SUMMARY

To reduce energy consumption and thereby, indirectly, reduce CO_2 emissions, energy consumption in operating rooms (ORs) must be critically examined. The air handling units are estimated to use more than 90% of the total energy consumption of the operating rooms. This is about 10% of total healthcare emissions. The majority of Dutch operating rooms are equipped with an Ultra Clean air supply system (UCV), suitable for large joint replacement procedures (class 1+ operating rooms). This is not necessary according to the FMS guideline 2022 and costs (too) much energy. We will discuss in this article the various air handling systems, the relationship with wound infections, the existing guidelines and the possible savings potential. We realize it is tough stuff. However, it is essential to take note of it, because in terms of energy reduction and thus CO_2 emissions, there is a lot of room for improvement.

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LEARNING OBJECTIVES

After studying this article:

- Know the different types of OR air handling installations;
- Have an understanding of the purpose of an OR air handling system;
- Can you explain the difference between an Ultra Clean and a conventional ventilation system;
- Know the classification of operating rooms according to the (new) FMS guideline;
- have insight into measures to save energy in the operating room.

Operating room energy savings through air treatment modifications

Introduction

Energy consumption in healthcare is high. Worldwide, hospitals account for about 6% of total building energy use, and the richer the country, the greater the emissions. An operating room is three to six times more energy-intensive than the rest of the hospital. About 90-94% of all the energy of an operating complex is used by air handling[1]: heating, cooling, humidification and ventilation. In addition, energy is used (6-10%) by equipment (including medical equipment, warming cabinets, patient heating systems, refrigerators) and lighting.

Goals of OR air treatment include minimizing postoperative

Table 1 Classification of operating rooms according to FMS guideline of 2022.

	operating room class 1+	operating room class 1	operating room class 2	independent treatment room
air changes/hour	at least 20x	at least 20x	at least 6x	at least 4x
air quality (iso classes)	ISO 5 (NEN EN ISO 14644-1)	ISO 7 (NEN EN ISO 14644-1)	ISO 7 (NEN EN ISO 14644-1)	no special requirement
recovery time (1:100)	≤ 3 min	≤ 20 min (EN ISO 14644-3).	irrelevant	irrelevant
filtration air	at least HEPA filter H13 (EN 1822)	at least HEPA filter H13 (EN 1822)	at least HEPA filter H13 (EN 1822)	no specific requirements
temperature*	18° - 23°	18° - 23°	18° - 23°	no specific requirements
relative humidity*	< 65%	< 65%	< 65%	< 65%
pressure hierarchy/flow direction	3 zones descending in purity (on construction drawing insightful) relative to the remaining building	3 zones descending in purity (on construction drawing insightful) relative to the remaining building	2 in purity descending zones (on construction drawing insightful) relative to the remaining building	irrelevant

ISO 7 applies to the entire operating room.
* The temperatures and relative humidity recommended are directional; see notes.

wound infections (POWIs) and creating a safe and comfortable working environment for staff (comfortable it is rare for anesthesia). The more advanced the air treatment, the greater the energy demand. We distinguish three classes of operating rooms, namely class 1+, class 1 and class 2 (Table 1).[2] For an OR class 1+ and 1, the requirement is that there must be three pressure zones on the OR complex. For an OR class 2, two pressure zones suffice. In addition, there are different air supply systems. The simplest OR air supply system is a conventional system. This system, according to the FMS guideline, can be used for a class 1 and 2 operating room and, when considering energy consumption, is the most favorable.
There are three different types of the Ultra Clean system (UCV) on the market. All meet the requirements for an OR class 1+.

UCV systems were developed to minimize the risk of post-operative wound infections in major joint replacement procedures.[3] Looking at the table for classification procedures by operating/treatment room in the FMS guideline (page 40), the balance between evidence and, in many cases, the need for UCV systems seems lost. An initial analysis shows that (almost) all operating rooms in the Netherlands performed are with an air handling unit equipped with a UCV.

Research on energy consumption by The Rural Network the Green OK The Rural Network the Green OK is a partnership of 15 scientific and professional associations that want to make OR care more sustainable and is a co-signatory of the Green Deal 3.0 "Working Together on Sustainable Care. The National Network encourages and supports individual medical specialists and healthcare professionals working in the OR to contribute to climate goals in a sustainable way. The Energy Working Group is concerned with CO_2 reduction and energy savings in the surgery complex.
The energy consumption of an operating complex is substantially different from that of an entire hospital. For an operating complex, more than 90% of the energy consumption is caused by air treatment. The National Network the Green OR conducts research into the energy use of air treatment systems of operating rooms.
This study is being commissioned by the Ministry of Health, Welfare and Sport (VWS) based on Urgendaag Measure 51.

To reduce our emissions, we must take a critical look at the number of operating rooms with a UCV system (class 1+). There are also numerous other measures by which the energy consumption of an operating room can be reduced. From the national network the Green OR (see box), we are initiating research into the energy consumption of operating room air treatment systems. This article discusses this in more detail.

Through a survey to all hospitals, several measurements in various hospitals to determine actual energy consumption, computer simulations and theoretical determinations, we will substantiate our findings. Among other things, we will ask the following questions:

1. What types of OR air handling/air supply systems are there and which are installed in Dutch hospitals?
2. Is there international consensus and evidence on the relationship between POWIs and air treatment?
3. Is it necessary to perform all interventions in a system with the highest energy consumption?
4. What are the opportunities to save energy in operating rooms?

With the answers to these questions, among others, we will advise Dutch hospitals in 2024 how to responsibly reduce their energy consumption and indirectly the can reduce CO_2 emissions in the operating room.

OR air handling systems/ air supply systems

The main purpose of an OR air treatment system is to ensure that there are as few pathogens as possible in the air around the surgical area. The air brought into the operating room lowers the concen- tration of (anesthesia) vapors, diathermy smoke and odors and reduces the amount of microorganisms present in the air.[4,5]

Regular air changes in an OR are important. Part of the air comes from outside and is brought to the right condition (temperature and relative humidity) by the air treatment plant. This part also ensures that an overpressure (zones) is established in the operating rooms. The idea here is that because of the higher pressure in an OR, relatively dirty air from outside the operating room cannot flow in. This outside air is "expensive air," because it is conditio- nal. needs to be cleaned. In addition to this air, there is recirculated air that is brought back into the operating room through a HEPA filter. These two air flows together determine the total number of air changes.

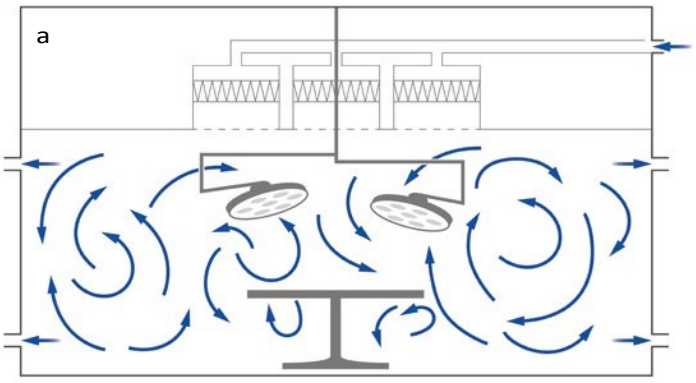
In addition to the difference in the number of pressure zones, the minimum number of air changes and ISO classification in terms of maximum room particle concentration (Table 1). The consequence of a higher number of air changes is the higher amount of air supplied to the operating room. This is called the air flow rate in m3/h. Increasing the air quantity (the air flow rate) leads to fewer particles in the room (ISO 5 vs. ISO 7) and also to a faster recovery of air quality in the operating room (recovery time).[6] A shorter recovery time of air quality in the operating room results, in an operating room in use, in a lower number of measured colony-forming units per ^{m3} ($^{CFU/m3}$). ISO 5 and ISO 7 say something about the maximum allowable concentration of $^{particles/m3}$ in the air. For example, for ISO 5, the number of $^{particles/m3}$ of size $\geq$ 0.5 µm is 3520 and for ISO 7, the number of $^{particles/m3}$ of size $\geq$ 0.5 µm is 352 000. The number of airborne particles measured at ISO 5 is 100 times lower than at ISO 7.

For infection-sensitive operations (major joint replacement procedures = class 1+), more air changes are desirable than for less infection-sensitive operations.[3] The number of air changes in the operating room for a class 1+ is higher than the listed number of 20 in Table 1. In practice, the number of changes often exceeds 60 per hour. For each specialty, the FMS guideline indicates per procedure in which OR class it should take place.

Air supply systems

There are two types of air supply systems, conventional air supply (CV = mixing system) and Ultra Clean (UCV). A CV system is for Class 1 and 2, a UCV for a Class 1+ operating room.

Conventional systems mix the supplied air evenly throughout the OR and dilute the concen- tration of microorganisms and pollutants.
UCV systems bring air into the protected area through specially designed OR air supply systems and displace the air present where the protected area is located. The protected area is for patient positioning (the wound area), sterile personnel and instrument tables. The air quality requirement for



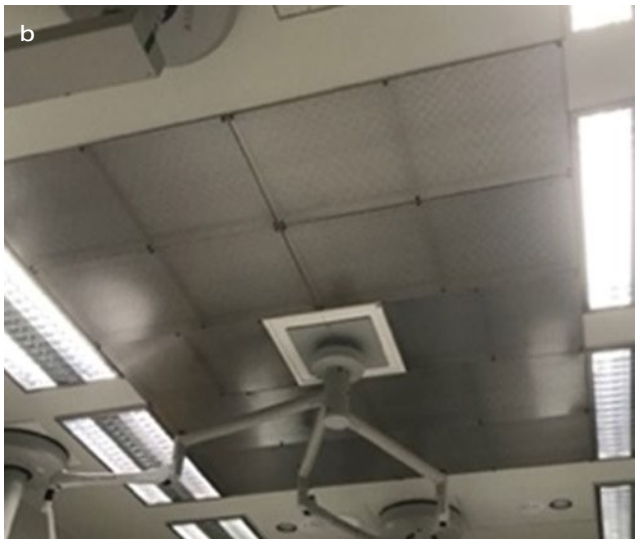


Figure 1 Operating principle (a) and photo (b) of a CV system.

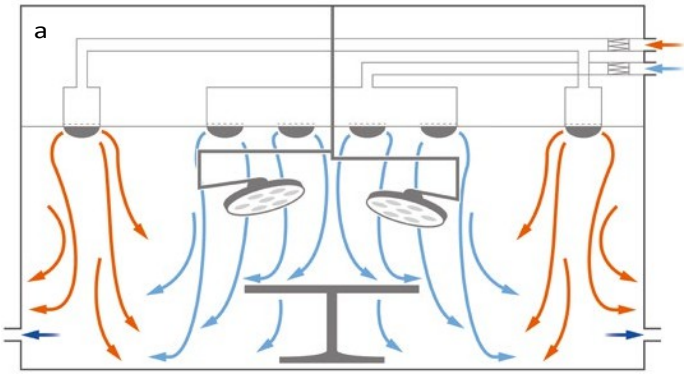


Figure 2 Operating principle (a) and photo (b) of a temperature-controlled system.

a UCV system in the protected area, in terms of the number of microorganisms, must not exceed 10 $^{CFU/m3}$ during an operation.[7,8] Our preliminary investigation shows that the UCV systems examined installed in the Netherlands meet this CFU requirement.

To meet these requirements, higher air volumes are supplied in the OR.[3] The air volumes of UCV systems are higher (about 7000 - 10 000 $^{m3/h}$) compared to the air volumes of conventional systems (about 3000 - 4000 $^{m3/h}$). When using lower air volumes, the recovery time of the air is lower, which increases the number of microorganisms measured throughout the OR. This can be a risk factor for the development of POWIs. The number of microorganisms also depends on the number of people, type of clothing, procedures, door movements and number of air changes.

In the Netherlands, we currently have the following four types of OR air supply systems:[6]

1. Conventional Ventilation Air Supply (CV)
2. Temperature Controlled Air Flow (TcAF).
3. Controlled dilution ventilation (cDV).
4. Uni Directional Air Flow (UDAF).

The first is considered class 1 or 2 air supply system. Numbers two through four are considered Class 1+ UCV systems. These systems are suitable for major joint replacement procedures.

Conventional air supply system (CV)

A conventional air supply system (Figure 1b) is a mixed air supply system. The conventional system brings HEPA-filtered air into the OR through several intake diffusers (Figure 1a). HEPA is short for *high-efficiency particulate air* and is a specific type of air filter. It can stop a minimum of 85% and a maximum of 99.99% of all dust particles from 0.3 micro meters (microorganisms need dust particles to travel through the room).

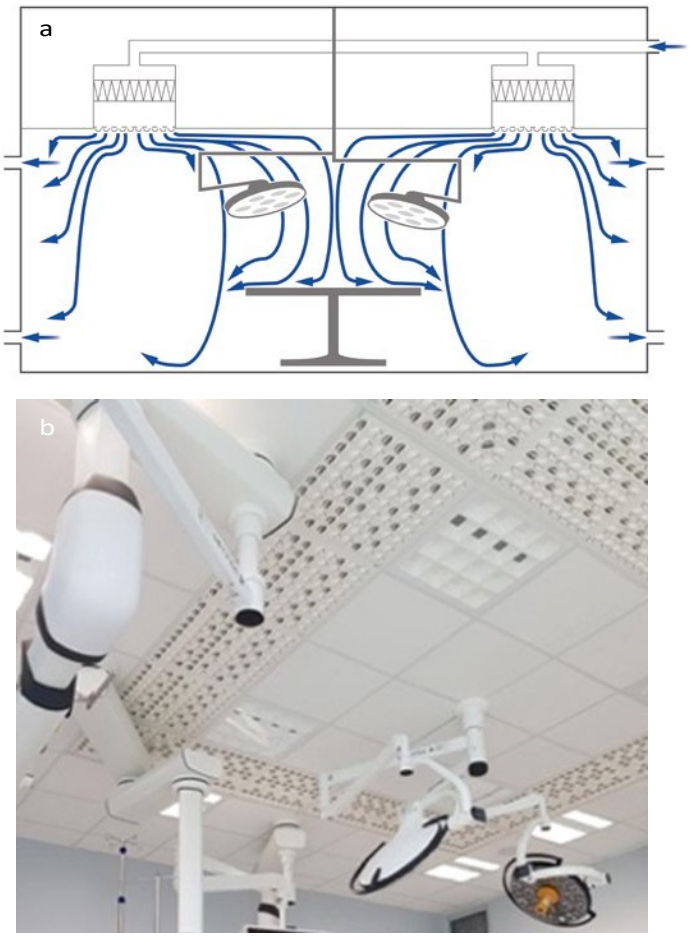


Figure 3 Operating principle (a) and photo (b) of a controlled mixing system.

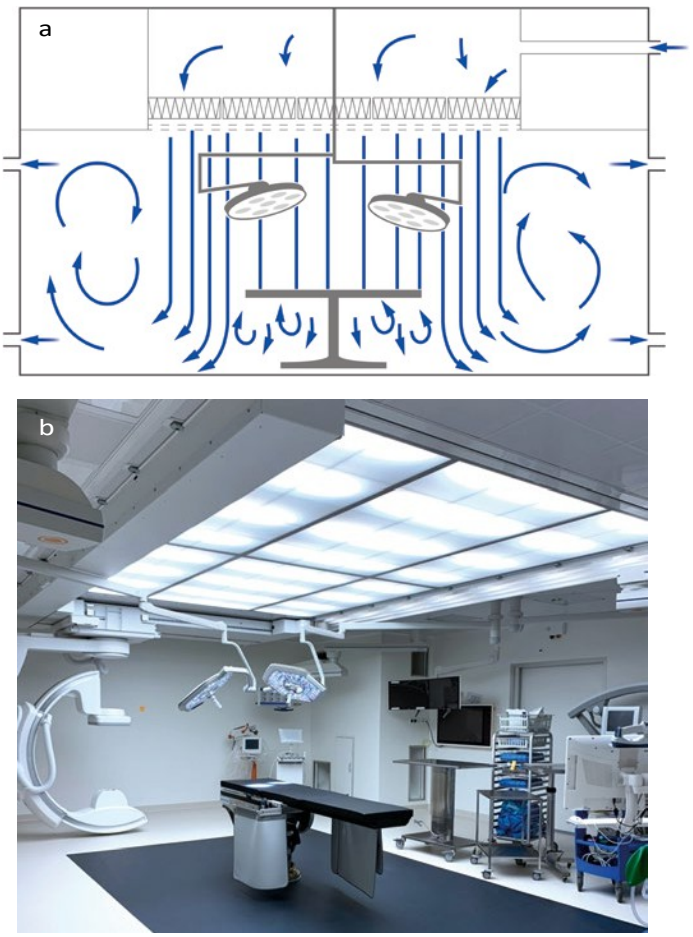


Figure 4 Operating principle (a) and photo (b) of a UDAF system.

Temperature-controlled air supply system A temperature-controlled system (Figure 2b) is defined as a temperature-controlled air supply system in which cooler HEPA-filtered air is supplied above the OR table and warmer air in the periphery by means of spherical discharge orifices. The introduced air above the OR table flows downward due to density differences. In the periphery, the spherical discharge ornaments create a mixed air flow.

Controlled mixed air supply system A controlled mixed air supply system (Figure 3b) is a mixed air flow. The air is filtered by HEPA filters and supplied into the OR through several nozzles in the ceiling. The supply air flow is directed partly toward the ultrasound zone and partly toward the periphery of the operating room, creating a good mixing of the supply air with the room air present (Figure 3a).

Unidirectional airflow systems (UDAF) Unidirectional airflow (Figure 4b) is defined as a turbulence-poor airflow with a unidirectional direction. This air is supplied over the protected area and continuously replaces the air present (displacement) with new HEPA-filtered air. It creates a HEPA-filtered protected area at a constant velocity (Figure 4a). The supplied air flows to the periphery where it is exhausted through the extraction grilles placed in the OR wall.

In a Class 1+ OR, it is commonly recommended that a protected area of at least three by three meters be created in which the patient, OR table and sterile material can be positioned. Research shows that, in case this is not possible, the air outside this area with smaller Uni Directional AirFlow (UDAF) air supply systems of 2.4 by 2.4 meters, is also already sufficiently clean to position instrument tables here.[9] This means that in some cases

a smaller UDAF system can be used and less air needs to be supplied to the OR. A smaller UDAF system therefore saves energy compared to a larger UDAF system.

Postoperative wound infection in relation to air treatment

The occurrence of POWIs is influenced by many factors, with the type of surgery and the health status of the patient having the most influence. Other important factors are (hand) hygiene, correct use of antibiotics (prophylaxis), adequate disinfection, prevention of patient hypothermia, dress discipline and movements of personnel in the operating room (Table 2, RIVM). To prevent POWIs due to airborne microorganisms in the operating room, adequate ventilation and the total number of air changes are important. Currently, almost all procedures in the Netherlands are still performed in a class 1+ operating room. We operate in operating rooms that, in some cases, run at full capacity day and night.

The World Health Organization (WHO) states that existing research on the use of a
UCV system (class 1+) for operating rooms is scientifically limited and weakly substantiated and that, as a result, there is (too) little evidence that such systems contribute to reducing POWIs.[10] In addition, according to the WHO[10] and the Centers for Disease Control and Prevention (CDC)[11], the investment cost in a facility equipped with a UCV system is higher than that of a central heating system as recommended by the WHO.

In 2022, the Federation of Medical Specialists (FMS) published a new guideline on air treatment, *Air Treatment in Operating Rooms and Treatment Rooms*.[2] This guideline classifies surgical procedures into different categories. Each specialty has been given the opportunity to specify which procedure should be performed in which type (class 1+, 1 or 2) of operating room. According to this recommendation, the strict requirements of class 1+ are only necessary for major joint replacement procedures.[12]

International guidelines[7,13,14] and the Dutch Orthopaedic Association (NOV)[12] recommend that major orthopaedic implants (primary and revision prostheses) of the large joints (as hip, knee, shoulder, elbow, ankle), and major spinal surgery (e.g., scoliosis) be performed in an OR class 1+.[2]

Table 2 Influential risk factors postoperative wound infections. Source: RIVM.

general condition of the patient (such as obesity, malnutrition and low serum albumin levels, smoking, poorly controlled diabetes mellitus and use of immunosuppressants)
nasal carriage with *Staphylococcus aureus*
infections elsewhere in the body
preoperative removal of hair
incorrect preoperative hand disinfection surgical team
inadequate cleaning and sterilization of instrumentation
inadequate ventilation of operating room
improper disinfection of surgical area
improper clothing surgical team (mask, gloves, etc.)
combining multiple interventions
peroperative use of blood transfusions
under-temperature of the patient during surgery
surgical technique (including size of wound bed, degree of tissue damage, use of foreign material and drains, manner in which procedure is performed)
discipline on the OK
pressure hierarchy on the OR

This opinion stems from several studies showing that fewer POWIs occurred in systems with higher air volume.[3] Air quality here was defined as air with a quality of less 10 KVE/m3. For other surgeries, there is no evidence that fewer POWIs occur with a Class 1+ operating room. These may be performed in a class 1 or class 2 operating room, depending on the specialty. There is international advice in some standards and guidelines to use a displacing Uni Directional Air Flow (UDAF) (Figure 4)[13,14] while others have requirements for the number of KVE/m3 measured during the surgical procedure.[7]

What are the opportunities to save energy in the surgery department?

If one wants to save energy, a commonly used method is trias energetica:

1. **Prevent waste of energy.** One way to do this is to work with sensors or automatics. These ensure that equipment and lights are turned off when not in use, and that the air operation switches to a minimum setting when the OR is not in use. Turning off all computers, anesthesia machines, microscopes and the like when the OR is out of use. This can save up to about a third of the total annual energy consumption.
2. **Maximum use of renewable energy sources.** This CO_2 reduction can be achieved by generating as much sustainable energy as possible ourselves. This can be done, for example, with solar panels on roofs and facades, heat recovery systems and (if possible) by small to medium-sized wind turbines on the site.
3. **Using fossil fuels as efficiently as possible to meet remaining energy needs.** This includes adjusting room-by-room adjustable air treatment to the required OR class and maintaining a range for humidification[15] rather than pursuing a single value. Also, halogen, incandescent or replaced fluorescent lighting with LED lighting.

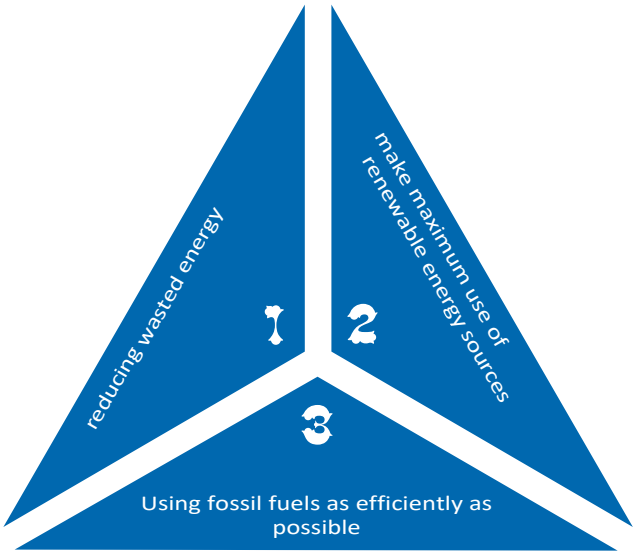


Figure 5 Trias energetics.

How can you save energy with air treatment?

The most important measure is to switch the air treatment to minimum settings (air volume) when the OR is not in use (for long periods of time). Research by Loomans (2020) shows that reducing the number of air changes when the room is not in use maintains an equal rating (ISO 5).[16] This applies under the conditions that the system remains on for at least 30 minutes after use, the room is properly airtight, the overpressure is at least 7.5 Pa, the number of air changes per hour is at least four, and the doors remain closed. The energy savings associated with retrofitting the air handling system were based on the savings in fan energy. This saved 32% of energy per year. This study showed that 30 minutes after start-up, the room was back to full compliance with all set initial conditions.[16] Our preliminary study in operating rooms showed similar results to the clean room study.[17,18] Our advice is to put the air treatment system on standby when an operating room is not in use.[18] Standby does not mean completely off. After all, a minimum flow is still needed to maintain the pressure hierarchy.

A second way to save energy is to allocate a number of rooms as class 1+ and the remaining rooms as a class 1 or 2 operating room, depending on the type of operation. By determining together with the responsible persons within the hospital what is really needed, savings can be made in energy and perhaps purchase and maintenance costs. Previous estimates in the WIP guideline (2014) were that 85-90% of operations can be performed in Class 2 operating rooms.[19]

A third strategy is limited humidification, where the relative humidity (RH) in the OR is between the 30-70% is kept instead of a target value of 50-65%, as advised in the past.[20,21] TNO and TU/e studied in May 2021 that there is no evidence for such a strict value for relative humidity and it is better to keep a bandwidth.[15] When the RH can move freely between two limit values, the air does not need to be humidified or dehumidified as often.

To ensure that modifications to the air handling system do not compromise staff and patient safety, further research will be conducted by the research team of the Green OR National Network.

search will be carried out in various hospitals. The logistical, procedural and technical (im)possibilities that adaptation of the ventilation system can bring about are examined. It will be investigated which components in the ventilation system are critical for reducing the air volume. Overpressure and a stable operating air handling system remain important at all times.

Training of OR and technical staff is evident. An important part of this will be making the technical and OR staff aware of the potential energy savings on the OR complex.

Video: tips for saving energy in the OR

Scan the QR code below to view a video from National Network the Green OR that provides six concrete tips for saving energy in the OR.

Note: The terms '(performance) level 1' and '(performance) level 2' used in this video are still based on the 2014 WIP guideline. In the new FMS guideline (and in this article), the terms class 1+, class 1 and class 2 are used.

Literature

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Jos Lans is CEO of Medexs, supplier of operating rooms, clean rooms and laboratories. The other authors have no financial ties to the pharmaceutical industry, do not receive research funds from commercial parties
and have no business interests or other type of financial relationships related to this subject matter.

FINAL TEST

1 Increasing the air flow rate reduces particulates in the room and restores air quality in the operating room faster.

a right
b incorrect

2 The air quality requirement for a UCV system in the protected area, in terms of microorganism counts, must not exceed ... KVE/m3 during an operation.

a 25 KVE/m3
b 20 KVE/m3
c 10 KVE/m3
d 5 KVE/m3

3 In the Netherlands, we currently know the following four types of surgical air supply systems. Which of these air supply systems are considered a Class 1+ UCV system?

a Conventional Ventilation Air Supply (CV)
b Temperature Controlled Air Flow (TcAF).
c Controlled dilution ventilation (cDV).
d Uni Directional Air Flow (UDAF).

4 A *high-efficiency particulate air (HEPA)* filter is a specific type of air filter that can stop a certain percentage of all dust particles of 0.3 micrometers. How high is this percentage?

a minimum 50% and maximum 75%
b minimum 75% and maximum 90%
c minimum 85% and maximum 99.99%
d minimum 95% and maximum 99.99%

5 Characteristic of a controlled mixing air supply system are the spherical discharge ornaments in the ceiling.

a right
b incorrect

6 The Federation of Medical Specialists (FMS) published a new guideline on air treatment in 2022, *Air Treatment in Operating Rooms and Treatment Rooms*. This guideline classifies surgical procedures into different categories. According to this recommendation, the strict requirements of class 1+ are only necessary for major joint replacement procedures.

a right
b incorrect

7 What is the number of particles/m3 of size ≥ 0.5 µm allowed at an ISO Class 5 installation?

a 352 particles/m3
b 3520 particles/m3
c 35 200 particles/m3
d 352 000 particles/m3