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Hospital HVAC Design : A Challenge for IAQ, Energy Recovery and System Reliability

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This article is written from the perspective of consultants and does not cover any particular project but draws on authors' experiences from a number of hospital projects completed in Singapore. The climatic conditions in Singapore are tropical with high humidity levels, much like coastal cities in India.

Human will to live healthy and longer lives and continued advances in medical science and technology have turned hospitals from merely buildings to sophisticated facilities for preventing and treating diseases. HVAC system in a hospital assumes high significance due to its sensitive relationship with the health of the patients, caregivers and visitors. HVAC system is also important as the cost of its operations affects the cost of healthcare in a significant way. This article focuses on three important issues in hospital HVAC design: Indoor Air Quality (IAQ), energy recovery and system reliability.

Twin Views of a Hospital Facility

While designing a hospital HVAC system, designers have to hold twin views of the facility: One from the functional point of view and the other from the HVAC point of view. Both views, of course, are inter-related.

According to the ASHRAE, from the functional standpoint, a typical hospital facility basically comprises seven categories of areas:

– Surgery and critical care (operating room, delivery room, etc.)
– Nursing (patient rooms, intensive care unit, etc.)
– Ancillary (radiology, laboratories, etc.)
– Administration (offices)
– Diagnostic and treatment (examination room, therapy room, etc.)
– Sterilisation and supply (steriliser room, equipment storage, etc.)
– Service (kitchen, laundry, etc.)

The functional requirements dictate the HVAC requirements. The HVAC view, however, boils down to seeing all the spaces from the point of view of:

– Temperature and humidity
– Ventilation
– Pressure relationship with surrounding spaces
– Air cleanliness level
– Air distribution

– Operating hours

– System reliability

Proper understanding of both functional and HVAC views of each and every space is the foundation for a successful HVAC design.

Hospital IAQ challenge

Perhaps nowhere is Indoor Air Quality (IAQ) as critical as in hospitals. In the hospital context, IAQ aspect is more than just the promotion of comfort. In many cases, proper IAQ is a factor in patient recovery and in some instances, it is the major treatment.

At present, Singapore does not have its own standard for hospital IAQ and adopts recommendations of ASHRAE or HTM (Health Technical Memorandum, a publication of Department of Health, UK) or both. **Table 1** shows temperature and humidity requirements for four most critical areas of a hospital.

While temperature and humidity requirements are important in hospitals, it is the issue of crosscontamination and bacterial concentration that assume critical importance in HVAC design. The fundamental reason behind this is the presence of airborne pathogens that can create havoc by infecting healthy people, and complicating recovery of patients.

Table 1 : Temperature and humidity requirements in hospitals

Standards	ASHRAE	HTM	Singapore	ASHRAE	HTM	Singapore
Room	**Temperature (°C)**			**Relative Humidity (%RH)**		
Operating Theatres	17~27	15~25	19- 21	45~55	40~60	50~60
Intensive Care Unit	24~27	-	22-23	30~60	-	55~65
Wards (airconditioned)	24	-	22~23	30~60	-	55~65
Isolation Ward	24~27	-	22~23	30~60	-	55~65

Airborne Pathogens

Pathogens are any disease-causing microorganism, which fall into three major taxonomic groups: Viruses, bacteria, and fungi. The single most important physical characteristic of airborne pathogens is their size, as it directly relates to the filtration efficiency and their ability to stay airborne. Preventing airborne transmission of diseases through pathogens is one of the key challenges for HVAC system design in hospitals.

Contagious viruses and bacteria come almost exclusively from humans and their path of transmission is return air. Spores and environmental bacteria may enter from the outdoors, but once growth (amplification) occurs indoors they may appear in the return air at higher levels than in the outdoor air. Spores can initially enter a building by various routes, including inlet air or infiltration, or they may be brought in with building materials, carpets, clothes, food, pets, or potting soil. Once spores germinate and growth occurs in an AHU or anywhere inside the building, new spores may be generated and appear in the return air. Filters may intercept spores, but moisture may cause them to "grow through" the filter media.

The risk of infection is proportional to the concentration of pathogens. The risk of infection is linked not only to the purity of the air, but also to the air distribution patterns that should shield a wound site by forming a protective layer.

Strategies for Maintaining Hospital IAQ

Typically, the strategies available for controlling the spread of airborne pathogens include dilution through ventilation, filtration, ultraviolet germicidal irradiation (UVGI), air purging and isolation through pressurisation control.

UVGI has not been applied so far in Singapore hospitals due to concerns about its reliability. There is, however, growing interest and trend towards adopting it. It offers advantages in terms of offering alternative to HEPA filters for non-critical areas (areas other than OT), providing an added layer of protection when used with HEPA filters and also helping to prevent growth of algae, etc., in the AHU drain pan.

Increased ventilation rates reduce the overall concentration of pathogens. ASHRAE recommends ventilation rates in accordance with ASHRAE Standard 62, Ventilation for Acceptable Indoor Air Quality. Each project, however, may have specific ventilation rate requirements that may differ from ASHARE. **Table 2** shows ventilation rates for four most critical areas of a hospital.

Table 2 : Ventilation requirements in hospitals

Standards	**ASHRAE**	**HTM**	**Singapore**
Room	**Minimum no. of air changes/hour**		
Operating Theatres	15	20	20
Intensive Care Unit	6	15	15
Wards (airconditioned)	4	-	15
Isolation Ward (air-conditioned)	6	-	15

For one of the hospitals, the concept of air purging was employed for maintaining IAQ in private air-conditioned wards. Under this arrangement, once the patient is discharged, the foul air trapped inside the room is purged by simply opening the windows and stepping-up the speed of the toilet exhaust fan (2-speed fan). The foul air is extracted out of the room through the toilet and discharged externally. The room air is completely replaced with clean and fresh air before the next patient moves in. During the purging mode, air-conditioning to the room is shut off to avoid condensation. With this arrangement, IAQ in the room is improved without additional equipment since every attached toilet and bathroom is provided with a mechanical ventilation system.

As mentioned earlier, there is a direct relationship between the filtration efficiency and the size of pathogens that need to be arrested. Studies have shown a relationship between improved air filtration and viable pathogen concentrations and patient infection rates.

Proper pressurisation, to prevent exfiltration/ infiltration of pathogens, is an absolutely essential strategy for many of the critical areas in a hospital. But, there can be significant energy penalties for increasing ventilation to maintain the required pressurisation levels.

In addition to ventilation, filtration and pressurisation, air distribution assumes an import criteria for maintaining the IAQ.

How some of the above factors come into play can be seen in the design of the most critical room in a hospital: operating theatre (OT).

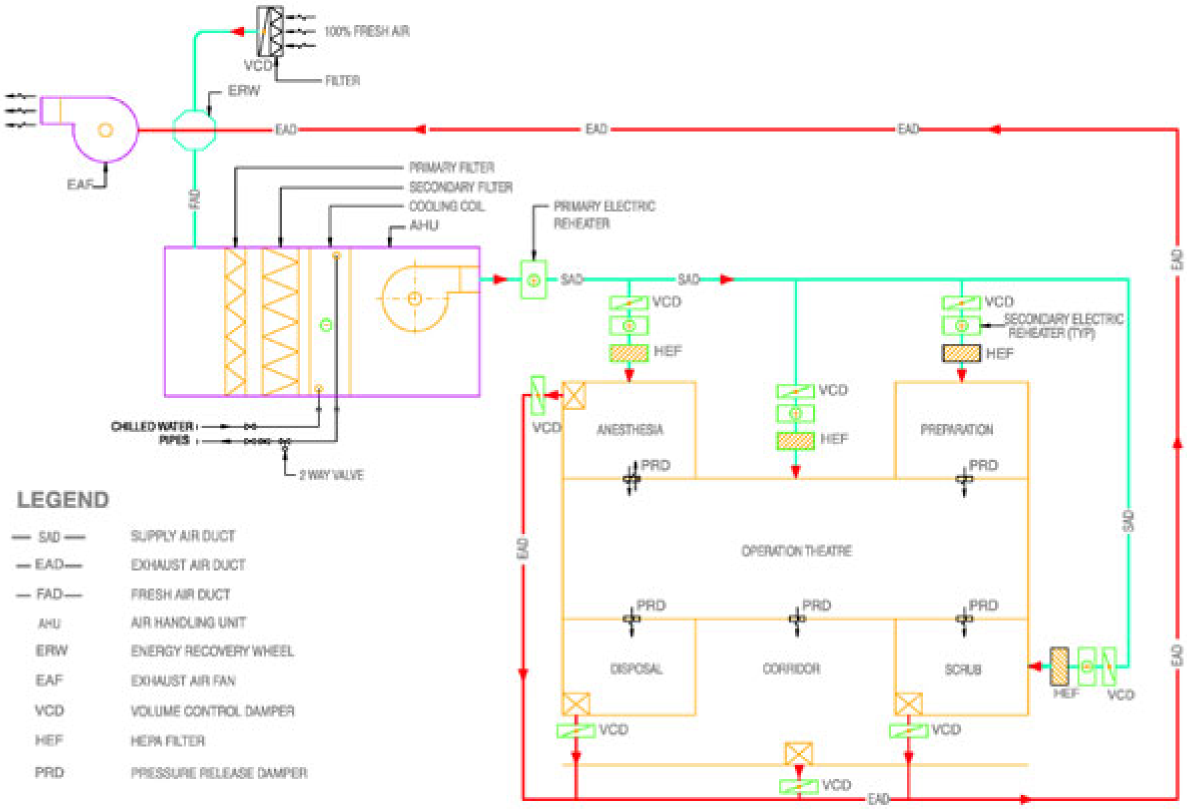

Figure 1 : HVAC schematic for operating theatre

Click to view clear picture

Design of an Operating Theatre

HVAC system design for an operating theatre starts with a reminder of the following key objectives:

– To control the concentration of harmful bacteria;

– To prevent infiltration of less clean air into the operating theatre;

– To create an air flow pattern that carries contaminated air away from the operating table;

– To provide a comfortable environment for the patient and operating team;

– To ensure uninterrupted operations;

– To save energy.

The operating theatres are categorised as 'general' and 'ultraclean'. Ultra-clean OTs, used for procedures, such as, organ transplant, orthopaedic surgery, neurosurgery, etc., where bacterial contamination is relatively more critical.

Table 3 : Design parameters for operating theatres

Design parameters	General	Ultra-clean
1. Temperature	20±1 °C	20±1 °C
2. Relative Humidity	55±5%	55±5%

3. Bacterial count	<35 cfu/m3	<10 cfu/m3
4. Supply air velocity at the operating table	0.38 m/s	0.38 m/s
5. Fresh air (no recirculation)	20 air changes/hour	20 air changes/hour
6. Total number of air changes	20 air changes/hour	>300 air changes/hour
7. Pressurisation	+25 Pa	+25 Pa
8. Filtration efficiency	99.997% at terminal	99.997% at terminal
9. Supply air discharge area	2.4m x 1.8m	2.8m x 2.8m

Table 3 shows basic design parameters for HVAC design of an OT.

Figure 1 shows a schematic diagram for HVAC system for a general OT. The system used is CAV (constant air volume) type. The fans, both on the supply and exhaust side, however, are provided with Variable Speed Drive (VSD). The VSD basically helps to maintain the flows against varying static (filter clogging, etc.) and also for set back for unoccupied hours. The supply air passes through an energy wheel before treatment by a dedicated set of AHUs. The treated air is supplied through terminal HEPA (99.997% efficient) filters. In the past, the return air was collected through return air openings provided near the floor level at the four corners of the OT. The current designs, however, are allowing the return air to be collected from the adjacent rooms. This change stems from the fact that there was practically very little return air collection within the OT and most air was exfiltrating to the surrounding rooms, basically to maintain the pressure differential. In addition, the practice of collecting return air from the OT itself was prone to infiltration of outside air when the OT doors were opened for any reason. OTs are provided with relief dampers for maintaining positive pressure. The humidity is maintained by using heaters.

Unlike general OT, an ultra-clean OT allows recirculation of air within the OT. The return air for these OTs passes through 80- 90% efficiency filters before passing through 99.997% efficient terminal HEPA filters and discharged vertically to provide a laminar downflow pattern. The low turbulence downward airflow combines the effect of both, air dilution and room air displacement.

Besides operating theatres, the others areas of the hospital, which require similar control of the aseptic conditions are the postoperative recovery rooms, ICUs, burn wards, isolation units. Other areas, which require high rates of ventilation and pressurisation control are radiology department, laboratories, infectious disease and virus laboratories, autopsy rooms and animal quarters.

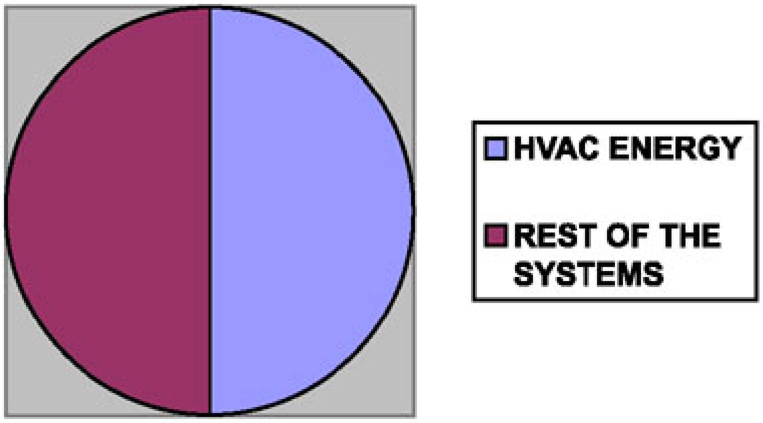

Fig 2 : HVAC energy cost v/s rest of the systems in a typical hospital

Energy Recovery

In today's competitive world, saving lives and providing high quality medical services are not the only parameters for the success of a hospital. Energy efficiency is a major factor in hospital's financial well-being and eventually its affordability for the patients. Energy efficiency is a broad term, which includes strategies such as using efficient chillers within their most optimum performance zone, using variable speed drives for pumps and air handling units, maximising areas with natural ventilation, etc. One of the strategies, however, is to recover waste energy. Energy recovery has been found to be an effective way of saving energy cost and the following discussion pertains to the practices that have been successfully used for hospitals in Singapore.

An energy analysis of a 800 bed hospital (120,000 sq. m gross floor area, 2 basements, 9 storeys) showed that the energy cost for HVAC system was about 50% of the total energy cost of the hospital (**Fig 2**). The total energy cost included, besides HVAC, cost for other systems, such as, lighting, power (medical equipment, office, etc.), lifts, fire, sewage, gas, etc.

For the same hospital, it was calculated that about 70% of the total HVAC cost was due to the chiller plant - chillers, pumps and cooling towers. The high concentration of energy in the chiller plant necessitates consideration of using a heat pump system for recovering condenser heat for heating domestic water. Such a system was recently used for a hospital where two heat pumps were coupled to the condenser water circuit from the chillers. With this arrangement, the waste condenser heat is reclaimed to generate sufficient hot water for the whole hospital. Boilers are not required as a result.

For the same hospital, it was identified that operating theatres (total 14 in number, 2 ultra clean and rest general type) alone contributed about 200 TR air-conditioning load, which was slightly less than 10% of the overall load (2250 TR). Again, it shows that energy recovery from the operating theatres is also an important area to focus on as part of the overall energy efficiency efforts.

Energy recovery wheel or enthalpy wheel, which can recover both sensible and latent energy, has been used for the operating theatres. The wheel, installed upstream of supply air AHU, recovers energy by allowing transfer of heat (sensible and latent) from the outdoor air to the exhaust air. To get an idea of the performance just in terms of the sensible energy, the outdoor air can be expected to cool from 32°C to 26°C when passing through the wheel and transferring energy to the exhaust air (typically at about 21°C).

System Reliability

HVAC system reliability in hospital context is a very important issue. Unreliable systems can lead to highly undesirable situations, such as, cross-contamination, high temperature, high humidity, etc. Apart from selecting reliable equipment and following proven practices, providing standby HVAC equipment is a crucial element of the overall system reliability.

While deciding the extent of standby HVAC equipment, one invariably has to strike a balance between ensuring required level of system reliability and keeping the capital cost down. The following discussion provides insight on the practices used for ensuring system reliability for chiller plant and air-handling system for hospitals in Singapore:

Table 4 : Chiller plant configuration for n+1+1 reliability

Item	Data
Background Information	– 800 bed hospital – 2 basements, 3 storeys podium and 6 storeys tower block (total 9 storeys) – gross floor area: 120,000 sq. m (approx.)
Key input data/considerations	– estimated block load: 2250 TR – estimated night load: 600 TR – peak chiller efficiency: at about 70% – configuration desired: n+1+1
Chiller configuration used	– 6 x 750 TR water cooled centrifugal chillers – 6 sets of matching pumps and cooling towers

Chiller Plant

Chiller plant is the heart of an HVAC system. The configuration adopted for the chiller plant (chillers, pumps and cooling tower), as elaborated in **Table 4**, for one of the recently constructed hospitals in Singapore is n+1+1. The objective behind this arrangement is to ensure 100% system availability in the event when one piece of equipment (chiller/pump/cooling tower) is under preventive maintenance and one more piece of equipment is under breakdown.

With the above arrangement, at the most 4 chillers will be working with 2 chillers remaining as standby.

Air Handling System

The reliability of air handling system is critical for areas like operating theatre (OT), intensive care unit (ICU), radiology lab, etc. The standby provision ranges from 100% standby AHU to merely providing a standby motor.

The practice used for OT is to provide two AHUs in parallel with each rated at 75% of the total requirement. Both would work under normal circumstances. In the event of a failure of one of the AHUs, the other AHU would be capable of supporting OT, though at a reduced performance level (75%). The fans for exhausting the OT air are also configured on the same lines. This arrangement, though not ideal, seeks to balance the conflicting needs of highest reliability, smallest plant foot print and lowest cost. It also serves a very important purpose, especially in the context of OT, which is to ensure uninterrupted airconditioning/ ventilation.

An alternative to providing a complete standby AHU is to provide only the standby motor for the AHU. For areas like, ICU, radiology, etc., this approach has been adopted which shields against prolong break in airconditioning due to the breakdown of AHU motor. Unlike parallel AHU configuration, the areas served with this arrangement would be prone to interruption in air-conditioning supply, even though it may be for small periods - the time required for replacing an AHU motor. The main advantage of this arrangement is saving on space and, of course, cost.

Conclusion

HVAC system design for a hospital is a challenging undertaking. It involves deep appreciation of the relationship between the performance of HVAC system and the health of patients, care givers and visitors. So, IAQ is of prime importance. Besides IAQ, energy recovery and system reliability demand special attention. A well-rounded HVAC design would adopt without compromise all the proven practices and principles for these three pillars of hospital HVAC design.

References:

1. 1999 ASHRAE Handbook: HVAC Applications
2. Health Technical Memorandum 2025
3. Manufacturers'/suppliers' catalogues and literature