Performance Evaluation of HVAC (Heating, Ventilation and Air Conditioning) Systems in Healthcare Facilities

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Abstract— In this study deals with the method employed to improve the air quality of the hospitals in order to provide healthy environment. This paper consist of coil selection, filters maintenance of Air Handling units and the new design is compared with the existing model at industrial level in Arogyam hospital based on Mumbai . Also, in this paper the cost comparison of both models i.e existing model and new model. This leads to improvement in the air quality and preserve a comfortable & healthy environment for patients and staff of hospital. Also, has reduced the cost of certain extent and payback period.

Keywords: Hospital, Operation Theatres, HVAC Design, Indoor Air Quality (IAQ), Air Filters, Air Handling Unit (AHU), Energy Efficiency

I. INTRODUCTION

Hospitals are among the biggest energy users in the building segment. According to the EIA (Energy Information Administration 2008), healthcare buildings are the second largest energy users per unit floor area of all building types. The US Department of Energy (cited in (ASHRAE 2003)) states that the average acute care, full-service hospital is documented to have an average consumption of about 1040 kWh/m2-yr. The average specific final energy use for tertiary and residential buildings in the Mediterranean area is 275 and 150 kWh/m2-yr, respectively (Ortiz et al. 2012). The large energy use of hospitals is due to their unique processes and their continuous operation 24 hours a day, 365 days a year. HVAC is usually the largest energy use in hospitals accounting for roughly 30-50% of the total final energy (although this largely varies depending on the type of hospital and its location including ventilation fan energy, outdoor air cooling and dehumidification, outdoor air heating and humidification, as well as thermal mixing and reheating required to maintain space comfort.

"HVAC systems that can deliver clean air quietly and at the correct volume, temperature, humidity, and pressure to support infection control and help keep patients comfortable" (ASHRAE et al. 2012). While health and safety must remain top priority in hospitals, the high energy use (and derived energy cost) of HVAC systems in hospitals makes these systems a clear target for energy efficiency strategies.

Beyond the direct benefits of cutting energy use and derived costs, energy efficiency projects in hospitals and healthcare buildings are particularly important in terms of dissemination and public awareness. "Healthcare facilities play an influential role in promoting public wellness by educating their staff on the importance and techniques of sustainability, which they take home and spread to their communities at large. Some healthcare institutions have leveraged sustainability efforts to provide even greater value to their communities" (ASHRAE et al. 2012).

Surgery rooms is the space type within hospitals with the most stringent and demanding conditions of supply airflow, overpressure and indoor environmental quality (ASHRAE 2003). These requirements translate to very large energy use intensities. This thesis addresses strategies to reduce energy use in surgery rooms without compromising the fundamental indoor environmental quality requirements.

Health care facilities and services are characterized by high rates of modification because of the continuously evolving science and economics of health care, and consume large quantities of energy and potable water. The often unique environmental conditions associated with these facilities, and the critical performance, reliability, and maintainability of the HVAC systems necessary to their success, demand a specialized set of engineering practices and design criteria established by model codes and standards and enforced by authorities having jurisdiction.

II. STUDIES ON HEALTHCARE FACILITIES:

As we all know air plays major role in our life and it is our priority to take care of it as well. HVAC design for health care facility is all about providing a safe and healthy environment not only for patients but also to the doctors, staff in the premises.

In earlier days hospitals were a place where they diagnose and treat the patients for various diseases with very basic use of technologies and very basic ventilation and cooling systems. But nowadays hospitals are becoming so modern and futuristic than never before. Today hospitals are not only diagnosing and treating human diseases but also providing them health education, training and many more activities to enhance the awareness of good and healthy life for all. Actually hospitals are very complex functional organizations with multiple angles in development of society not only by curing them from various diseases but also making them aware by educating them for good health and happy life. Hence being an engineer, it becomes our first priority to provide the best indoor air quality for these premises using new technologies and value engineering for various aspects. Now the basic difference between air conditioning for healthcare facility and other building are as below (ASHRAE standard 2015: Chapter 8: Health care facility) :

- No cross movement of air is allowed in and between the various departments to avoid contamination and viral infections etc.
- Direct discharge of inside air to the atmosphere shall be restricted. Air should be treated to remove or kill various

bacteria or infectious viruses before discharging outside of the premises.
- To control air quality we require various filtrations starting from 20 microns to 0.3 microns or more depending on the need of area.
- The specific requirements of ventilation system to ensure sufficient flow of air volume for supply inside the premise as well as for exhaust outside the premise.
- Ventilation effectiveness should be taken care to maintain appropriate indoor air quality.
- To enhance indoor air quality (IAQ) require necessary filtration which shall be capable to remove or dilute contamination in the form of odour, air-born microorganisms, viruses, hazardous chemicals and radioactive substances etc.
- The various temperature and humidity requirements for various areas and the accurate control of environment condition.
- The prime motto of design should be to minimize the risk of hazardous chemicals, bacteria and viruses in air and provide a comfortable and healthy environment for patients and working staff.

To achieve these parameters require very high quality of outside air along with significant treatment of this outsides air before entering to the premise, which requires cooling, reheating, humidifying and filtration of air.

III. SYMTOMS CAUSES & CONSEQUENCE OF POOR INDOOR AIR QUALITY (IAQ)

Some of the symptoms of poor IAQ in a building, which is common for people to report one or more of the following symptoms:
- Dryness and irritation of the eyes, nose, throat, and skin
- Headache
- Fatigue
- Shortness of breath
- Hypersensitivity and allergies
- Sinus congestion
- Coughing and sneezing
- Dizziness
- Insufficient fresh air.

Hospitals and health care facilities must comply with ASHRAE and other regulatory standards with respect to air change rates, humidity requirements, and pressurization. (ASHRAE Standard 62.1) is the most commonly referenced standard to meet appropriate HVAC system design. It is important to understand that most IAQ standards and guidelines are established to ensure the comfort of people inside the premises. So these values tend to be lower than regulatory values that are set to protect people from possible health based hazards.

IV. IMPORTANCE OF AIR FILTER & DUCTS IN HVAC SYSTEMS TO MAXIMIZE IAQ

Clean and fresh air is always the first thing that comes to mind when we considers the concept of good IAQ. While reviewing the various standards and codes that define the amount of fresh air necessary for the particular space, ensure that we design to the one that requires the greatest volume to ensure that all of the applicable codes and standards are met. It is very important that the air filters in the system shall be cleaned or changed often. That is because filters are the best location for fungus to grow also for Bacteria microorganisms, which are less than 1 micron. They reproduce rapidly and develop to resist any antibiotic. Generally one out of ten people who suffer from allergies, do so because of the direct contact with fungi and bacteria in air distribution systems. All parts of the humidification and dehumidification systems must be kept clean and dry to prevent growth of bacteria. Viruses is an another infection mechanism found in almost every living organism, divided into 70 families over 4100 known types, 30-450nm, 95 times smaller than bacteria. Viruses do not reproduce but replicate by injecting their genetic information into a cell, which acts as a host. It damages or destroys host cell e.g. Cancer. Many diseases are the result of viral infection e.g. cold, flu, rubella, measles, chickenpox and shingles.

Bacteria or viruses spread so easily through air entering the premises. When someone sneezes, coughs, laughs or exhales air, respiratory droplets can become aerosolized and can stay airborne for hours. Complete removal of indoor contaminants is very difficult for various reasons as mentioned below:
- Poor design and / or material selection of HVAC system and building materials.
- Air is recycled for energy efficiency.
- No / low efficiency internal filtration.
- Physical constraints--not easy to check or clean the filters regularly.

TENTATIVE ANNUAL MAINTENANCE COST FOR AHU's - 2016-17

		OT-1 / 3000 CFM	OT-2 / 3500 CFM	OT-3 / 3500 CFM	OT-4 / 4500 CFM	OT-5 / 4500 CFM	
1	Electrical Motors Light bill (working 12 Hrs/Day)	1,08,813.05	2,55,974.03	2,55,974.03	2,60,902.53	2,60,902.53	11,42,566.16
2	Filter Replacement Charges						
a)	Pre-filters (10-Micron) / per quarter	12,000.00	14,000.00	14,000.00	18,000.00	18,000.00	
b)	Fine Filters (3-Micron) / per quarter	18,000.00	21,000.00	21,000.00	27,000.00	27,000.00	
c)	Hepa Filters (0.3 Micron) / per quarter	1,20,000.00	1,40,000.00	1,40,000.00	1,80,000.00	1,80,000.00	
3	Coil Maintenance	12,000.00	12,000.00	12,000.00	12,000.00	12,000.00	
4	Annual Maintenance small hardware's	12,000.00	12,000.00	12,000.00	12,000.00	12,000.00	
5	Changing of V-belts	2,500.00	2,500.00	2,500.00	2,500.00	2,500.00	
6	Changing of Drive sets	4,000.00	4,000.00	4,000.00	4,000.00	4,000.00	
7	Duct Cleaning	6,000.00	6,000.00	6,000.00	6,000.00	6,000.00	
	Total Maintenance cost (per Annum)	2,95,313.05	4,67,474.03	4,67,474.03	5,22,402.5	5,22,402.53	22,75,066.16

TENTATIVE ANNUAL MAINTENANCE COST FOR AHU's - 2018-19

		OT-1 / 3000 CFM	OT-2 / 3500 CFM	OT-3 / 3500 CFM	OT-4 / 4500 CFM	OT-5 / 4500 CFM	
1	Electrical Motors Light bill (working 18 Hrs/Day)	1,00,959.25	2,43,060.54	2,43,060.54	2,43,060.54	2,43,060.54	10,73,201.41
2	Filter Replacement Charges						
a)	Prefilters (10-Micron) / per 4 Months	9,000.00	10,500.00	10,500.00	13,500.00	13,500.00	
b)	Micro V Filters (5-Micron) / per 6-Month	6,900.00	8,050.00	8,050.00	10,350.00	10,350.00	
c)	Fine Filters (3-Micron) / per 6 Months	9,000.00	10,500.00	10,500.00	13,500.00	13,500.00	
d)	Hepa Filters (0.3 Micron) / per 6 months	60,000.00	70,000.00	70,000.00	90,000.00	90,000.00	
3	Coil Maintenance	2,000.00	2,000.00	2,000.00	2,000.00	2,000.00	
4	Annual Maintenance small hardwares	12,000.00	12,000.00	12,000.00	12,000.00	12,000.00	
5	Changing of V-belts	-	-	-	-	-	
6	Changing of Drive sets	-	-	-	-	-	
7	Duct Cleaning	6,000.00	6,000.00	6,000.00	6,000.00	6,000.00	
	Total Maintenance cost (per Annum)	2,05,859.25	3,62,110.54	3,62,110.54	3,90,410.54	3,90,410.54	20,94,901.41

Hence it is very important to select and design the appropriate filters in the air handling units (AHU) while designing the HVAC system using the ASHRAE guidelines, to ensure good IAQ.

The ambient air taken into the system, needs to be filtered as it contains different bacteria, microorganisms, dust or other diseases. The applicable codes and standards will provide the minimum requirements for filtration based on what spaces are being served by the system. There are several types of filters to use inside the air handling units (AHU) or in ducting depending upon the particular space requirement as guided by ASHRAE standard 52.2-2007. Particulate filters are rated in terms of efficiency with a minimum efficiency reporting value (MERV). MERV ratings, as established in ASHRAE Standard 52.2-2007: Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size, range from the lowest rating at 1 to the highest efficiency at 16.

Filters with a MERV rating of 1 are based on retaining particles larger than 10 microns (dust and pollens), while filters with a MERV rating of 16 are based on a filter's efficiency at retaining particles as small as 0.3 microns (smoke and bacteria). High-efficiency particulate arrest (HEPA) air filters and ultra-low particulate arrest (ULPA) air filters have efficiencies even greater than those identified in ASHRAE Standard 52.2 and are given MERV ratings in the 16 to 20 range which shall be referred in ASHRAE standards 52.2-2007. HEPA filters are 99.97% efficient at removing particles 0.3 microns in size and ULPA filters are 99.999% efficient at removing particles 0.02 microns in size are commonly used in hospitals for almost all operation theatres. Particulate filters are typically provided in pleated media, bag type and cartridge types. In critical spaces, filters are not just used in the air-handling equipment, but also at supply diffusers or grilles, which are the point of air delivery to the particular location, where they act as the last line of defense to arrest contaminants from entering the space.

In general practice while designing air handling units for comfort areas one can use filtration maximum up to 3- Micron starting from 20 micron at fresh air and return air duct or fresh air and return air mouth at mixing chamber in air handling unit (AHU), after which 10-micron takes place to resist the particles before cooling coil and then after blower we can add 5-micron or 3- micron filters for arresting the particles further. But in case of hospital and particularly for operation theatre (OT) areas where doctors operate on various parts of patients, we must select the filters carefully inside the air handling units (AHU) while designing as the filters are the prime responsible media in whole HVAC system for maintaining IAQ.

V. INSTALLATION OF AIR FILTERS IN AIR HANDLING UNITS AND DUCTS FOR MAXIMIZING IAQ

In conventional design of air handling unit we face many problems in maintaining the good IAQ some of them are as mentioned below:

– In conventional design theory we install only 3- filters inside the system in which Pre filters with efficiency of 90% down to arrest 10- micron particles along with fine filters having efficiency of 97% which is capable to arrest the particles upto 3-micron in size are installed inside Air handling unit (AHU), and HEPA filters having efficiency of 99.99% and capable to arrest upto 0.3 micron particle shall be installed inside the supply air duct at terminal inside operation theatre as shown in Fig.1.

– Fixing filters by conventional design can create many problems few of them are as mentioned below:

1) Using only pre filter with 90% efficiency will resist the particle upto 10-micron size in air but major particles present in air which are much smaller than 10-micron shall enter through this filters and then while crossing the cooling coil which is generally installed immediately after pre filters will choke the coil very rapidly. Which will reduce the performance of cooling coil and affects the entire system performance.
2) In many cases AHU's are generally installed outside the building open to atmosphere, where there is major chance of choking of filters and coils very often if we do not maintain them regularly.
3) In this arrangement life of filters reduces, which also affects other components like cooling coil, uv-lights, electric heaters, fan & motor etc.
4) As there is no arrangement after pre filters which are arresting particle upto 10-micron, it becomes prime duty to regularly maintain cooling coil, fan & motor which will gets dirty very often.
5) In running condition, where the fan is sucking the air at very high static pressures to reach the end terminal point at supply, air velocity is very high, generally reaches upto 1200 to 1500 ft/min. in such condition it become very difficult to arrest the dust or impurities present in air, hence we have to take of filtration as our prime concern.
6) Also in this arrangement as there is only fine filters (97% down to3-micron) at the supply point at AHU, and HEPA filters are installed at the terminal which is inside the operation theatre hence it becomes very difficult to control the air quality. This also results in choking the HEPA filter media very rapidly. And as HEPA filters are not reusable so replacing the filters in short time shall also affect commercially.
7) Replacing the HEPA so often becomes a challenge as it is installed inside the operation theatre and it becomes very difficult to take shut downs for O.T. areas and change the filters in working hospital.

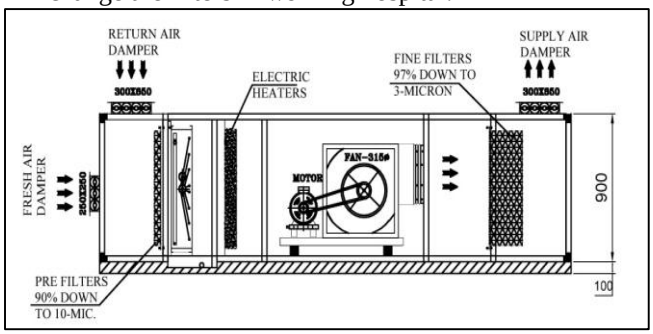

Fig. 1: Conventional arrangement of Air handling unit (AHU) for hospital O.T. Area

While facing all the above mentioned problems in conventional design of air handling unit we have proposed

few additions to install air filters to improve the Indoor air quality (IAQ) which are as below:

- At least 20-micron filters shall be added to fresh air and return air path entering the air handling unit (AHU) to arrest the major particle present in air. This will help in increasing the working efficiency of further filters like 10-micron, 5-micron, 3-micron and HEPA filters inside the air handling unit. Which also results in the increasing the working efficiency of ULPA filters at terminal as shown in Fig.2.
- HEPA filters shall be added inside the air handling units used for all operation theatres and critical care areas which will allow the arrest of air particle up to 0.3 microns before entering into the duct systems. Also installing the HEPA filters inside the air handling units which are generally installed outside the buildings or terrace shall give the ease in changing or removing of filters without disturbing the patients or hospital indoor environment. This will help maintenance team to trace the filters for percentage of choke and change the filters if required without taking shut downs or affecting the occupants inside the operation theatre.
- Ultra-low particulate arrest (ULPA) filters which are 99.999% efficient to resist 0.02 microns particle in size shall be used for operation theatres and critical care areas and shall installed at the supply air duct as shown in Ahu fig.2, which is the last position of air path travelling all the way from ambient to hospital premise crossing air handling unit and duct, and entering the actual area via grilles and diffusers to arrest the smaller most possible particle in air.

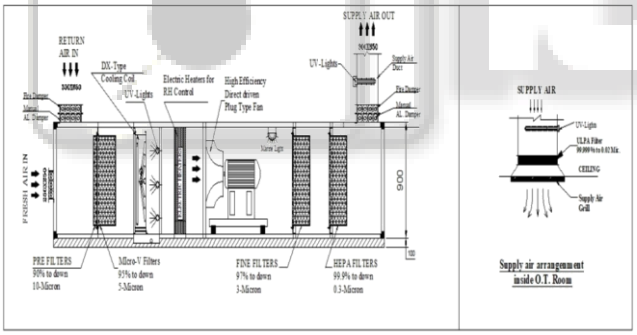

Fig. 2: Proposed arrangement of Air handling unit (AHU) for hospital O.T. Area

- UV-lights shall be added after cooling for not only killing the harmful bacteria in water at drain but also in air travelling through coil, which will results in increasing the efficiency and performance of the cooling coil.
- UV –lights shall added at the supply path before ULPA filters to kill the additional available bacteria or impurities in air to increase the IAQ. Also this results in increasing the performance of ULPA filters by increasing the choking time of filters.
- Direct driven or Plug type fan and motor assembly shall be preferred over conventional belt driven for better efficiency and lesser wear and tear. In belt driven system we use the V-belts for driving motor and fan. V-belts used in air handling units (AHU) are generally made of rubber which will break in small parts while continuous running. The small rubber particles will travel further and increases the chances of choke at filters which will decrease the performance efficiency of filters. Installing plug type fan and motor assembly shall resolve this issue as motor is directly coupled to fan shaft.

VI. CONCLUSION

In this paper we have done the study to improve the indoor air quality of air for hospitals. The overall maintenance cost of existing AHU (Air Handling Unit) is 22,75,066.16 Rs. and after replacing the existing model with the new model we get the annual maintenance cost is 20,94,901.41 Rs. From above study it is seen that there is a cost reduction\ cost saving in annual maintenance, to new model is preferable. Also, the direct driven plug type motor was used in the new model which gave higher efficiency as compared to belt driven of existing model. As V-belt cause wear and tear which will chock and reduces the efficiency of unit. V-belt is replaced by direct driven plug type.

This paper provides the practical study of the challenges in maintaining the good indoor air quality (IAQ) for hospitals and health care facilities while supplying air through air handling unit (AHU) to various critical areas. Also helps to understand the various air filtration used for cleaning the air before supplying to hospital premises. From the study of this review it could be concluded some basic points are as followed:

- No cross movement of air is allowed in and between the various departments to avoid contamination and viral infections etc.
- Direct discharge of inside air to the atmosphere shall be restricted. Air should be treated to remove or kill various bacteria or infectious viruses before discharging outside of the premises.
- To control air quality we require various filtrations starting from 20 microns to 0.3 microns or more depending on the need of area.
- The specific requirements of ventilation system to ensure sufficient flow of air volume for supply inside the premise as well as for exhaust outside the premise.
- Ventilation effectiveness should be taken care to maintain appropriate indoor air quality.
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