HVAC Design for Hospitals

The Growing Challenges!

Asian Heart Institute, Mumbai, completed in 2002 with 160 beds & 5 OTs. Installed chiller capacity 1025 TR

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It will come as a surprise to many to know that the healthcare industry in India is moving neck to neck with the pharmaceutical and the software industries. Till date, approximately 12% of the potential offered by the healthcare industry has been tapped and the current worth of this industry is estimated at US$ 35 billion, which is expected to reach over US$ 75 billion by 2012 and US$ 150 billion by 2017. The sector offers immense potential to healthcare players due to the following reasons:

- ***Changing Lifestyles:*** The country is witnessing a rise in the incidence of lifestyle-related and other diseases. A growing elderly population and rise in income levels are also pushing for better facilities in the country.
- ***Health insurance:*** Currently only 10% of the Indian population has health insurance and this business is growing @ 50% annually. With increasing average household consumption, the annual healthcare expenditure is projected to grow at 10%.
- ***Medical Tourism:*** In 2007, India treated 450,000 foreign patients ranking it second in medical tourism with the potential to reach US$ 2 billion by 2012. The key selling points of the medical tourism industry are its cost effectiveness combined with the attraction of tourism. Besides, world class medical facilities, India is also trying to promote its traditional medicine such as Ayurveda.

Driven by strong local demand, the Indian healthcare market is expected to continue growing @10 to 12% annually, attracting investments of US$ 50 billion annually for the next 20 years and add 3.1 million beds by 2018 to the existing 1.1 million. This sector, hence, has been attracting huge investments from domestic players, financial investors and private equity (PE) firms.

Hospitals

Healthcare building design is rapidly undergoing transformation that has significantly changed the appearance of our hospitals in the last one decade. Due to the social fabric of our society, modern hospital design challenges include a need to create a healing environment for patients, family and staff, along with energy-efficient design practices that include appreciation of classical elements of healing such as nature, daylight and fresh air. Also, with growing competition, hospitals extend a red carpet treatment for making the stay of patients and their relatives comfortable. Today, patients are greeted at the registration areas and escorted to their room. The escorting family members find their path lined with gift, convenience shops and fancy eateries.

Modern hospitals are multi-specialty, comprising of a wide range of services and functional units, thus making its designing

Medanta – The Medicity, Gurgaon, when fully completed in 2010, will have 1600 beds - 1250 normal, 350 critical care & 45 OTs. Installed chiller capacity 4800 TR. ***Photo & other details courtesy of Manish Bhatia***

complex. The traditional image of a hospital comprising of Doctor and Patient rooms, has broadened to include Imaging & Diagnostic areas, Clinical Laboratories, Emergency Rooms, Surgery Suite, Intensive Care Units (like NICU, PICU, ICCU, ICU etc.), support functions, such as Cafeteria, Laundry, Kitchens, Central Sterile & Storage Department (CSSD), Offices, Support and Housekeeping. With continuous advancement in the medical field and challenges of new mutant viruses/bacteria, the traditional design methods have become obsolete.

Lastly, hospitals are now growing in size and turning multi-speciality which makes their design a tough task. During the course of this article, many references are made to the upcoming *Medanta-The Medicity* hospital in Gurgaon (NCR) which is spread over 43 acres with 1250 beds, 350 critical care beds, 45 operation theatres, over 25 medical divisions and a capacity to treat over 5000 patients per day.

Codes and Standards

Due to diversity in the type of functions and nature of operation, hospitals are probably amongst the most regulated of all building types, as they have to comply with several criteria, like National Building Code (NBC), Ministry of Environment & Forests (MoEF) regulations, Energy Conservation Building Code (ECBC) guidelines, Central Pollution Control Board (CPCB) norms etc. In addition to the above, Indian hospitals aim for competing with their international counterparts and also follow norms like AIA (American Institute of Architects) guidelines, NFPA (National Fire Protection Agency) life safety codes, ADA (American Disability Act) and regulations of the Occupational Safety and Health Administration (OSHA). The associated services design follows ASHRAE (American Society of Heating, Refrigerating & Air conditioning Engineers) standards/codes for HVAC design, NFPA for fire safety, NEC for electrical system, Uniform Plumbing Code for public health engineering, etc. It is difficult for one individual to be familiar with all such codes and regulations, which is why specialised consultants play an important role in hospital planning.

Lastly, most modern hospitals in India aim for *Joint Commission International (JCI) Accreditation Standards for Hospitals* which also has its own guidelines.

Necessity of Air Conditioning

The necessity of Heating, Ventilation and Air Conditioning within buildings has been well established over the years, and in hospital designing, it assumes an even more significant role due to the following reasons:

- Different temperature & relative humidity guidelines for various functional spaces and their accurate control.
- Varying air quality needs, resulting in different filtration standards.
- Air pressure relationships for restricting air movement within and between various departments.
- Requirements in specific areas to dilute and remove contaminants in the form of airborne micro-organisms, viruses, odour, hazardous chemicals and radioactive substances.
- Operation of sophisticated medical equipment that requires controlled conditions.

In addition, the microbiological transmission in a healthcare setting is a potential risk through carriers (both patients and visitors) like droplets, physical contact, vehicle and air borne transmissions. Proper air conditioning of a medical-care facility is thus helpful in the prevention and treatment of diseases.

Sustainability Aspects in HVAC Design

Hospitals are large public buildings that have a significant impact on the environment and economy of the surrounding community. They are bulk users of energy and water, and produce a large amount of waste thus making them natural candidates for following sustainable design practices.

The recommended design strategy for hospitals is as follows:

Passive Design Strategies. Air conditioning engineers have a major role to play in working closely with architects to incorporate passive design strategies at the beginning of a project, like climate-friendly envelope design, incorporation of shading devices, day-lighting of buildings and optimised window wall ratios (WWR). It is a well documented fact that these passive strategies can help reduce air conditioning loads by nearly 30%. Energy Conservation Building Code (ECBC) categorises hospitals under 24 hours usage facility and recommends following envelope design parameters for all climatic zones (except cold &

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moderate) which covers a majority of India.

- Wall thermal conductivity as 0.07 Btu/hr/sft/°F (thus requiring at least 25 mm thick insulation)
- Roof thermal conductivity as 0.05 Btu/hr/sft/°F (thus requiring at least 50 mm thick insulation)
- Glass thermal conductivity as 0.56 Btu/hr/sft/°F and Solar Heat Gain Coefficient (SHGC) of 0.2-0.25 thus requiring double glazing.

Active Design Strategies. Use of high COP chillers, VFD for air handling units/pumps/chillers/cooling tower fan motors, Demand Control Ventilation (based on internal CO_2 levels for non-medical areas), Airside and Waterside economisers etc. are recommended active design strategies that need to be considered by engineers for lowering the annual power consumption demand.

Energy Recovery. It is recommended to recover energy using heat recovery wheels, heat pipes etc. Most hospitals require large amounts of outside air for infection control and it is desirable to extract the energy from spent air and pre-cool the outdoor air.

Reduce Internal Loads. Some of the areas have high internal loads and also highly transient instantaneous loads in a hospital environment like imaging equipment. It is important to factor them in the design to prevent oversizing of systems.

Hospitals in future will also add the following to their sustainability aspect:

Onsite Power Generation. It is important to optimise the internal demand and thereafter employ renewable sources like solar or wind energy as these are expensive options.

Offset Carbon Footprint. Follow the three R's of sustainability (Reduce, Recycle & Reuse) and offset the carbon footprint.

Indian Green Building Council currently categorises hospitals under the category of New Construction (LEED NC). Several new upcoming hospitals are thus opting for a green rating and one such upcoming hospital is Kohinoor Hospital in Mumbai which is attempting a LEED Platinum rating.

It is important to mention that conventional thumb-rule design practices need to be challenged by HVAC designers as hospitals following the above measures can easily reach installed capacity averaging around 300-400 sft/TR and this benchmark continues to get pushed further.

Indoor Environment Quality (IEQ)

Modern hospitals are now shifting their focus to providing wholesome care by providing a healthy indoor environment to the patients, healthcare givers (doctors, nurses, staff) and visitors (attendants, relatives). This broad topic encompasses the following issues:

- Temperature
- Relative Humidity
- Indoor Air Quality (outdoor ventilation air)
- Lighting
- Filtration
- Noise Control

Table 1 gives the commonly followed guidelines for temperature, relative humidity, filtration and air-pressure relationships followed in designing of hospitals. This table is reproduced from an ASHRAE Handbook but modified, based on the experience of Indian hospitals and its users. The above parameters are discussed in detail below.

Temperature & Humidity Control

Small micro-organisms are commonly transmitted through dust particles whose movement is greatly affected by low relative humidity due to static energy. On the contrary, at high relative humidity, a very thin invisible moisture film is formed over surfaces that help in multiplication of micro-organism colonies. It is therefore a good practice to maintain the relative humidity between 40-60%.

The choice and need for installing dedicated humidifiers/dehumidifiers is left to the designers for various spaces. Some designers have adopted the concept of using both chilled water and hot water coils in AHU's serving critical areas like OT, ICU, CSSD, Radiology, Pre & Post Operation, Laboratory etc. The need for RH control assumes special significance in case of Operation Theatres. It is important to note that use of spray type humidifiers should be discouraged in hospital application.

Kokilaben Dhirubhai Ambani, Mumbai, completed in 2009 with 700 beds & 21 OTs. Installed chiller capacity 3000 TR.

Kohinoor, Mumbai, completion in 2010 with 150 beds & 5 OTs. Installed chiller capacity 600 TR.

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Area / Room	Design Temp. (deg.C)	Relative Humidity (%)	Min. total ACPH	Outdoor ACPH	Air Pressure in relation to adjacent area	Recir-culation of Air	No. of stages of filtration
SURGERY AND CRITICAL CARE							
Operating Room	18-24	50±5%	15	100%	Positive	No	3
Sterile (Clean) Corridor	22-24	30-60	6	2	Negative	Yes	2
Cath Lab	20-22	30-60	15	3	Positive	Yes	2
Delivery Room	20-22	Less than 60%	15	3	Positive	Yes	2
ICU/CCU	22-24	Less than 60%	6	2	Equal	Yes	2
Treatment Rooms	22-24	Less than 60%	6	2	Equal	Yes	1
NURSING							
Patient Room	22-26	Less than 60%	6	2	Equal	Yes	1
Toilet	--	--	10	--	Negative	No	--
Nurseries	24-26	Less than 60%	6	2	Equal	Yes	2
Protective Isolation Room	22-24	Less than 60%	12	2	Negative/ Positive		2
Patient Corridor	26-30	--	6	--	Equal	Yes	1
Radiology & Imaging							
X-ray	22-24	30-60%	6	2	Positive	Yes	2
CT/MRI	20-22	30-60%	6	2	Positive	Yes	2
Clinical Laboratory / Blood Bank							
General	22-24	Less than 60%	6	2	Equal	Yes	2
Biochemistry / Serology	22-24	Less than 60%	6	2	Negative	Yes	2
Cytology / Histology	22-24	Less than 60%	6	2	Negative	Yes	2
Pathology / Microbiology	22-24	Less than 60%	6	2	Negative	Yes	2
Sterilizing Area	22-24	Less than 60%	10	2	Positive	Yes	2
Ancillary							
Treatment Room	22-24	Less than 60%	6	2	Equal	Yes	1
Soiled Workroom or Soiled Holding	--	--	10	--	Negative	No.	--
Sterile (Clean) Room or Holding	26-28		4	2	Equal	Yes	1
Sterilizing & Supply							
Sterilizer Room	22-24	30-60	10	100%	Negative	No	2
Sterilizer Equipment Room	--	--	10	100%	Negative	No	2

Table 1: Broad Guidelines for Indoor Environmental Quality

MERV Std 52.2	Average ASHRAE Dust Spot Efficiency Std 52.1	Average ASHRAE Arrestance Std 52.1	Particle Size Ranges	Typical Filter Type
1-4	<20%	60 to 80%	> 10.0 μm	Permanent / Self Charging (passive) Washable / Metal, Foam / Synthetics Disposable Panels Fiberglass / Synthetics
5-8	<20 to 35%	80 to 95%	3.0 - 10.0 μm	Pleated Filters / Extended Surface Filters / Media Panel Filters
9-12	40 to 75%	>95 to 98%	1.0 - 3.0 μm	Non-Supported / Bag Rigid Box Rigid Cell / Cartridge
13-16	80 to 95%	>98 to 99%	0.30 - 1.0 μm	Rigid Cell / Cartridge Rigid Box Non-Supported / Bag
17-20	99.97 99.99 99.999	N/A	≤ 0.30 μm	HEPA / ULPA

Table 2: Filter Selection Guidelines

The recommended temperature ranges are defined in *Table 1*. The Green Building Rating systems also place significant emphasis on thermal comfort where both temperature and relative humidity compliance need to be demonstrated.

Lighting

Hospital lighting system design must take three main factors into account i.e. patient comfort, medical staff needs and, energy efficiency (with consequent effect on HVAC design).

Hospital lighting design is today moving away from the traditional clinical, dimly-lit-sterile- environment feel to a more 'SPA-like' atmosphere, by incorporating gardens, waterfalls, and bringing natural light in to patient's room/ corridors and atriums. In fact, *Medanta - The Medicity* project has expanded the concept to bring in natural light into most of its areas including ICU, Laboratory, Blood Bank etc. Studies confirm that the Sun is known to reduce pain and depression in patients, as natural light increases levels of serotonin, a neurotransmitter that is known to inhibit pain pathways.

It is important to note that HVAC designers need to closely coordinate with architects so as to avoid direct sunlight ingress and help plan shading devices. Careful selection of glass ensures enhanced day-lighting effect with minimum solar radiation. Thus, a combination of day-lighting and energy-efficient lighting fixtures (T5 lamps, CFL, LED) coupled with sensors (daylight and occupancy) can help in greatly reducing the cooling load and upto 5% of annual electricity bills.

Recognising the effect of lighting on health, the Green Building Rating systems (like LEED) offer credits under 'daylight &

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views', 'controllability of systems' and 'energy & atmosphere'.

Indoor Air Quality & Filtration

Micro-organisms (including bacteria and virus) are transmitted inside and outside the hospital through dust, air & visitors as well as they originate inside the hospital and pose a risk to patient and community health. Ventilation and filtration provide a means of combating contaminants by diluting their concentration and are important aspects of HVAC system design.

Desired indoor air quality (IAQ) can be achieved in a hospital by following the fundamental principles:

- Control the contaminants at source by following good hygiene practice (like epoxy flooring of mechanical rooms), specify non corroding stainless steel drain pans (for FCU & AHU), maintain at least 25 feet gap between outdoor air intake and building exhaust, direct the contaminants out through dedicated exhaust ducts etc. It is important to note that virus burners or HEPA filters may need to be provided at some places while exhausting the air.
- Provide adequate outdoor air in all areas as per ASHRAE Standard 62.1-2007. The popular adage of "Solution to pollution is dilution" holds good. Outdoor air in comparison to room air is virtually free of bacteria and viruses. Properly designed, constructed and maintained ventilation systems preserve the correct pressure relationship between functional areas.
- Maintain relative humidity at specified optimum levels to prevent growth of bacterial colonies.
- The velocity of air in ducts should be sufficient to prevent condensation of liquid (to avoid deposition) on walls of the ducts.
- Exhaust air should be ducted while passing through other areas.
- Using UV lamps in the air-handling units, which are now readily available in India, can enhance the sterility of indoor spaces.
- It is a good practice to use non-corrosive Aluminum ducts in clean areas like Operation Theatres, ICU, Pre and Post operation, CSSD etc. Conventional GI sheet ducts have a tendency to corrode or flake over a period of time and damage the IAQ.
- Based on the required cleanliness levels for various areas, provide applicable filtration levels with easy accessibility for maintenance.

It is important to note that ASHRAE Standard 52.2 (which is followed to define filter efficiency) rates filter arrestance differently than the previous Standard ASHRAE 52.1 protocol, which used either weight or particle numbers to generate a ratio, or efficiency. It is now common practice to follow the minimum efficiency reporting value (MERV) to describe filter performance. The MERV is based on the worst-case performance of a filter through all six stages of dust loading and all particles 0.3-10 microns. Refer *Table 2* for determining filter selection.

Noise Control

Noise is a primary cause of sleep deprivation and disturbance amongst patients. It increases their anxiety, contributes to patient falls, causes confusion and can result in increased medication.

Noise in hospitals is a significant problem that needs to be addressed by HVAC designers and architects. Noise from mechanical systems can be a major source of complaints. Conventional acoustical treatment (using fibre-glass lining covered with perforated mesh) is used sparingly in hospitals as the pores may act as breeding grounds for bacteria. Fiberglass duct liners deteriorate with aging and shed into the space, resulting in IAQ complaints, adverse health effects and maintenance problems. Thus, use of smooth, hard, flat surfaces is recommended, as they are easy to clean. Consequently, these hard surfaces tend to be acoustically reflective and aggravate mechanical noise problem. Hence, any acoustical treatment in hospitals not only faces great noise abatement challenges, but must also meet the most stringent hygienic standards. A recent introduction of rubber foam materials may offer a solution to designers, but their fire properties must be carefully evaluated prior to use.

It is recommended that well established acoustical design principles and guidelines be followed. Good practices include locating air handling units away from critical areas (on service floor), providing bends in ducts etc.

Pressure Differentials

Table 1 stipulates the general pressure differential relationships that are followed in hospitals. Room pressure differentials are important for controlling airflow between areas in a building. Based on patient's need, pressure differentials may be negative (to keep potential infectious agents within the rooms) or positive (for immune-compromised patients) with respect to adjacent spaces.

As a good practice, special attention may be paid to the following:

a) Laboratories must be maintained under negative pressure in relation to the corridor or other less hazardous areas.

b) Clean rooms requiring positive pressure may be provided

Hiranandani, Mumbai, completed in 2009 with 100 beds & 4 OTs. Installed chiller capacity 400 TR.

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with entry vestibules with door-closing mechanisms, so that both doors are not open at the same time.

c) As a general rule, airflow should be from areas of low hazard to high hazard.

d) The maintenance staff should not adjust the air balance of the room.

e) Where appropriate, general ventilation systems should be designed, such that, in the event of an accident, they can be shut down and isolated.

f) Room exhaust outlets to be provided where necessary, to maintain minimum air change rates and temperature control.

It is important to note that since the percentage of outdoor air is high in most areas of a hospital, designers must plan a dedicated exhaust arrangement (using relief fans/dampers) to prevent over-pressurisation of the space, which can affect the air pressure relationships.

Direction of airflow should always be from clean to less clean areas. Airflow rate of 0.28 -0.47 m /sec is desirable across an open door to prevent back flow into a cleaner area. In clean areas, the airflow should not be less than 0.2 m/sec at one meter above the door.

Infection Control during Construction

Despite the best HVAC system design, actual practices and procedures during construction have been identified as a major risk of introducing pathogens and their propagation. It is a good practice in hospitals to follow the following guidelines during construction:

- Ensure ductwork is clean both internally and externally before closing the false ceiling.
- Ductwork should be fully protected with covers during transport and ends to be covered after installation.
- Similar practices to be followed for air handling units and other air-system components.
- Cleaning of all systems and concealed spaces before being closed, including riser shafts, walls and ceilings, so that the completed installation has all rubbish, dirt and dust removed.

Some projects have also followed the practice of washing/coating the internals of the duct with anti fungal/bacterial solutions prior to installation.

Patient Rooms

As a common practice, each patient room is air conditioned using independent fan coil units located above the suspended ceiling space in the entrance vestibule. Conditioned air is supplied through a supply air duct and return air is brought back through slits or a return air grille in the suspended ceiling. Tempered fresh air is supplied directly to each patient room and an equivalent amount exhausted through the room toilet. Tempered fresh air is also supplied to corridors in front of the rooms.

Patient rooms are classified under following sub-heads based on their usage, patient immunity, and related pressure relationship with adjacent spaces:

- ***Class S or Standard Pressure Room:*** This is for general patients who require contact and only droplet isolation.
- ***Class N or Negative Pressure Room:*** This is for patients who require airborne droplet nuclei isolation to reduce transmission of disease via the air-borne route. A dedicated exhaust system is mandatory for each room, which is capable of removing a quantity of air greater than that of the supply system.
- ***Class P or Positive Pressure Room:*** These are rooms with a positive pressure relative to the ambient pressure to isolate immuno-suppressant patients such as certain transplant and oncology patients.

It is also important to bring out at this point that some new generation hospitals (like *Medanta - The Medicity*) have raised the bar of patient comfort by providing fan coil units (FCU) with a 4-pipe system (especially for Class S patient rooms), which have both hot water and chilled water coils, thereby being capable of simultaneous heating and cooling in different rooms based on the patient requirement.

Surgical Suite (Operating Rooms)

The air conditioning system in an Operating Room should be designed to cater to the following requirements:

Provide Temperature & RH control. Modern surgeries require different indoor conditions based on the type of procedure and doctor's needs. Thus, the surgeon's control panel placed inside an operation theatre assists the doctor to set the temperature and RH based on his requirement, which in turn is linked to the building management system. Thus the OT AHU must be capable of simultaneous cooling/heating/humidification/dehumidification based on the need. Ideally, the operating room should be 1°C cooler than the outer clean corridor as it aids in the outward movement of air because the warmer air in the outer area rises and the cooler air from within the operating theatre moves to replace it.

Medanta-The Medicity has 45 operation theatres where internal temperature can be controlled between 20 to 24°C. However, two OTs have used desiccant wheels, wherein internal temperature and RH can be accurately maintained at 16°C and 40% RH.

Sterility. After every procedure, the operation theatres are fumigated to create sterile conditions. It is therefore essential to either provide one-to-one AHU (i.e. one AHU for each OT) or group the AHUs based on OT usage pattern. Also, there should be routine maintenance of the AHUs and these units should not be turned off, unless being serviced, as this destroys the sterile environment inside.

Filtration & Air supply. During an operation, most members of the surgical team are in the vicinity of the operating table, creating the undesirable situation of concentrating contaminants in this highly sensitive area. Laminar airflow is therefore designed inside an OT to move particle-free air over the aseptic operating field in one direction. It can be designed

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to flow vertically or horizontally.

The supply air should pass through a combination of MERV 8 and MERV 13 filters installed within the AHU before being supplied in to the room after passing through a bed of terminal HEPA filters.

Some designers and owners prefer recirculation of air in the operation theatres. However, it is important to understand the critical nature of usage of the room before deciding the quantity of recirculation air, as some of the procedures like Ortho, call for 100% outdoor air. Major new hospitals like *Medanta-The Medicity, Kohinoor Hospital, Hiranandani Hospital* etc. have adopted 100% outdoor air designs for all OTs. In view of the large outdoor air requirement, it is good practice to install heat recovery devices where the coolness of exhaust air is transferred to incoming hot outdoor air, thereby conserving energy by reducing the air conditioning load.

The air handling units serving operating rooms must be capable of delivering air at high static for overcoming pressure drop in various filtration stages and across the heat recovery devices.

Pressure Relationship. Positive pressure with respect to the corridors and adjacent areas, in the operating theatre where surgical procedures are performed, should be maintained.

Fire Safety

Fire safety in hospitals is a critical issue. Due to lack of fire fighting infrastructure, the *National Building Code of India* does not make any reference to hospital design beyond 30 m height. However, with growing pressure on space and population, new hospitals are growing taller. *Kokilaben Dhirubhai Ambani Hospital* and *Medanta-The Medicity* have already breached the 45 m height mark. Besides, conventional fire fighting devices like sprinklers, hydrants, detectors etc., HVAC designers have a big role to play in enhancing the fire safety. Pushed by local authorities, some new hospitals are installing a smoke evacuation system for all floors coupled with pressurisation of fire escape staircases, elevator hoistways and elevator lobbies to provide a bigger window for evacuation of patients in case of emergency.

Conclusion

This article only touches upon a few critical aspects of hospital designing. With growing sophistication, each area like Laboratory, CSSD, Imaging, Blood Bank, OPD etc have their own design challenges and needs. With India's edge in medical tourism, hospitals in future will rub shoulders with their counterparts in developed countries. In addition, the explosive growth in second and third tier cities of India will also bring quality healthcare to these cities. Already, major healthcare players in the market like Fortis and Apollo have announced their plans to construct several hospitals in the coming years. The government too has opted for modernisation of its existing hospitals and adding several more. HVAC engineers will have a major role to play in the design and operation of these sophisticated buildings of the future. ❖