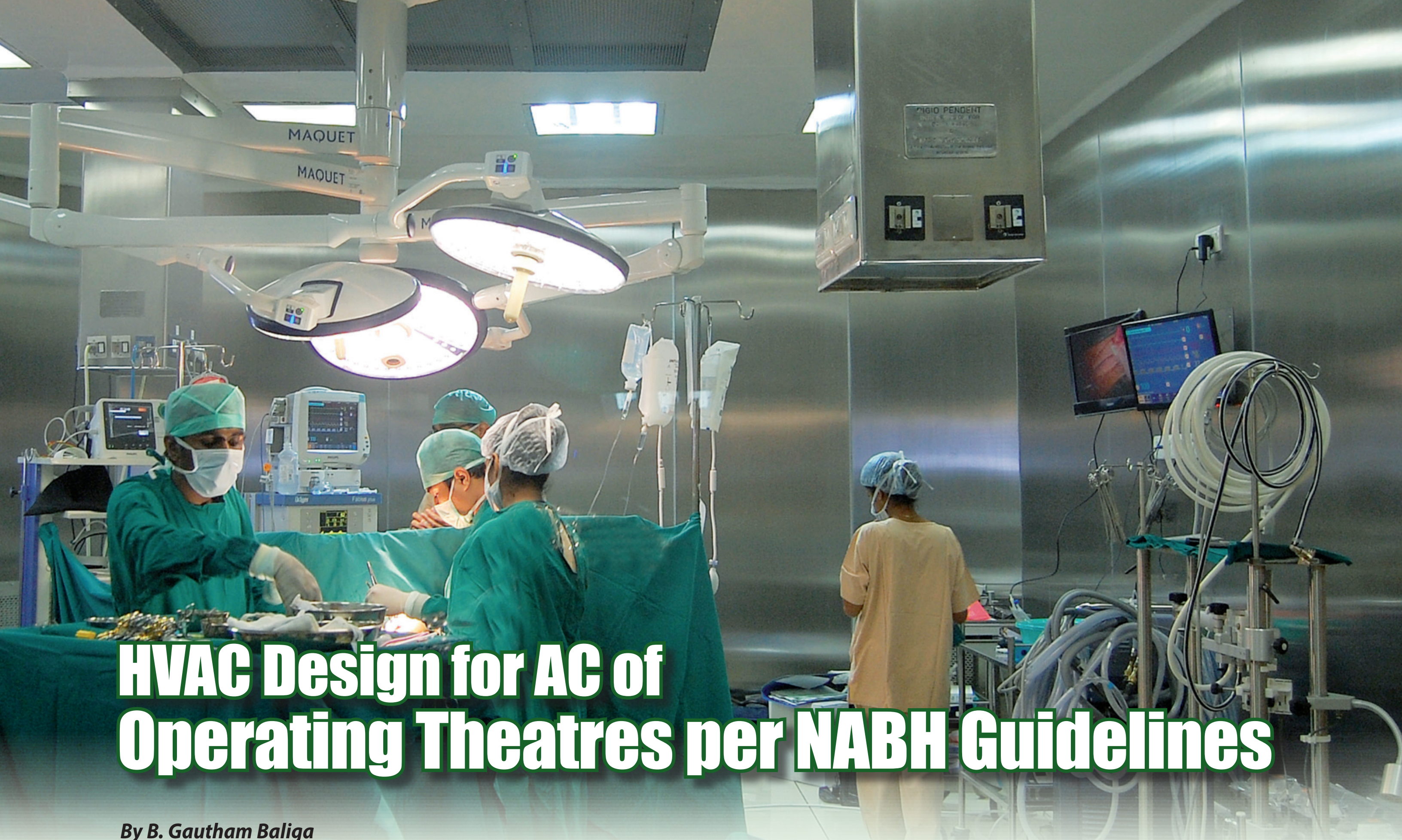

HVAC Design for AC of Operating Theatres per NABH Guidelines

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A surgery being performed at a recently refurbished OT at Godrej Memorial Hospital, Mumbai

Introduction

The important aspect about air conditioning of Operation Theatres (OTs) is that the patient and the operating personnel are susceptible to surgical site infection (SSI). The environment inside the OT is considered an important factor (along with a host of other factors) that can be the cause of SSI.

The HVAC system for an OT needs to be designed with utmost care to provide a safe environment.

ASHRAE and the Centers for Disease Control and Prevention (CDC)[1] of the U.S. Department of Health and Human Services have elaborate guidelines for the air conditioning of OTs. In India, the National Accreditation Board for Hospitals and Healthcare Providers (NABH) standards are being adopted by hospitals. NABH, in their *Guide Book to NABH Standards for Hospitals*[2], have given specific guidelines for the air conditioning of OTs.

This article sets out with describing the HVAC requirements as per NABH recommendations and comparing them with CDC/ASHRAE requirements. Thereafter, we shall discuss psychrometrics and cooling and aspects about the specific air-handling units for OTs.

HVAC Requirements

NABH recognises two distinct types of OTs:

Super-speciality OTs: Operations related to Neurosciences, Orthopaedics (Joint Replacement), Cardiothoracic and Transplant Surgery (Renal, Liver etc.) are carried out here, and the patients are at high levels of risk.

General OTs: Here, operations related to Ophthalmology and all other basic surgical disciplines are carried out.

Super-speciality OTs

The NABH guidelines lay down very specific recommendations as given in *Table 1*.

There are a few observations here:

i. Temperature of 21±3°C is recommended, which is a range from 18°C to 24°C. In actual practice, depending on the type of operation, the surgeon may want to have the set temperature as 18°C or as high as 24°C. The HVAC designer will be well advised to consider designing a system capability to achieve 18°C at 55% RH right up to 24°C at 55% RH.

ii. Room overpressure of 15Pa is much higher than the recommendation of 8Pa as per CDC. The OT tends to be

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Table 1: NABH guidelines for super-speciality OTs

Sr. No.	Parameter	Data
1	Room size	Around 2ft x 20ft x 10ft height till false ceiling
2	Occupancy	5 to 8 persons
3	Equipment load	5 to 7 kW
4	Total air changes per hour (ACPH)	Minimum 30ACPH; more air changes may be required if the air-conditioning load so demands
5	Fresh air make-up	Minimum 5ACPH
6	Inside temperature and humidity	Temperature should be maintained at 21± 3°C inside OT all the time with corresponding relative humidity between 40 to 60%, though 55% is considered the ideal RH
7	OT room overpressure w.r.t. adjoining areas	This needs to be maintained to prevent infiltration of outside air into OT; the minimum positive pressure recommended is 15Pa
8	Terminal air supply	Air to be supplied through terminal HEPA filters in the ceiling; minimum size of filter area to be 8ft x 6ft to cover the entire OT table and the surgical team
9	Terminal supply air flow velocity	Airflow needs to be unidirectional and downwards on OT table; air velocity recommended is 90-120 fpm at grille/ diffuser level
10	Air filtration	There must be two sets of washable flange type pre filters of capacity 10 microns and 5 microns with aluminium/ SS 304 frame within the AHU; necessary service panels to be provided for servicing the filters, motors and blowers; HEPA filters of efficiency 99.97% down to 0.3 microns or higher to be provided in OT and not in AHU
11	Return air	Return air to be picked up and taken out through exhaust grille located near floor (approximately 6 inches above floor level)
12	Air cleanliness class	Air quality at supply i.e. at grille level should be Class 100/ *ISO 14644* Class 5 (at rest condition) *Class 100 means there are no more than 100 particles of 0.5 micron and above in a 1 cubic feet sample*

a little noisier with 15Pa, as it results in higher exfiltration velocities through door cracks. However, considering the fact that there will be a minimum of 5 air changes per hour of fresh air make up, it is conveniently possible to achieve 15Pa with fairly good quality OT doors.

iii. Laminar flow velocity of supply air, recommended as 90 to 120fpm over the supply air grille as per NABH can be 50 to 100fpm as per CDC. Excessive air velocity over incisions causes faster drying and can be detrimental to operations.

iv. The filtration requirement as per ASHRAE is MERV7 as backup, MERV8 in plenum and MERV17 in terminal location for supply air, and this is in line with NABH recommendation.

v. For OTs located in dry regions, the HVAC designer should incorporate humidifiers. The humidification process should not become a source of contamination.

General OTs

The NABH guidelines for General OTs are given in *Table 2*.

Table 2: NABH guidelines for general OTs

S. No.	Parameter	Data
1	Room size	Around 20ft x 20ft x 10ft height till false ceiling
2	Occupancy	5 to 8 persons
3	Equipment load	5 to 7 kW
4	Total air changes per hour (ACPH)	Minimum 25ACPH; more air changes may be required if the air-conditioning load so demands
5	Fresh air make-up	Minimum 4ACPH
6	Inside temperature and humidity	Temperature should be maintained at 21± 3°C inside OT all the time with corresponding relative humidity between 40 to 60%, though 55% is considered the ideal RH
7	OT room overpressure w.r.t. adjoining areas	This needs to be maintained to prevent infiltration of outside air into OT; the minimum positive pressure recommended is 15Pa
8	Supply air	Air to be supplied from the ceiling through a minimum area of 6ft x 4ft to cover the entire OT table and the surgical team
9	Terminal supply air flow velocity	Airflow needs to be unidirectional and downwards on the OT table; air velocities not specified – they should be adequate to keep particulate and bacteria load away from the OT table
10	Air filtration	There must be two sets of washable flange type pre filters of capacity 10 microns and 5 microns with aluminium/ SS 304 frame within the AHU; necessary service panels to be provided for servicing the filters, motors and blowers; HEPA filters of efficiency 99.97% down to 0.3 microns or higher to be provided in the AHU after the 5 micron filters
11	Return air	Return air to be picked up and taken out from exhaust grille located near floor (approximately 6 inches above floor level)
12	Air cleanliness class	Air quality at supply i.e. at grille level should be Class 1000/ *ISO 14644* Class 6 (at rest condition) *Class 1000 means there are no more than 1000 particles of 0.5 micron and above in a 1 cubic feet sample*

Observations:

i. As in the case of super speciality OTs, the HVAC designer will be well advised to consider designing the system capability to achieve 18°C at 55% RH right up to 24°C at 55% RH. Humidifiers should be considered for OTs in low humidity regions.

ii. Room overpressure of 15Pa can be conveniently achieved with the minimum 4 air changes per hour of fresh air make up with fairly good quality OT doors.

iii. *ASHRAE Standard 170-2008*[3] recommends air conditioning in terms of Type A, B and C surgeries.

Class A: Minor procedures under topical, local or regional anaesthesia without preoperative sedation and excluding intravenous, spinal and epidural procedures.

Class B: Minor or major procedures with oral, parenteral or intravenous sedation or analgesic or dissociative drugs.

Class C: Major procedures with general or regional block anaesthesia and support of vital body functions.

The filtration, air change and fresh air requirements for Class A, B and C surgeries are graded and less stringent compared to NABH recommendations.

This graded approach recognises that Class A and B procedures can make do with more economical HVAC systems.

Designing HVAC System for OTs

Psychrometrics

The HVAC designer, considering 18°C and 55% RH as the set point on the minimum side, will have to reckon with a dew point of 8.84°C. The apparatus dew point (ADP) could be in the range of 7.5°C.

Chilled water from the central AC system is likely to be at 8°C or above at the inlet of the chilled water cooling coils, which can at the best pull down the supply air temperature to 13 to 14°C.

To get the supply air temperature down to 7.5°C will require supplementary cooling with a DX cooling system or a brine system operating at, say, 2°C at the inlet to the cooling coils.

Another aspect that needs to be considered is the dehumidified air quantity and total air quantity. It is quite possible that the total air quantity works out to, say, 4000cfm and the dehumidified air, say, 3000cfm. In order to achieve the temperature and RH in the OT, the extra air needs to be bypassed.

Bypassing air can result in a particularly problematic situation for the HVAC engineer. This is on account of the fresh air that will get bypassed along with the unconditioned room return air. The fresh air, if hot and humid, will land up in the OT and disturb the RH there.

The way out of this piquant situation is to supply treated fresh air which is tempered to around 13°C using chilled water. Whilst this can be conveniently done if there is a separate treated fresh air AHU (TF AHU) serving a cluster of OT AHUs, it can also be done quite practically using a chilled water cooling coil and plenum (without blower) for the fresh air intake.

Another important consideration is the control system for part load operation. Under part load conditions, it is still imperative to achieve the design ADP of around 7.5°C. This would mean that the DX plant is always operative using a supply temperature sensor, and the chilled water cooling coil regulates the room temperature using a room temperature sensor.

Plants using brine systems instead of DX can adopt a similar control strategy.

Electric or hot water heaters will need to be installed for RH correction.

AHU Running Hours and Implications

The OT AHUs have to be running on a 24x7 basis, except during maintenance. The AHU fan speed can be lowered by using VFD, and the OT room temperature elevated during non-usage hours to conserve energy. When lowering fan speed, it is imperative that the positive pressure gradient of the OT room is not disturbed.

As a result of operating the OT air conditioning at low temperatures, the exterior surfaces of the OT partition walls and the floor above and below could sweat. The HVAC designer should examine these eventualities and recommend insulation as necessary.

Fresh Air Make-up

The quality of the outdoor air delivered to the operation theatre affects the quality of air inside the OT. The orthopaedic OTs of KEM hospital in Mumbai had to be shut down for three days in February last year after the discovery of dead pigeons in the air intake duct. This had led to infestation of maggots.[4]

Air intakes are accumulation sites for dirt and debris, including rotting botanical materials like leaves, which are growth sites for fungi such as *Aspergillus fumigatus*.

Air intakes should not be located near equipment exhausts, vehicular traffic and cooling towers. As per Table 5.1 of *ASHRAE Standard 62.1*[5], outdoor air intakes need to be located at least 25 ft (7.6 m) from plume discharges and upwind (prevailing wind) of cooling towers, evaporative condensers, and fluid coolers. In addition, outdoor air intakes need to be located at least 15 ft (4.6 m) away from intakes or basins of cooling towers, evaporative condensers, and fluid coolers.

The air intakes need to be well above the ground level to avoid contamination from wet leaves, standing water or piled leaves. In the case of roof-mounted air intakes, it is similarly advisable to take the intake about 4ft (1.2 metres) above the roof level.

It is imperative to provide proper access to maintenance personnel to clean the air intakes.

Condensate Drain Pans

The condensate drain pan in the AHU needs to quickly remove the condensate water from the AHU. If water stagnates

Figure 1: AHU condensate SS drain pan sloped in two directions

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in the drain pan, fine dust accumulates over it and a thick bio film of bacteria, fungi and protozoa grow on the metal surfaces. The drain hole has to be flush with the bottom of the pan. The pan should be made ideally of smooth stainless steel and sloped in two directions (see *Figure 1*) so that the possibility of water stagnation is eliminated.

Ultraviolet Germicidal Irradiation (UVGI)

UVGI is being used to limit the growth of micro-organisms in AHUs. UV light, especially around 265 nano-meters (NM) damages the DNA of micro-organisms. UVGI from the lamps in AHUs inactivate microorganisms present in the airstream and on surfaces such as cooling coils and drain pans. Vegetative bacteria including mycobacteria and viruses are very susceptible to UVGI, whereas fungal and bacterial spores are least susceptible.

The residence time of the microbe under UVGI illumination, as well as the intensity of the irradiation, are important factors for the inactivation of microorganisms. Low airflow conditions (less than 400fpm, see *Figure 2*) and appropriate intensity ensure that a substantial amount of vegetative bacteria and fungal spores are inactivated.

The placement of the UV lamps affects its efficacy. UV systems may be installed either upstream (return side) or downstream (supply side) of the evaporator coil. Either installation will keep the evaporator coil clean. (2008 *ASHRAE Handbook HVAC Systems and Equipment*, Chapter 16.)[6]

Figure 2 shows that UV output efficiency is greater when the UV lamps are placed upstream of the cooling coil where the air temperature is higher.

The UV lamps have to be turned towards the cooling coils and away from filters. Filter media decay in UV light. The lamps have to remain ON at all times, even when the AHU is switched OFF, except during maintenance.

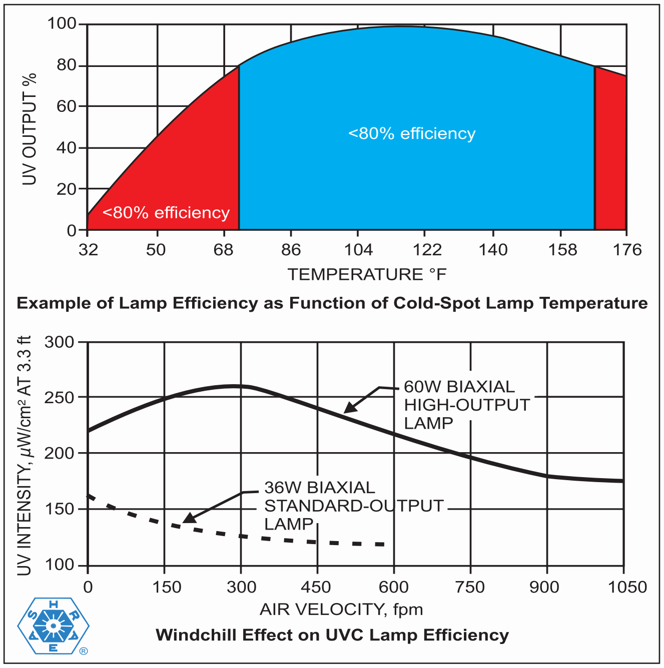

Figure 2: UV lamp efficiency

Healthcare facilities using UV lamps in AHUs have reported that the drain pans and cooling coils remain in prime condition for years after installation.

While using UV lamps, safety considerations are paramount. Safety cut outs are essential to prevent accidental turning on of the lamps when maintenance work is being carried out inside the AHU.

Regular maintenance of UVGI systems is required and usually consists of keeping the bulbs free of dust and replacing old bulbs as necessary after their life, determined by hours of operation by the manufacturer, is over.

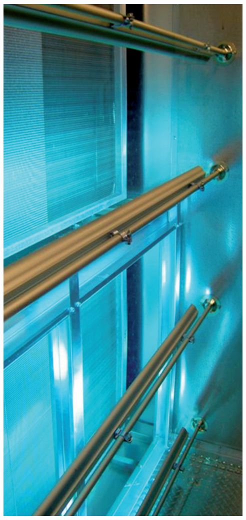

Figure 3: UVGI lamps inside AHU

Installation, Commissioning and Validation of the HVAC System

Cleanliness is the dominant consideration during the installation process.

The ducts should have their open sides closed with PVC sheets so that dust does not ingress.

Installation of ducts at site should be undertaken only after all the masonry work is completed, a point often ignored due to exigencies of time.

The AHU and the laminar flow module too should be installed with cleanliness in mind. One should seriously consider the possibility of bringing in the AHU in assembled condition to site.

The supply air ducts of OT HVAC system are subject to as high a positive pressure as 3″wg, and the return ducts are subject to negative pressure as low as -1″wg. The ducts should be tested for air leakage with duct pressure testing equipment. Duct pressure testing will ensure that energy loss due to air leakage is minimised and in the case of return air ducts, the chances of ingress of contaminated outside air into the ducts is minimised. Testing can be done as per the relevant SMACNA standard for duct testing.

After installation, an 'air blow down' process should be undertaken and documented before loading the HEPA filters. Before the AHU is started, the OT should be cleaned and mopped dry. AHU should be run on pre-filters for 24 hours or more to dislodge the coarse dust in the ducts. After mopping and cleaning of the OT again, the post filter should be loaded. After running on post filters for at least 24 hours and after ensuring that there is no traffic of installation personnel in the OT, the HEPA filters are to be loaded.

After air-balancing and adjusting the psychrometric process to achieve the air quantity, temperature, humidity and over

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pressure, the OT is ready for HEPA filter Dispersed Oil Particulate (DOP)/ Poly Alpha Olefin (PAO) challenge test and particulate counting. This process of determining that the designing parameters are met is called the 'validation process'.

OT validation process is to be carried out at least once a year or after change of HEPA filters.

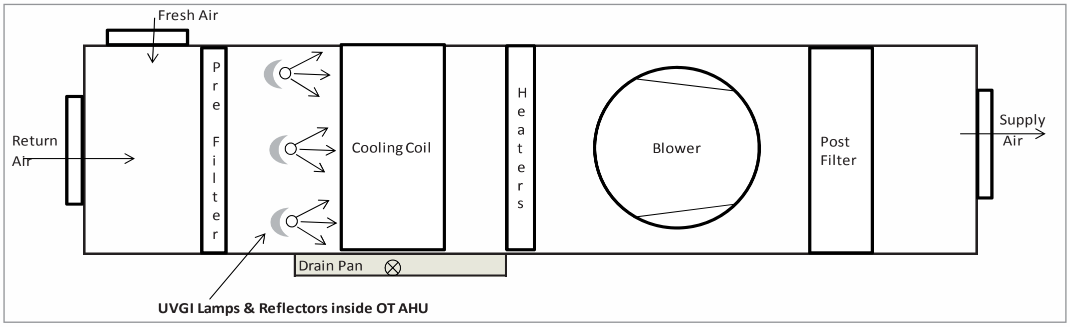

Figure 4: UVGI lamp placement schematic

In Conclusion

Air conditioning of OTs is a matter of great responsibility for the HVAC engineer. It is important that the relevant codes are adhered to and the temperature and humidity needs of the surgeon and OT staff are understood.

Since the systems will run round the clock, year after year, energy efficient equipment should be used together with energy saving options during non-OT usage hours.

Special care with respect to cleanliness has to be practiced at the installation stage itself.

Periodic validation of system is a necessity.

References

1. *Guidelines for Environmental Infection Control in Health-Care Facilities,* U.S. Department of Health and Human Services Centers for Disease Control and Prevention (CDC)
2. *Guide Book to NABH Standards for Hospitals*
3. *ASHRAE Standard 170-2008*
4. Times of India, 28th February 2012
5. *Indoor Air Quality Guide Best Practices for Design, Construction, and Commissioning,* ASHRAE
6. *ASHRAE Handbook HVAC Systems & Equipment*

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