Centrifugal chiller installed in the Central Plant room

HVAC Systems for US Hospitals

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General hospital design considerations are described in this article. The data and pictures furnished for the St. Luke's East are representative of hospital construction in the US. For example, at St. Luke's East : ■ Single duct, hot water reheat type air system is used. ■ Surgery AHUs incorporate DX cooling after chilled water coil. ■ All the AHUs incorporate economizer cycles, so the refrigeration system is de-energised when the outside air temperatures are below 50°F. ■ Centrifugal chillers with VFDs are used with 0.58 kW/ton at full load.

Hospital construction/renovation in the United States is a multi-billion dollar industry. As of July 2009, the hospital construction projects being designed by architects and engineers exceeded $7 billion in construction costs (Ref: 1). In 2008, hospitals spent more than $60 billion on new projects and renovation projects. During the 60s many hospitals were built as part of "Hill-Burton" code, which provided funding for new hospitals, by the federal government. Since then, new medical technologies have been discovered; newer medical diagnostic equipment is available; newer and safer ways to heal patients have been implemented; use of electronic equipment has grown and facilities have aged. All this necessitates infrastructure upgrade and major upgrade of these aging facilities. In the last nine years, from year 2000 to now, hospitals have spent more than $500 billion in replacement facilities or upgrading of existing facilities.

HVAC systems are a major portion (roughly 20%) of the construction cost for a new facility. For renovation or infrastructure upgrade projects, HVAC systems represent much higher (roughly 30%) portion of the construction costs. So, HVAC systems play an important and major part in hospital construction. This article describes HVAC systems generally used in United States hospitals.

Codes

For designing HVAC systems for hospitals "AIA Guidelines" (Ref: 2) are used as a design standard. Even though these are "Guidelines", most of the states have adopted them as code requirements. Some of the states have their own requirements, which differ from the "AIA Guidelines". *Table 1* shows the difference between "AIA Guidelines" and State of Missouri (Ref: 3) requirements for some areas of the hospital. ASHRAE/ASHE Standard 170-2008 (*Ventilation of Health Care Facilities*) was issued last year. The requirements in ASHRAE/ASHE Standard 170-2008 differ from those in "AIA Guidelines", which has created more confusion for HVAC design engineers. It is a general practice and sound engineering judgment to use the more stringent requirements in case of conflict. Trying to streamline the requirements between "AIA Guidelines" and ASHRAE/ASHE Standard 170-2008 is under way and it is hoped that the 2010 edition of "AIA Guidelines" will match ASHRAE Standard 170-2008.

	MIN. OUTSIDE ACH	MIN. TOTAL ACH	RH RANGE	TEMP. RANGE
SURGERY ROOM				
AIA	3	15	30 TO 60	68 TO 73
MISSOURI	5	25	50 TO 60	68 TO 76
NURSERY				
AIA	2	6	30 TO 60	72 TO 78
MISSOURI	5	12	30 TO 60	75
TRAUMA ROOM				
AIA	3	15	30 TO 60	70 TO 75
MISSOURI	5	12	30 TO 60	72 TO 78

Table 1 : Comparison between "AIA Guidelines" (2006 edition) and State of Missouri Code of State Regulations (Jan. 2002 Edition)

SURGERY ROOM				
AIA	3	15	30 TO 60	68 TO 73
ASHRAE/ASHE	4	20	30 TO 60	68 TO 75
NEGATIVE ISOLATION				
AIA	2	12	-	75
ASHRAE/ASHE	2	12	MAX. 60	75
TREATMENT ROOM				
AIA	-	6	-	75
ASHRAE/ASHE	2	6	30 TO 60	70 TO 75

Table 2 : Comparison between "AIA Guidelines" (2006 edition) and ASHRAE/ASHE Standard 170-2008

The codes stipulate minimum outside air changes, total air changes, pressure relationship to adjacent areas, whether exhaust to outside is required, and temperature and relative humidity requirements for most spaces of the hospital. *Table 2* shows a comparison between "AIA Guidelines" and ASHRAE/ASHE Standard 170-2008 for some areas of the hospital. These codes also stipulate the number and arrangement of heating/cooling infrastructure equipment, location of outside air intakes, filtration requirements, duct lining limitations etc.

Other than the main codes listed above, the HVAC design engineer has to be cognizant about codes for special areas. These include Isolation rooms, which also have requirements from CDC (Ref: 4), Pharmacy areas that are regulated by USP 797 (Ref: 5). Other codes that impact HVAC systems include NFPA and Life Safety Codes (Ref: 6). These do not impact HVAC system selection or sizing, but require co-ordination with control systems.

Air Systems

The single duct reheat or double duct air systems are most popular to serve hospital areas. The capacities of the systems are not only based on heating/cooling load calculations, but also on number of air changes required for the areas. Single duct systems are more prevalent, since they require less space in the ceiling and have lower first installed costs. Double duct systems are as good in maintaining air changes and space conditions, but require additional space above the ceiling for additional duct. Typically,

Information on St. Luke's East-Lee's Summit

Owner:
Saint Luke's Health System, Kansas City, Missouri
www.saintlukeshealthsystem.org

Location:
Saint Luke's East-Lee's Summit, 100 NE Saint Luke's Boulevard, Lee's Summit, Missouri 64086

Description:
A brand new hospital campus on a 33-acre site. Construction started in 2002, for first phase and completed in 2005. Expansions have been underway since 2005. The site has been laid-out on a campus style with circular public drive with access to each building.

Buildings:
Hospital - 4 floors with Surgery suite, ICU suite, Delivery suite, 110 Patient rooms, LDRP rooms, Nursery, Laboratory, Cafeteria with kitchen, Offices; Emergency - Treatment rooms, Pain Management; Imaging - MRI, Breast MRI, Cat Scan, Mammography suite, Catherization Lab., Interventional Lab., X-ray rooms; Surgi-Center - Outpatient Surgery suite, Recovery bays, Orthopaedics suite; Medical Office - Rehabilitation suite, Doctors offices.

Areas:
Hospital - 258,000 sq.ft.; Emergency - 17,000 sq. ft.; Imaging - 39,000 sq. ft.; Surgi-Center - 42,000 sq. ft.; Medical Office Building - 60,000 sq. ft.; Total (As of Oct. 2009) - 418,000 sq. ft.

Const. Costs:
Total (As of Oct. 2009) - $121,000,000 approx. (Excludes costs for land); MEP - $52,000,000 approx.; HVAC System - 1,500 Boiler HP installed capacity of heating hot water boilers (1 Boiler HP = 33,480 BTUH); 300 Boiler HP installed capacity of steam boilers; 4 Primary and 2 Secondary heating hot water pumps; 2,650 Tons installed capacity of centrifugal chillers; 650 Tons Installed capacity of gas-fired absorption chiller; 4 Primary and 2 Secondary chilled water pumps; 4 condenser water pumps; 4 1,000-ton cooling tower cells; 17 major air handling units with installed capacity of 580,000 cfm.

About the Author

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Jayant migrated to the US in 1971 after graduating in mechanical engineering from Visvesvarayya College of Engineering, Nagpur in 1965 and working with Blue Star Ltd. for six years.

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Photo 1: Typical custom built AHU

the hot duct is sized at 75% of cold duct capacity. The selection of the air system is many times based on availability of space above the ceiling and Owner preference. Some Owners do not prefer heating hot water piping above the ceilings, which can spring leaks. Generally the supply air quantities for hospitals range from 1.2 cfm to 1.8 cfm per sq. ft.

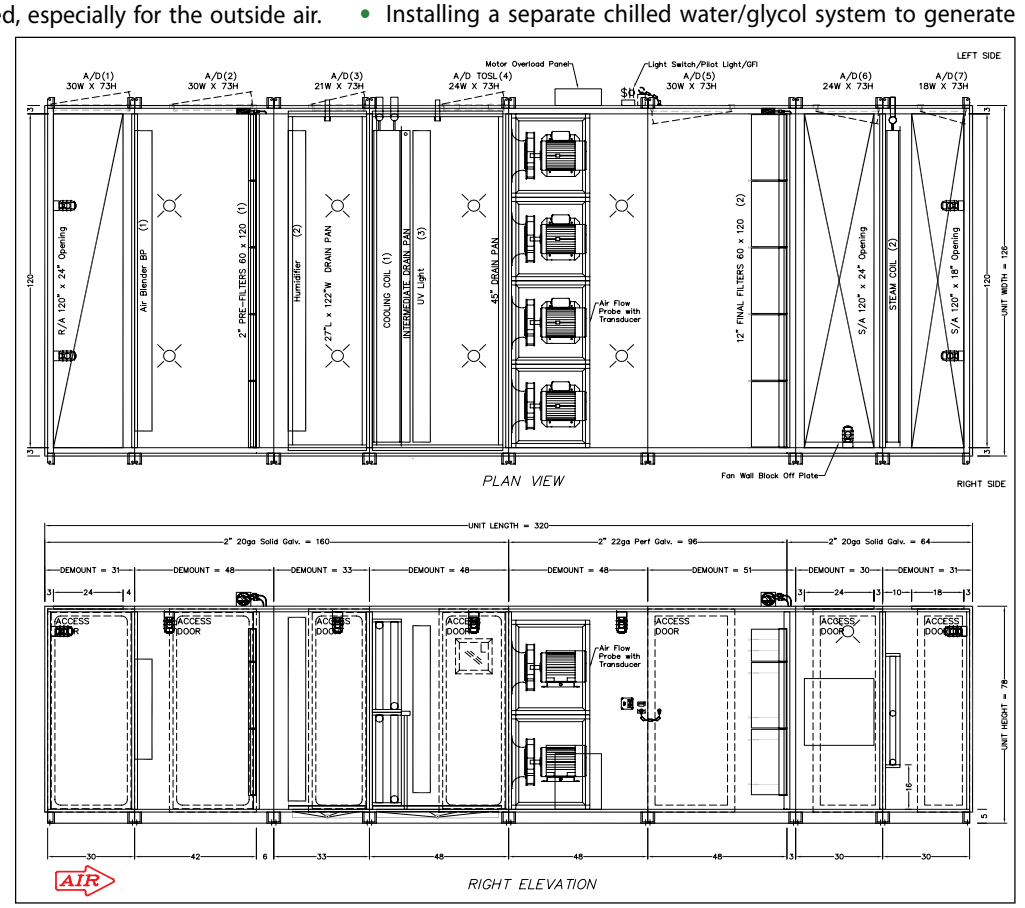
Variable air volume systems are acceptable in the hospital, since they save energy. However, the lower airflow is set based on minimum air changes required, especially for the outside air. The general trend is to utilize constant volume systems for critical areas such as Surgery Suites, Delivery Suites, ICU/CCU, Nurseries, Special Procedures (Catherization Lab., Interventional Lab.), Isolation rooms and Pharmacy areas. The codes do allow the airflow to be reduced for Surgery Suites, when they are not in use, provided positive pressure is maintained in the Surgery rooms.

Two-inch insulated double wall construction is used for the air handling units. Typically, the components within an AHU include return air plenum, return/relief air fan, return/relief section, mixing box, air blenders, MERV 8 filters, cooling coil, UV lighting, steam humidifier, supply air fan, MERV 16 filters, supply air plenum. For double duct systems, the supply air plenum includes a heating coil and two duct connections (Ref: *Drawing 1*). Note that the arrangement is draw-thru type, with cooling coil up-stream of supply air fan. The added supply air fan motor heat helps in keeping the final filters dry. Some state codes, including California, do not allow blow-thru design for AHUs.

The supply air temperature is typically designed between 52°F to 54°F with dew point temperature of 52°F or lower. This assures relative humidity of less than 50% at 75°F DB. For the double duct system, the heating coil is recommended in reheat position to keep supply air dew point low to maintain low relative humidity levels during the part load conditions. UV lighting downstream of cooling coil is pretty much standard to prevent mold growth and to reduce operating costs.

The hospital staff and equipment vendors generally require Surgery rooms, Delivery rooms and Special Procedure rooms to be maintained at 68°F DB and 40% RH. These conditions can be achieved with supply air from AHU at 42 to 43°F dew point temperature. This can be achieved by any of the following:

- Installing an additional DX cooling coil downstream of the regular chilled water coil. Generally, with chilled water supply at 42°F, the chilled water coil is designed to provide supply air at 47 to 48°F dew point temperature. The DX cooling coil is designed to further cool the air down to 42 to 43°F dew point temperature. The control strategy is designed to allow the DX system to be energized only after the chilled water coil is at full load.
- Installing a separate chilled water/glycol system to generate



Drawing 1 : Showing draw-thru type arrangment with cooling coils up-stream of supply air fan

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water/glycol supply at 32 to 34°F. In the AHU, water/glycol coil is installed instead of chilled water coil. This option has much higher first costs.

- Installing either dry or fluid desiccant system in the AHU to lower the dew point temperature of supply air.

Return/relief air fan is used to relieve the return air to outside during economizer cycle (also known as "free cooling cycle") operation. In the northern parts of the US, outside air temperatures fall below 50°F quite often in late fall, winter and early spring. For example, in the Kansas City area, weather records indicate, that on an average the outside air temperatures are below 50°F for approx. 2,000 hours annually. During those periods, all outside air or a mixture of return air and outside air can be used to provide supply air at design temperatures (52°F to 54°F), thus saving cooling energy. 'Air blenders' are used to prevent stratification of cold outside air during winter months. Blenders help in mixing the outside air and return air streams to prevent freezing of coils. Supply air fans are generally centrifugal, either housed–casing type or plenum type fans. Plenum type fans are more popular due to lower first costs, requiring less space and are now capable of generating higher static pressures. Many facilities are specifying multiple, direct-drive plenum fans for AHUs that serve Critical areas. This arrangement provides redundancy and minimizes shut down of Critical areas in case of fan failure. These multiple direct drive fans are factory built and installed in the AHU fabrication shop. This enables the AHU manufacturer to obtain AMCA rating for the AHU.

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Generally, supply air ducts are sized at medium velocity/medium PD (2,500 FPM max. or 0.5" PD per 100 ft max.) mainly to keep duct sizes smaller. Supply air ducts are externally insulated. Duct liners are not allowed for ducts serving Critical areas. The general trend is not to use duct liners in hospitals to prevent flaking or erosion of the lining material in the air stream. Pressure independent boxes (single duct with reheat coil or double duct) are provided for individual space control. Each patient room and each critical area requires individual space control, so typically, hospitals end up with lots of

Photo 2: Boilers installed in the Central Plant Room

Photo 3: Primary chilled water pumps & header

boxes and control zones. Areas requiring minimum humidity levels of 30% RH, which are mostly critical areas, are provided with booster steam humidifier in the supply air duct downstream of the box. In many areas of the US, the outside air absolute humidity is very low in winter. This causes moisture migration from inside the hospital to outside. Booster humidifiers in ducts add moisture in the supply air to maintain minimum relative humidity levels in critical areas.

Return air is ducted from the grilles in spaces back to the AHU, since codes do not allow return air plenums in most hospital areas. This is to prevent spread of smoke in other areas and to contain the smoke within a system. Return air ducts are sized at low velocity/low PD (2,000 FPM max or 0.1" PD per 100 ft) basis.

Central Plant

Most hospitals are designed with Central plants that house major heating/cooling equipment. Smaller community hospitals (less than 50,000 sq. ft.) are designed with local rooftop equipment with DX cooling to keep construction costs low. Hospitals with 100 beds or more (200,000 sq. ft. or larger) are designed with a Central plant for operational efficiency, operating flexibility and ease of maintenance. Generally, the Central plant includes heating equipment (boilers, de-aerators, condensate pumps, heat exchangers etc.); cooling equipment (chillers, chilled water pumps, condenser water pumps); medical gas equipment (air compressors, vacuum pumps, air purification system); electrical equipment (main switch gear, distribution boards, emergency generators, transfer switches etc.); domestic water equipment (water softeners, water heat exchangers etc.).

Boilers are equipped with combination natural gas/oil burners for dual fuel capability. Codes require that adequate on-site fuel be available to operate boilers at full load for 72 to 96 hours, in case gas service is interrupted. Boilers for heating systems are either hot water type or steam type. Heating hot water systems are designed with 20°F temperature difference (160°F to 180°F) for smaller systems and with 40°F temperature difference for larger

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systems. Steam boilers are provided for sterilizing equipment and humidification systems. Steam boilers are designed to operate between 80 to 150 PSIG. Usually, stack economizers are installed on boiler flues to recover heat. Exterior underground oil storage tanks with pumps are installed for the oil circulation system.

Chillers are centrifugal or screw type for higher efficiency and superior part load performance. The sizing and arrangement of chillers is based on minimum loading and adequate stand-by capacity in case of one chiller failure. Codes do not require stand-by chiller, however most Owners prefer to have additional capacity to ensure adequate cooling all the time. One direct- gas fired or steam absorption chiller is provided for operation on emergency power. Even though the absorption chiller is not very energy efficient, it requires very little power, so it makes it convenient to put it on the emergency power system. Some hospitals also power one of the centrifugal chillers on emergency power, so that cooling can be provided to critical areas in case of normal power failure. Chillers are typically designed for 10 to 12°F temperature difference on chilled water; on larger systems 16°F temperature difference is normal to keep the distribution piping smaller and pumps of smaller size. The chilled water supply temperature is normally 42°F for most systems. Generally, the cooling capacity for hospitals ranges from 200 to 275 sq. ft. per ton.

For larger chilled water systems, primary and variable flow secondary loops are utilized. Variable primary flow systems are now getting popular since most new chillers are available for low-flow applications. It is also great for energy savings. Schedule 40 steel pipes are common for chilled water and heating hot water systems usually with Victaulic fittings for quicker installation and to minimize welding at sites. Smaller piping (2" and less) is copper type L, since it is more economical to install.

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Concrete enclosure cooling towers are more cost effective for larger installations, (more than 5,000 tons) and for aesthetic reasons. For smaller installations, cross–flow induced draft or up–flow forced draft cooling towers are utilized. For northern US locations a basin-heating system is installed to prevent the basin water from freezing.

All chillers, pumps, fan motors are equipped with Variable Frequency Drives to save energy, reduce the demand on the power system and for integration with control systems.

Special Systems

Negative Isolation rooms require all air to be exhausted and the room to be maintained at minimum negative 0.01" wg with respect to the adjacent corridor. Good design practice is to locate the exhaust grille low on the wall behind the bed. This ensures air exhaled by the sick patient to be drawn behind the bed and away from health care workers. Either venturi valves (Ref: 7) or modulating dampers are provided in the system to ensure the required negative pressure is maintained.

Positive Isolation rooms do not require air to be exhausted, but the room has to be maintained at minimum positive 0.01" wg with respect to the adjacent corridor. Supply air in the room is supplied by a HEPA filter (99.9% at 0.3 microns) equipped diffuser. Either venturi valves (Ref: 7) or modulating dampers are provided in the system to ensure the required positive pressure is maintained.

Hospitals typically have large laboratories, which require air to be exhausted to outdoors. The air-handling unit serving the area thus requires a larger amount of outside air to offset the exhaust airflow. To reduce energy for heating and cooling of this outside air, generally, run-around type liquid heat recovery systems are utilized. Heat exchanger coils are installed in the main exhaust duct and outside air duct and glycol/water mixture is circulated to recover heat. In summer months the outside air is pre-cooled and in winter months the outside air is pre-heated. The heat recovery efficiency of these systems is between 60% to 75%.

Surgery rooms, Delivery rooms, Catherization Lab. and Interventional Lab. are provided with laminar flow non-aspirating type diffusers, generally located in the center of the room. Two low–return grilles, located diagonally across, remove air from the room. Laminar flow diffusers provide a low velocity of clean supply air over the table and staff creating a sterile environment. Codes do not require HEPA filters at diffusers for these rooms. If HEPA filters are requested by the Owner, then HEPA–filter–equipped laminar flow diffusers are installed. HEPA filters at the AHU are not recommended to prevent contamination of supply air in the duct system. 100% outside air for Surgery rooms is only provided if specifically requested by the hospital or if the Surgery room is designed to handle pandemic cases in bio-hazard attacks. These rooms are also required to be maintained at 0.01" wg positive with respect to the adjacent corridor.

Dos and Donts

Based on past experience on projects and having seen the changes hospitals go thru all the time, following are some of the Dos and Donts for the HVAC design engineer -

1. Do size the AHUs at 10% more capacity than the load calculations or air balance. This will take care of duct leakage and will provide flexibility for the system as medical equipment is changed, which is very frequent in hospitals.
2. Do design AHUs with minimum 20% outside air to meet minimum outside air requirements for most areas.
3. Do design supply air from AHUs at 50 to 52°F dew point temperature. This will assure relative humidity levels below 50% at 75°F DB.
4. Don't use duct liners, instead insulate supply air ducts externally. Why take a chance on possible flaking or erosion of lining material in future.
5. Do design the overall facility at slightly positive pressure (2% to 5%) to prevent the dirty outside air from coming into the hospital.
6. Don't design Isolation room exhaust system with one fan serving several rooms. Separate exhaust fan for each Isolation room is recommended to prevent cross contamination and

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loss of room with fan failure.

7. Don't design HVAC system to provide less than 1 cfm per sq. ft. or 8 total air changes to areas, except corridors. Areas initially labeled "Storage", "Supplies", "Resource" etc. are usually converted to offices or examination rooms with people and computers, sooner or later.

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