

REVIEW OF OPERATING ROOM VENTILATION STANDARDS

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ABSTRACT

This article reviews standards applied to operating room ventilation design used by European, South and North American countries. Required environmental parameters are compared with regard to type of surgery, and ventilation system. These requirements as well as their relation to infection control issues are discussed in this paper.

INTRODUCTION

It is very important to maintain good indoor air quality (IAQ) in OR to ensure health and safety for the patient and surgical team. A significant consideration in ORs is the control of aerosols, anaesthesia gases and smoke.

Aerosols are solid and liquid particles, and microorganisms dispersed in the air. The aerosols sources could be introduced from outside when the filters are not efficient, or because of air infiltration due to improper room pressurization. In OR, however the main sources have an indoor origin are the patient, the surgical team and equipment. A form of control of aerosols in the OR is through the ventilation system, pressure hierarchy and air change. The ventilation system's filters work like a barrier, pressure hierarchy ensures that the aerosols from one place do not reach other cleaner places. The ventilation system changes the air in such a way as to dilute the concentration of pollutants in the environment. Other types of control of aerosols are achieved by the use of adequate clothes, hygiene, quality of the work, etc. Source control should always be from the starting point.

The anaesthesia gases dispersed in ORs are also considered as pollutants. The anaesthesia gases are dispersed in the environment through problems in the equipment and from the exhalations of the patient. Some gases used in the surgery, for example, NO₂ will continue to be exhaled by the patient for up to one hour after the surgery is finished – Moore, 1997 (referenced by McCarthy *et al.* 2000). During surgery the highest concentration of gases is on the floor. However, with the movements of people these gases can be mixed with room air and inhaled by the surgical team. The

concentration of gases in the OR is critical and needs to be controlled, otherwise the productivity and quality of the work of the surgical team can decrease, and in the medium and long term health problems may occur. Halothane gas, for example, has a high toxicity and can affect the central nervous system. The gas concentration is controlled by the air change rate in the OR by dilution to acceptable levels.

The smoke can be generated by laser or electro-surgery unit. "Research studies have confirmed that this smoke plume can contain toxic gases and vapours such as benzene, hydrogen cyanide, and formaldehyde, bioaerosols, dead and live cellular material (including blood fragments), and viruses. At high concentrations the smoke causes ocular and upper respiratory tract irritation in health care personnel, and creates visual problems for the surgeon. The smoke has unpleasant odors and has been shown to have mutagenic potential" (NIOSH, 1998). Other authors (Hainer, and Usatine, 2002; and Clinical notes, 2002) also reported that the smoke represents a substantial evidence of viable virus and risk to transmit infection (i.e., when treating lesions of viral origin, especially HPV infections).

The ventilation requirements are defined in line with standards for the IAQ in hospitals and the type of surgery. The standards establish the limits for the temperature, the relative humidity, the rate of air change, the types of filters, the pressure relationship to adjacent areas, and the cases when the air may be recirculated. Some these variables are also related for the thermal comfort, but in this paper they will be discussed in terms on the IAQ. The type of surgery will define these requirements, in order to meet the needs of the patient, the surgical team and also to ensure the security aspects of the infection control. Each type of surgery presents a particular characteristic that requires different care. This phase is very important to evaluate, because the standards present different patient's requirements and different limits, for example, for the temperature and relative humidity. Another point to evaluate is the standards that apply to different

types of surgery. This question is relevant because some categories of patients, for example AIDS patients, have grown in number. For such patients the temperature must be kept low enough to ensure that the growth of certain microorganisms cannot take place. It is also important to verify to which standards the individual types of surgery should refer to.

In some critical situations the indoor air in OR will be ultra-cleaned, for example, for orthopaedic surgery, traumas, implants, burn patients, and other situations where the patient is immunocompromised. Otherwise, when the surgery is septic, there should be also a higher control in the indoor environment, to protect the adjacent areas.

The type of surgery will define other parameters too, for example, the number and type of equipment, lights, the time spent in OR, the type of clothing worn by the surgical team, and the type and intensity of the work being carried out. The ventilation system also needs to comply with the requirements for thermal comfort of the surgical team and for the patient in order to prevent the hypothermia.

RESEARCH METHODS

In order to investigate the ventilation requirements in OR, standards, guidelines, and academic papers and books were reviewed. The areas studied were the Heating, Ventilation and Air-Conditioning (HVAC) and medical field (CDC and HICPAC, 2003). The standards reviewed were: Europe (DGKH et al., 2002; CBZ, 2004; VDI, 2004; NFS90:351:2003), Brazil (NBR 7256, 1982 and MS, 2002), USA (ASHRAE, 2004; ASHRAE, 2005; ASHRAE, 2003; ASHRAE, 1999, and the AIA, 2001; CDC and HICPAC, 2003). The analyses are made in accordance with the requirements recommended in these Standards.

RESULTS

DGKH et al., 2002, Germany standard that defines recommendations for drafting technical guidelines for HVAC in hospitals. It discusses many recommendations and established a set of requirements for ORs. An important recommendation is to take care about the contamination in the air of immediate surrounding area of the operating table and instrument table which may result in direct or indirect contamination of the surgical site. These areas should be separated from the surrounding area by a stable airflow that was filtered to remove particles which proposes the use of "dynamic protected area maintenance" principle. It is also commented that future developments in surgical clothing (i.e. source control) could permit the reduction in the amount

supplied air. A vertical, low-turbulence displacement flow with a primary degree of turbulence of less than 5 % is deemed to be an appropriate form of flow, and the use of the "laminar" vertical airflow would be of great value. To ensure adequate protection of the operating table and instrument table, the diffuser should be around 2.8 m x 2.8 m. Particulate class H14 [efficiency (E)=99.995%] filters are recommended as a terminal filter stage, while the retention capacity of impact filters might be of lower classes H10 (E=85%) to H13 (E=99.95%). In terms comfort aspects, it is important to ensure temperatures between 18°C and 24°C (if necessary as high as 27°C in paediatric surgery), and the humidity shall not exceed the value of 50%. Two other parameters are recommended: the outdoor air flow between 800 m³/h and 1200 m³/h due the anaesthesia gases, and the temperature of the supply air flow must always be at least 0.5 lower than the ambient temperature.

VDI, 2004, Germany and Swiss standard is a guideline that applies to HVAC systems in Health Care buildings which have hospital-specific procedures and activities, and where interventions on humans are carried out. This guideline can be applied to new systems and renovations. Like in ASHRAE, 2003, the guideline describes, but briefly, the relevance of three criteria: comfort, infection prevention, and functioning and safety. An important particularity of this standard, which was also found in some books, is the discourse on the protection level need of the instrument table and operating table. This care is very important, especially in orthopaedic, implants, burned, cardiovascular surgeries and neurosurgeries, as well as in situations that the patient is immunocompromised. This standard comments on various surgeries, in term of the care needs and the risk level. The recommendation in this case is to have different zones in OR. In the cleaner zones the patient and the instrument tables should be placed, while the other zones are dedicated to the surgical team and support. The requirements recommend in OR are: the supply air temperature of 21°C ±3,0 K, with the possibility of control in order to optimize the comfort of the surgical team; the minimum required relative humidity is 30%, the maximum is 50%, in special types of surgery and medical procedure; the minimum air supply velocity should be 0.20 m/s; and filters classes F7 (E=80-90%) and F9 (E>90%), and H10 (E=85%) or H11 (E=95%) may be used in existing systems with terminal particulate air filters.

CBZ, 2004, recommendations applied in The Netherlands, is a general document with information on the construction criteria involved in

an operating room. Various details are discussed, including the types of ventilation systems that can be applied in The Netherlands, and some requirements for the IAQ. The type of ventilation system recommended is the “laminar” down flow plenum with three different shapes (rectangle, T and octagonal). They allow different protection levels for the patient due the airflow dynamics, and furthermore some of them allow different temperatures in the supplied air. The requirements recommended are: filter F5 (E=40-60%), F7 (E=80-90%); F9 (E>95%) and H13 (E=99.95%); supplied air temperature of 21°C ± 3°C. As the activity level of the people in OR is different, this document suggests different temperatures for the surgical staff, i.e. 18 °C for the surgeon and 22 °C for the anaesthesiologists. In this document no information was included on the other requirements, for example, the relative humidity and air velocity.

According to Rao, 2004, the British Medical Council recommends basic requirements for the ventilation system in an OR. The ventilation system shall be able to attend various needs, including the dilution of bacteria generated by the surgical team and patient through an appropriate number of air volume changes. Furthermore the ventilation system should provide a comfortable environment for the operating team and patient with controlled temperature, humidity and ventilation. Related requirements are: temperature (23°C ± 3°C); relative humidity (40-60%); fresh air allowance 10 h⁻¹ with total air changes 25 h⁻¹; air filter using HEPA (E=99.97%); and positive pressure.

The NF S90-351 recommends the medical requirements in accordance with the needs of each area (Dorchies, 2005). Normally the ORs are classified as level 4 risk area, which is linked with a target technical efficiency level. An important detail discussed it is that the risk is not defined though the type of surgery, but in terms of the medical procedure (duration and complexity of the procedures, etc) and of the patient’s state of health. The surgeries considered include traumatology, ophthalmology, cardiovascular and neurosurgery. Some criteria recommended for 4 risk level are: minimum filtration chain – F6 [E=70-80%] then F7 [E=80-90%] and H13 [E=99.95%] (ceiling diffusion); and unidirectional flow.

Another standard evaluated in this paper is the UNE100713:2003, a Spanish standard, which recommends three-stages of filtration, [F6 (E=70-80%) then F9 (E>05%)] and H13 (E=99.95%) /H14 (E=99.995%) [ceiling diffusion]; two types of airflow for classes 1, A or B (type 1A – unidirectional flow and type 1B – unidirectional flow or non-unidirectional flow); and 100% fresh

air. Both standards recommend filters in the ceiling diffuses to ensure a better and easier maintenance.

NBR 7256, 1982, is a Brazilian Standard specific for the treatment of the indoor air in Health-Care Buildings. This document presents various recommendations and suggests some complementary bibliography – NBR 6410 and U.S. Federal Standard 209B. The requirements in this standard are presented for three types of surgery. The first type of surgery requires a very low level of germs (Class 1–e.g. orthopaedic, transplant and cardio surgeries). The second type of surgery requires low level of germs (septic and aseptic surgery – less than Class 1), and the last one is only caesarean surgery. The requirements recommended for the first type of surgery are: temperature of 19-24°C; relative humidity of 45-60%; minimum airflow rate of outdoor air (15 m³/(m²/h)); minimum air change rate (25 h⁻¹); minimum filter requirements (G2/F2/A3 – E=75-84%, 70-89%, 99.97%), recommended (G2/F2/A3); and positive pressure. For the second type of surgery is recommended temperature of 19-24 °C; relative humidity of 45-60%; minimum airflow rate of outdoor air (15 m³/(m²/h)); minimum air change rate (15 h⁻¹); minimum filter requirements (G2/F2 - E= 75-84%, 70-89%), recommended (G2/F2/A4 until A3); and positive pressure. The caesarean surgery requires a temperature of 22-26°C, while the other requirements are similar with the second type of surgery as commented. A particularity of this standard is the pressure requirement for septic surgeries that should be 0 pressure, while reference hallway and the air exhaust should pass through filter F1. Another recommendation is the recirculation air, using filters F3 and A3 should be applied. This Standard was referenced in other documents from the Ministerio da Saude, 2002.

ASHRAE, 2004, presents four requirements for OR. However, this standard does not give more information about the type of surgery and medical procedure. It recommends 15 L/s.person of outdoor air. The reference indicates that minimum ventilation rates are also determined by specific requirements. Procedures generating contaminants may require higher rates. This comment is very important, because some types of surgery present more risk for the environment due the gases used during the anaesthesia, and also because of the use of other equipment and substances during the medical procedure.

The ASHRAE, 2005, (Standard 170) is specific to ventilation of health care facilities. However, it is still a draft which is in the first public review. The requirements are applied to patient care areas and related support areas. It can be applied to new

buildings, and additions and alterations to existing buildings. This standard considers chemical, physical, and biological contaminants that can affect the delivery of medical care to patients and the security and health of the workers and visitors. This draft classifies the surgeries in three types: Class A, Class B and Class C, in accordance with the type of procedure and equipment used. The minimum filter efficiencies for HVAC in OR, are recommended the filters 8 (E=40-50%) and 14 (E=90-95%) for Class B and C surgery, while for "large organ transplant surgery" and orthopaedic surgery is recommended 8 (E=40-50%) and 17 (HEPA). The OR must be maintained at a positive pressure with respect to all adjacent spaces at all time. The other requirements described in this draft were: minimum air changes of outdoor air 4 h⁻¹; Minimum total air changes of 20 h⁻¹; 100% outside air shall include heat recovery; relative humidity of 30-60%; and design temperature of 20-23.9°C. (ASHRAE, 2005).

ASHRAE, 2003, is a manual that helps designers and users to understand each part involved in the process, the needs of each requirement (recommended and ideal), and the cost-benefits of some decisions. It also discusses important forms to prevent airborne microorganisms, and predictive and preventive methods to ensure a good IAQ, thermal comfort, and security aspects for the patient, workers and visitors. Other points, of the technical field are discussed, for example, the HVAC systems and energy efficiency. In accordance with this manual, the requirements for the OR are: positive pressure; minimum of 5 air changes of outdoor air per hour; minimum of 25 total air changes per hour; relative humidity of 30-60%; and design temperature of 20-23.9°C. The complementary information is: 100% outside air should be only used when it is required by the codes and only if the heat recovery devices are applied in the OR the minimum of 2.5 Pa; in order to control the exposure to Nitrous Oxide there is a need for both local exhaust systems and general ventilation of the areas in which the respective gases are utilized. These requirements were selected from the ASHRAE, 2003, and the AIA, 2001.

In according to CDC and HICPAC, 2003, the requirements in the OR are: temperature of 20–23°C; relative humidity of 30-60%; minimum filtration of supplied air of 90% and HEPA filter when the type of surgery is orthopaedic; positive pressure; minimum of 15 air change rate per hour which more or equal to 3 air change rate per hour should be fresh air; and no recirculation of the air is allowed. Requirements presented in this guideline are in according with the AIA, 2001. This guideline also gives recommendations in terms of infection

control, for example, to keep operating room doors closed except for the passage of equipment, personnel, and patients, and limit entry to essential personnel. Another detail of high importance discussed only in this guideline is on the care required in a case of a TB patient that needs emergency surgery. For this special surgery some recommendation are given including the use of a special respirator approved by the National Institute for Occupational Safety and Health without exhalation valves in the operating room; if intubating of the patient in the operating room is required do not allow the doors to be opened until 99% of the airborne contaminants are removed; when anesthetizing a patient with confirmed or suspected TB, place a bacterial filter between the anaesthesia circuit and patient's airway to prevent contamination of anaesthesia equipment or discharge of tubercle bacilli (TB) into the ambient air; if the patient has to be extubated in the operating room, allow adequate time for ventilation to clean 99% of airborne particles from the air. Because extubation is a cough- producing procedure use portable, industrial-grade HEPA filters temporarily for supplemental air cleaning during intubation and extubation for TB patients whose require surgery; and if possible, schedule TB patients as the last surgical cases of the day to maximize the time available for removal of airborne contamination.

According to Sze et. al, 2002, Singapore does not have its own standard for hospital IAQ and adopts recommendations of ASHRAE or HTM (Health Technical Memorandum, UK). The requirements reported for the HTM in this paper were: the room air temperature of 15-25°C, relative humidity of 40-60%, and air change rate of 20 h⁻¹.

DISCUSSION

The observed results in the separate standards as discussed above are summarized in Table 1.

The minimum and maximum temperature recommend for the Standards are different. The minimum temperatures are 15°C and 17°C, while the maximum is 27°C. The great difference between the standards makes it difficult to choose and to know that requirement is better to recommend in an OR, and to ensure safety for the patient and the surgical team. An important detail to be considered is that the low temperature can result in risks for the patient. To prevent hypothermia in the patient a high ambient temperature in the OR should be recommended. Johnston and Hunter, 1984 suggests that a temperature between 24°C and 26°C is suitable, while temperatures below 21°C put the patient in risk of becoming hypothermic. However, according to Leslie and Sessler, 2003, a temperature

above 23°C is usually intolerable for the surgical team. In OR it is very important to regard the security aspects of the patient in order to prevent hypothermia and to minimize the chance of a postoperative infection. However, it is also very important to improve the thermal comfort for the surgical team. Johnston and Hunter, 1984, recommend in the OR a temperature between 20°C and 22°C for the staff. While Olesen and Bovenzi [referenced by Mora, R., 2001] recommend 23-24.5°C for the anaesthesiologist, 22-24.5°C for nurses, and 19°C for the surgeon. A temperature for the auxiliary nurse was not recommended, however, they would occupy the same zone as the surgeon.

The maximum relative humidity reported range before a value of 60% and a minimum of 30%. These limits ensure that the growth of certain microorganisms cannot take place. However, it would be also important to evaluate the influence of the relative humidity to the thermal comfort, and if the relative humidity of 30% would not result in some problem for the staff, i.e. the sensation of dryness and irritation of skin and mucous membrane reported for EUR 14449 EN, 1992. Another consideration, the low relative humidity can increase the electric conductivity of the people and in case the floor is not adapted it can result in shock.

Other requirements reported are the air change rate, pressure and filters. In terms of the minimum air change rate per hour different values in some standards were given, and in others no recommendation were made. The air change rate minimum is 10 h⁻¹. The maximum reported rate is 25 h⁻¹. The minimum air change rate of 10, however, it does not specify for a determinate type of surgery. Perhaps, this rate would not be enough to ensure security aspects for example, in an orthopaedic surgery. A positive pressure was reported in the majority of the standards. The NBR 7256, 1982 recommend to use positive or neutral pressure for surgeries of Class II (i.e. abdominal surgery). In all standards, classified for different types of surgery, HEPA filters are recommended for surgeries Class I (i.e. the orthopaedic and transplant). Some standards report a minimum use of two filters for Class II and III, but they recommend using the HEPA filter, as well as for Class I.

Of the evaluated standards, the ASHRAE standards are used as a reference. This is common practice mainly in some developing countries that do not have their own particular standard for IAQ in hospital. They are also used as an additional standard, as is the case for Brazil. The Germany and Swiss standards have been used as a reference or as

a additional standard in some countries in Europe, for example, in The Netherlands, France and The Czech Republic. The advantage to use standards from another country is an easy access to documents that may help to ensure an appropriate IAQ, in accordance with the needs. Another advantage is to see the development in this area abroad. On the other hand such standard a way not give attention to specific requirements and operating conditions.

CONCLUSIONS

This paper summarizes operating room ventilation standards in some countries. From the comparison we can conclude that it is difficult to know the ideal limits of the individuals requirements, because the various standards present different values. It would be interesting to evaluate if these limits were recommended to ensure the security aspects for the patient only, or if it also addresses the thermal comfort and the energy consumption. These standards should consider different types of surgeries, if possible, because some patients need a specific care.

When a country uses a standard from another country, than it is important to know how the standard should be applied, and if this standard is the ideal for the needs of the hospital.

Some Standards do not present all requirements as showed in the Table 1. There are not recommended, for example, the air velocity which is very important in the issues of the IAQ and also thermal comfort.

Standards are usually revised in the period of 10 years. A suggestion, due the development in the medicine, new equipment and surgery procedures, perhaps the standards should be evaluated each 5 years and, if necessary, to adapt new recommendations and to improve other.

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Table 1. Standards evaluated (in no particular order)

Standard	Types of surgery	Air Velocity (m/s)	Design Temperature (°C)	Relative Humidity (%)	Minimum Air change rate of outdoor air per	Minimum Total Air Change per hour	Estimated Maximum occupancy P/1000 ft ² or 100 m ²	Air recirculated within room units	Pressure relationship to adjacent areas	Filter - Efficiencies %
A	Class I		19 -24	45 - 60	15	25			P	75-84 / 70-89 / 99.97
	Class II		19 - 24	45 -60	15	15			P	75-84 / 70-89 (min.) 75-84; 70-89; and 99.97 (recommended)
	Cesarean		22 - 26	45 - 60	15	15			P	
B			17 - 27	45 - 55	15	15		Yes	P	25; 90; and 99.97
			17 - 27		5	25		Optional	P	25; 90; and 99.97
C							20			
D	Class C								P	40-50; and 90-95
	Class B								P	40-50; and 90-95
	Class A		20 - 23.9	30-60	4	20		No		40-50 and 99.97
E	Class I		20 - 23.9	30 - 60	5	25		No	P	
F			20-23	30 - 60	3	15		No	P	99.97
G			20-23	30 - 60	3	15		No	P	99.97
H		0.25				20 - 25			P	99.97
I			20-25	40 - 60						70-80; 80-90; and 99.95
J								No		70-80; E>95; and 99.95 or 99.995
K			21 ± 3°C							40-60; 80-90; E>95; and 99.95
L			18 – 24 and 27	50						85; 99.95; 99.995
M		0.20	21	30 - 50						80-90; E>95; 85 or 95
N			23 ± 3°C	40-60		10	25		P	99.97
O			17-27	50-60			20	Yes		80-90 - 99.97
			15-25	40-60			20			

NOMENCLATURE

A - NBR 7256 and RDC N50
 B- HVAC Applications -C. 7 – Health Care Facilities.
 OBS.₁; the first columns are P (min. 15% excess air)
 C- Ventilation for Acceptable IAQ

D - Standard 170
 E- HVAC Design Manual Hospitals
 F – CDC and HICPAC
 G- AIA
 H- WHO
 I- NFS90-351
 J- UNE100713, 2003
 K- CBZ, 2004

L- DGKH, 2002
 M- VDI 2004
 N- Rao, 2004 (applied for the British Medical Council)
 O- Sze, G., 2002
 OBS.₂; Singapore, in the first row and the HTM in the second row.