborne contamination,
and wherein the HVAC system comprises at least one HVAC air handling unit supplying
treated air through a ducting system, and one or more constant air volume devices and/or
10 one or more variable air volume devices positioned in the ducting and generally
associated with each respective zone or room of the cleanroom, the system comprising:
sensing means for sensing a concentration of non-viable particles and/or viable
particles in real time or near real time; and
processing means for comparing the sensed concentration of non-viable particles
15 and/or viable particles against the desired concentration of airborne contamination and
outputting at least one control signal to the HVAC system based on the comparison,
wherein the processing means comprises a model predictive controller which comprises
a model component that receives a HVAC system operating condition from extrinsic data
analysis and which models HVAC system behaviour; and means for receiving the
20 modelled HVAC system behaviour and outputting the at least one control signal to the
HVAC system based on the modelled HVAC system behaviour and a cost minimizing
function.
2. The control system as claimed in claim 1, wherein the desired concentration of
25 airborne contamination is specified by the number of non-viable particles per cubic meter
having a particle size of equal to or greater than 0.1 μm , 0.2 μm , 0.3 μm , 0.5 μm , 1 μm
and 5 μm in diameter.
3. The control system as claimed in any of claims 1 or 2, wherein the cleanroom
30 being classified by particle size concentration as defined in ISO 14644-1 or any
classification standard related to particle size concentration as determined by the
cleanroom user.

4. The control system as claimed in any of the preceding claims, wherein the air treatment is selected from the group consisting, but not limited to, any one of the following: filtration, ventilation, heating, cooling, humidification, pressurisation, occupancy, and combinations thereof.

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5. The control system as claimed in any of the preceding claims, wherein the sensing means comprises one or more ISO 14644-1 calibrated laser particle counters and/or viable particulate air monitoring sensors positioned in the cleanroom or the ducting of the HVAC system.

10

6. The control system as claimed in any of the preceding claims, further comprising one or more secondary sensing means for sensing an environmental condition and/or process condition and/or HVAC system condition in real time or near real time.

15

7. The control system as claimed in claim 6, wherein the secondary sensing means further comprises one or more sensors selected from the group consisting, but not limited to, any one of the following: temperature sensor, humidity sensor, pressure sensor, differential pressure sensor, airborne molecular contamination sensor, contaminant deposition sensor, air flow sensor, proximity sensor, and combinations thereof.

20

8. The control system as claimed in any of the preceding claims, wherein the processing means receiving energy price data and/or usage data.

9. The control system as claimed in claim 8, wherein the processing means receiving the sensed environmental condition and/or process condition and/or HVAC system condition and/or energy price data and/or usage data and outputting one or more secondary control signals to the HVAC system.

10. The control system as claimed in claim 9, wherein the one or more secondary control signals are outputted without causing the sensed concentration of particles to depart from the desired concentration of airborne contamination.

30

11. The control system as claimed in any of claims 6 to 10, wherein the desired concentration of airborne contamination and/or energy price data and/or usage data being initially user configurable.

5 12. The control system as claimed in any of the preceding claims, wherein the at least one control signal to the HVAC system controlling the air volume supplied to the cleanroom.

10 13. The control system as claimed in any of claims 6 to 11, wherein the one or more secondary control signals controlling the filtration, ventilation, heating, cooling, humidification, pressurisation, occupancy, and combinations thereof supplied to the cleanroom.

15 14. The control system as claimed in any of the preceding claims, wherein the processing means implements a model predictive control (MPC) algorithm.

15. The control system as claimed in claim 14, wherein the model predictive control algorithm being able to self-adapt.

20 16. The control system as claimed in claim 1,
wherein the means for receiving the modelled HVAC system behaviour and outputting the at least one control signal to the HVAC system based based on the modelled HVAC system behaviour and the cost minimizing function and constraints.

25 17. The control system as claimed in any of the preceding claims, wherein the control system is implemented in a programmable logic controller (PLC).

18. The control system as claimed in any of the preceding claims, further comprising display means.

30

19. The control system as claimed in any of the preceding claims, further comprising means for enabling communication and/or integration and/or interoperability with third party building management systems (BMSs).

20. The control system as claimed in any of the preceding claims, further comprising means for monitoring the energy performance of the cleanroom and/or particle contamination concentration within the cleanroom.

5 21. A method of controlling air volume to maintain a desired concentration of airborne contamination in a cleanroom supplied by a HVAC system being operative to supply treated air to the cleanroom which comprises one or more zones or rooms, each of the zones or rooms having a respective desired concentration of airborne contamination, and wherein the HVAC system comprises at least one HVAC air handling unit supplying
10 treated air through a ducting system, and one or more constant air volume devices and/or one or more variable air volume devices positioned in the ducting and generally associated with each respective zone or room of the cleanroom, the method comprising the steps of:

sensing a concentration of non-viable particles and/or viable particles in real time
15 or near real time;

comparing the sensed concentration of non-viable particles and/or viable particles against the desired concentration of airborne contamination; and

outputting at least one control signal to the HVAC system based on the comparison,

20 wherein the outputting step comprises a model predictive controller which comprises a model component that receives a HVAC system operating condition from extrinsic data analysis and which models HVAC system behaviour; and means for receiving the modelled HVAC system behaviour and outputting the at least one control signal to the HVAC system based on the modelled HVAC system behaviour and a cost
25 minimizing function.

22. A computer program product for controlling air volume to maintain a desired concentration of airborne contamination in a cleanroom supplied by a HVAC system being operative to supply treated air to the cleanroom which comprises one or more
30 zones or rooms, each of the zones or rooms having a respective desired concentration of airborne contamination, and wherein the HVAC system comprises at least one HVAC air handling unit supplying treated air through a ducting system, and one or more constant air volume devices and/or one or more variable air volume devices positioned in the

ducting and generally associated with each respective zone or room of the cleanroom, the computer program product comprising:

computer program means for sensing a concentration of non-viable particles and/or viable particles in real time or near real time;

5 computer program means for comparing the sensed concentration of non-viable particles and/or viable particles against the desired concentration of airborne contamination; and

computer program means for outputting at least one control signal to the HVAC system based on the comparison,

10 wherein computer program means for outputting comprises a model predictive controller which comprises a model component that receives a HVAC system operating condition from extrinsic data analysis and which models HVAC system behaviour; and means for receiving the modelled HVAC system behaviour and outputting the at least one control signal to the HVAC system based on the modelled HVAC system behaviour
15 and a cost minimizing function.