IMPACT OF HVAC SYSTEMS ON IAQ IN BUILDING ENVIRONMENT

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ABSTRACT

The Heating, Ventilation, and Air-Conditioning (HVAC) systems are meant to provide the thermal comfort and clean healthy air to the building occupants. The cities like Hyderabad in India have seen a remarkable economic growth in recent times. It has resulted in a large number of air-tight sophisticated buildings that employ HVAC systems throughout the year. Hence, these systems are the only means of air supply to the building. A properly designed, commissioned and maintained HVAC system is thus crucial to good Indoor Air Quality (IAQ) inside these buildings. This paper presents the insight into various aspects of HVAC systems and the potential to improve the air quality within the building environment, as IAQ is vital to public health, their performance and productivity.

Keywords: Building Environment, Filtration, HVAC Systems, Indoor Air Quality (IAQ), Ventilation

I. INTRODUCTION

Today, many people spend most of their time inside modern buildings where the indoor climate is artificially controlled to achieve thermal, visual, acoustical comfort in addition to the acceptable indoor air quality (IAQ) conditions. IAQ has become an area of great interest because of its profound impact on the occupant's health and productivity. Occupants of buildings with air quality problems suffer from symptoms like eye, nose and throat irritation, dry skin and mucous membranes, fatigue, headache, wheezing, nausea and dizziness resulting in discomfort[1]. This leads to increased absenteeism, reduced performance and lower productivity.

Poor IAQ in buildings is primarily related to new building technology, building materials and energy management strategies. Acceptable IAQ is defined by American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standard 62 as "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80 percent or more) of the people exposed do not express dissatisfaction"[2]. This ensures that health considerations must be made along with the human comfort. Eventually buildings were classified as healthy and sick. A building is known as sick when more than 20% of its occupants exhibit any of the varied symptoms for more than two weeks and the symptoms disappear after leaving the building.

The air supplied through the air-conditioning system is increasingly becoming the only means to dilute indoor pollutants as the building envelope is becoming tighter to meet the requirements of energy efficient buildings. It

has resulted in much less air leakage to naturally dilute indoor contaminants and more reliance of the Heating, Ventilating, and Air-Conditioning (HVAC) systems.

Indoor building environment in general and IAQ issues in particular has not been a prime concern for research in India. In response to the global awareness for improved productivity and healthier occupants, it is high time to investigate the air quality in our indoor spaces.

1.1 Statement of the Problem

HVAC systems are meant to control the comfort conditions in buildings with regard to temperature, humidity, odour, air distribution and ventilation. These systems serve as the lungs to the building and the occupant's health depends on the effectiveness of these systems to a large extent. The cities like Hyderabad in India have, in recent times, seen a remarkable transformation with many multi-national and software companies opening their offices and facilities in the city. It has resulted in an increase in the number of air-tight modern sophisticated buildings using innovative building materials and state of the art environmental control mechanical equipments. These buildings employ HVAC systems almost throughout the year. All the air that building occupants breathe has to pass through this HVAC system. Hence it has the potential to improve and deteriorate the air quality.

In recent years, much importance has been given to energy conservation measures which have resulted in reduction of the outdoor air intake into the buildings and more re-circulated air is being used. With the reduction in the ventilation rate, the air quality is naturally compromised.

II. HVAC SYSTEMS

To enhance the comfort and well being of the building occupants, indoor environments have been controlled with extensive and often complicated HVAC systems. The primary function of these systems in a building is to regulate the dry-bulb temperature (22^0-26^0C), relative humidity (30%-60%) and air quality by adding or removing heat energy. Hence, these systems are responsible for providing thermal comfort and contaminant-free clean air to the building occupants. These systems employ filtration, water, air currents and mechanical & electrical devices which may accumulate organic dusts or microorganisms that become a source of bioaerosols. Fig. 1 indicates the ASHRAE summer and winter comfort zones on the psychrometric chart.

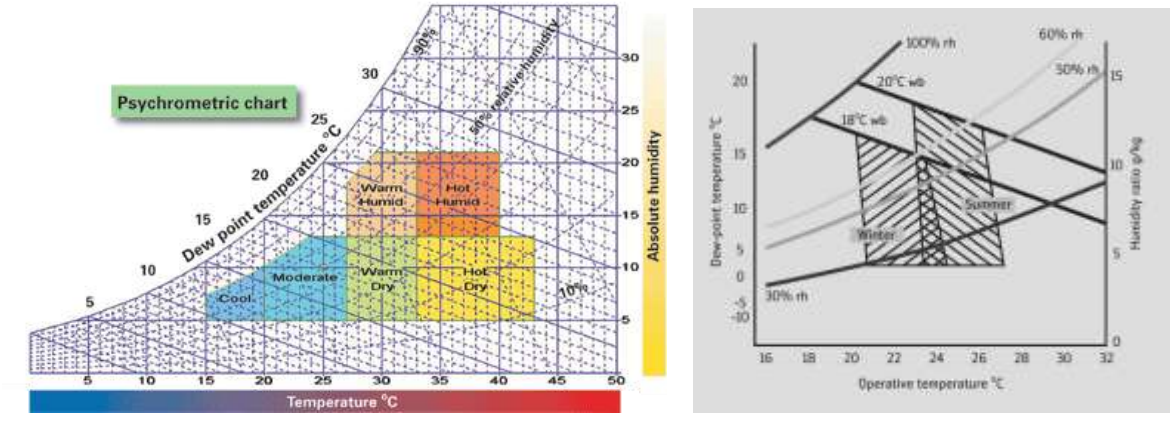

Fig. 1: Psychrometric Chart and ASHRAE Summer and Winter Comfort Zones

It has been indicated that HVAC-related inadequacies are the primary cause of most IAQ problems [1]. These problems could arise because of the deficiency in HVAC system design, maintenance, operation, controls, air balancing, and occupancy related issues[3]. Varius studies have established that the HVAC system is responsible for 50-60 percent of building generated IAQ problems, and it is capable of resolving up to 80 percent of these problems.

2.1 Types of HVAC Systems

A variety of HVAC systems are found in commercial and office buildings that differ from each other according to the building size, occupant activities, building age, geographic location and climatic conditions. ASHRAE has categorized the air handling unit systems as all-air system, all-water system, air-and-water system or packaged unitary system.

There are various types of HVAC systems with different mechanical design and operational strategies. Some of the most common types include the single zone system, variable air volume (VAV) systems, air handling units (AHU), fan coil units (FCU) (as shown in Fig.2) and individual packaged units.

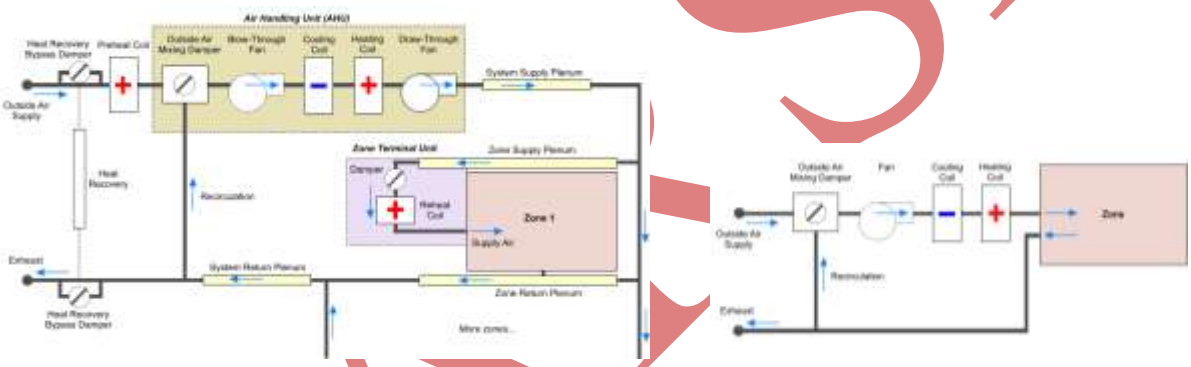

Fig. 2: Air Handling Unit (AHU) and Fan Coil Unit (FCU) with Exhaust and Outside Air Supply

2.2 HVAC Systems Design

A well-designed HVAC system is an essential component of healthy buildings. Poor design is frequently cited as the primary cause of IAQ problems. The Honeywell IAQ diagnostic team found most of the design difficulties in (a) ventilation and distribution (b) inadequate filtration and (c) maintenance accessibility[4].

The emphasis on energy conservation measures have resulted in the negligence of IAQ issues by HVAC designers. A balance has to be done between energy efficiency and air quality, and the HVAC design professionals must stay involved beyond the design stage. Many research works in the west have identified the source of IAQ problems to be malfunctioning, poorly maintained, or inadequately designed HVAC systems.

2.3 HVAC Systems Commissioning

The ASHRAE guidelines define commissioning as “the process of achieving, verifying, and documenting a concept through design, construction, and a minimum of one year of operation[5]. It establishes procedures for

the HVAC commissioning process for each phase of the project: program phase, design phase, construction phase, acceptance phase, and post-acceptance phase.

IAQ concerns should be addressed at each phase of the process to avoid sick building syndrome problems. It is estimated that the commissioning process could eliminate as much as half of all IAQ related complaints. This process requires that the components and systems are inspected and tested under actual installed conditions.

2.4 HVAC Systems Operation and Maintenance

The HVAC systems have been reported to be the cause of over 50 percent of all IAQ problems and complaints, therefore its maintenance is essential to the operation of healthy buildings[6]. The lack of trained maintenance personnel or an unsound operations and maintenance policy can be detrimental to the HVAC system's performance and can increase the risk of creating sources of contamination within the HVAC system. It has been recommended to train personnel of O&M departments, and periodically test, adjust and rebalance HVAC systems[7].

Poorly maintained ducts can be a major problem for IAQ. Moisture in the ductworks encourages microbial growth, which results in building related illness[17]. The diffusers, metal registers, and perforated grillwork also need regular maintenance. Volume dampers have to work properly for the adequate distribution of air[4].

2.5 Ventilation

Ventilation is the process of supplying and removing air by natural or mechanical means to and from the conditioned space. Ventilation standards have evolved over the years and prescribed as minimum ventilation rates in breathing zones for different occupancy category areas in ASHRAE standard 62.1 2010 "Ventilation for Acceptable IAQ". This standard suggests the following procedures for ventilation design:

(a) IAQ Procedure: This is a performance-based design procedure in which acceptable air quality is achieved within the space by controlling known and specifiable contaminants

(b) Ventilation Rate Procedure: This is a prescriptive design procedure in which acceptable air quality is achieved by providing ventilation air to the space based on space type/application, occupancy level, and floor area

(c) Natural Ventilation Procedure: This is also a prescriptive design procedure in which outdoor air is provided through the openings to the outdoors, in conjunction with the mechanical ventilation system

In many situations, occupant generated CO_2 can serve as a suitable surrogate measure for IAQ. The CO_2 content is a good predictor for the amount of outdoor air required, as the ASHRAE guidelines aims to hold CO_2 levels below 1000ppm[8]. Generally the outdoor air CO_2 levels are below 350ppm.

2.6 Filtration

The outdoor air that is required to replenish the oxygen and dilute the pollutants needs to be filtered to free it from the outdoor pollutants and particulate matter. Also the re-circulated air needs to be filtered to clean it from

the indoor generated contaminants. Providing an efficient air cleaning system is often the crucial step in assuring that HVAC system will provide healthy and clean indoor environment.

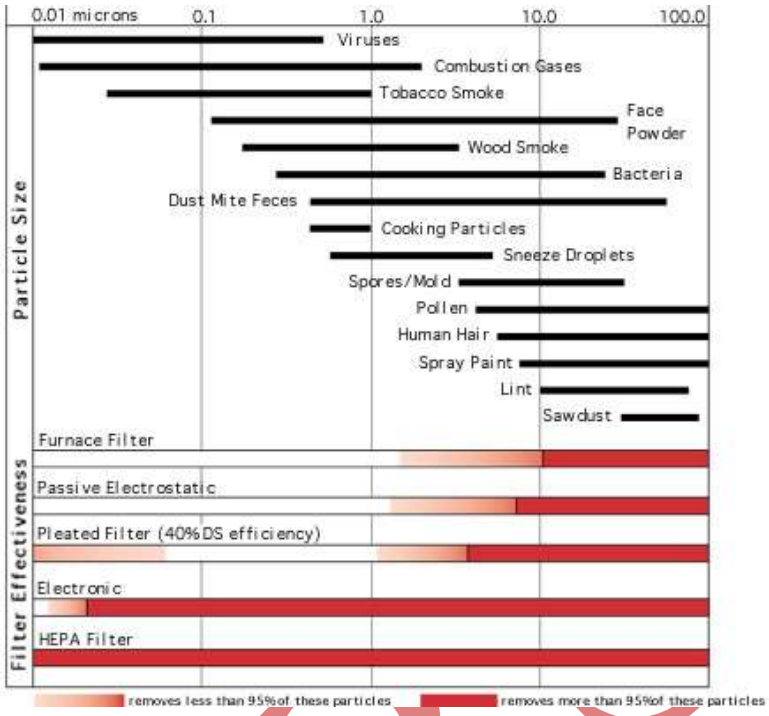

Fig. 3: Efficiency of a Variety of HVAC Air Filters

Air contaminants can be eliminated either by absorption, physical adsorption, chemisorptions, catalysis or combustion depending on the size and shape of the suspended particles in outdoor air. The influencing factor for filter design and selection is the degree of air cleanliness desired.

Air cleaning can result in valuable and cost effective tactics to achieve and maintain an acceptable environment. There are a variety of filters available with different efficiencies, airflow resistance and dust holding capacities as shown in Fig.3. Deciding on the right filter efficiency is crucial for achieving acceptable indoor particulate matter concentration and low energy use[18].

III. IAQ ISSUES

IAQ is of growing concern in modern airtight built environments. The World Health Organization (WHO) has estimated that 30% of the newly built or renovated buildings have IAQ problems or Sick Building Syndrome (SBS). Many reasons have been attributed to this enigma including energy conservation actions such as reduced ventilation, use of synthetic materials in construction, and increasing the levels of outdoor air[9].

ASHRAE standard 62.1 also specifies basic equipment requirements that include sloped condensate drain pans on cooling coils, cleanable surfaces, and accessibility to all areas of the air conveyance systems for inspection and maintenance. It also includes HVAC system installation, commissioning and maintenance issues.

Many IAQ issues in buildings are the result of one of the three sources: (a) outside fresh air dampers have either filed or closed to save energy, (b) indoor air pollutants generation rate is more than the ventilation rates, (c) outside air is polluted or contaminated[10].

3.1 Health Issues

The WHO defines health as a state of complete physical, mental, and social well being, rather than merely the absence of disability. And hence an adverse health effect is the one that compromises health. The relationship between health and IAQ is an area of concern to many researchers. Selected buildings are being investigated for health issues that include building occupants' questionnaire surveys and parametric measurements for temperature, relative humidity and carbon dioxide.

ASHRAE standard 62 has expressed concern for health in all its versions. ASHRAE standard 62 -1973 recommended ventilation levels to suffice "for the preservation of the occupant's health, safety, and well-being". Its revision ASHRAE standard 62-1981 stated "to specify IAQ and minimum ventilation rates which will be acceptable to human occupants and will not impair health". ASHRAE standard 62-1989 stated "to specify minimum ventilation rates and IAQ that will be acceptable to human occupants and are intended to avoid adverse health effects". ASHRAE standard 62-2010 states "to specify minimum ventilation rates and other measures intended to provide IAQ that is acceptable to human occupants and that minimizes adverse health effects".

3.2 Sick Building Syndrome & Building Related Illness

There are many reasons attributed to the contamination of spaces such as human occupancy, building materials, furnishings, space function, and impure outdoor air. When these contaminants increase beyond accepted specified levels, then the building is known as sick building. The American Thoracic Society recognizes the SBS syndromes as eye irritation, headache, throat irritation, recurrent fatigue, chest burning, cough, wheezing, concentration or short-term memory problems, and nasal congestions[11]. The Commission of European Communities and WHO add skin irritation to this list.

SBS has been recognized as a human health problem causing billions in lost annual productivity. These symptoms appear during working hours and diminish when the occupants leave the buildings for weekends or holidays[12]. Many sources of SBS have been indicated, including inadequate ventilation or thermal control, deficient building design or maintenance, macromolecular organic dust, molecules of biological origin, air borne endotoxins, and other physical, chemical, biological or psychosocial factors[11].

3.3 Contaminants

The major contaminants in building environment include carbon dioxide, carbon monoxide, volatile organic compounds, environmental tobacco smoke, radioactive materials, microorganisms, viruses, allergens, and suspended particulate matter. These pollutants vary considerably in terms of their classes, levels and sources. Measurement of environmental parameters have been suggested and adopted for IAQ assessment by researchers

because of their adverse effects on human health[16]. The health effects of exposure to different types of contaminants is shown in Fig. 4.

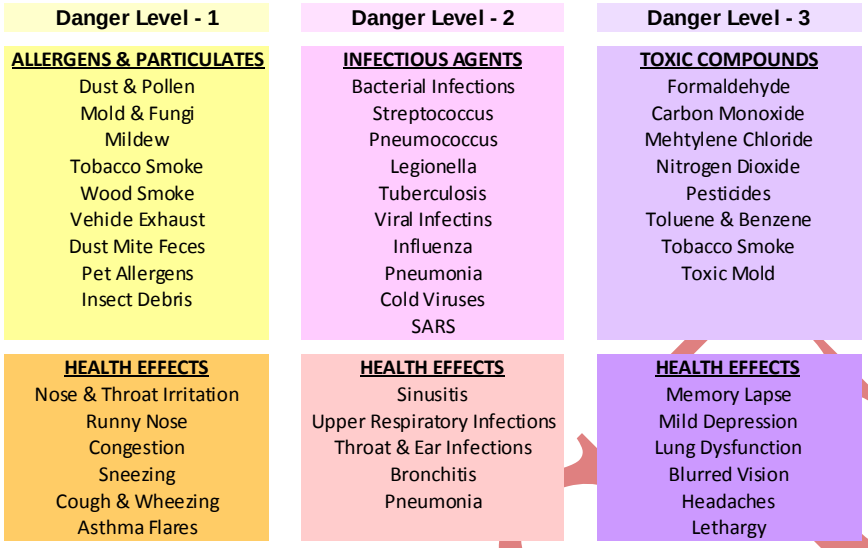

Fig. 4: Health Effects of Different Contaminants *(Courtesy: Center for Disease Control)*

3.3.1 Carbon Dioxide

Carbon dioxide is an exhaled byproduct of human metabolism, and for this reason CO_2 levels are normally higher in occupied spaces than for outdoor air. The Environmental Protection Agency (EPA) recommends a maximum level of 1000ppm for continuous CO_2 exposure. The measurement of CO_2 is utilized for a number of different investigations related to adequate outdoor air supply and distribution within the spaces, thus making it a powerful IAQ diagnostic tool[13].

3.3.2 Carbon Monoxide

Carbon monoxide (CO) is a chemical asphyxiant gas. Its affinity for hemoglobin in red blood cells is 200-250 times that of oxygen, which reduces the oxygen carrying capacity significantly. Tobacco smoking and incomplete combustion of hydrocarbon fuels are two main sources of CO. Its concentration is high in buildings with internal or nearby parking garages. CO is a toxic gas and levels near 15ppm can affect body chemistry to a large extent.

3.3.3 Formaldehyde

Formaldehyde gas is one of the most common volatile organic compounds (VOC). Its health effects include mucous membrane irritation, asthma, neuropsychological effects and malignant disease. It is used in the production of cosmetics, shampoos, carpets, pressed boards, insulations, textiles, paper products, and phenolic plastics, which continue to emancipate formaldehyde for long durations. Acceptable limit is 1ppm as a time weighted 8-hour average[8]. Exposure above 50-100ppm can cause serious injury like inflammation of lungs or death.

3.3.4 Environmental Tobacco Smoke

Environmental Tobacco Smoke (ETS) is release in the air when tobacco products burn or when smokers exhale. ETS contains a mixture of irritating gases and carcinogenic tar particles. It gives off other contaminants like sulfur dioxide, ammonia, nitrogen oxides, vinyl chloride, hydrogen cyanide, formaldehyde, radionuclides, benzene, and arsenic. It is a known cause of lung cancer and respiratory symptoms, and has been linked to heart disease[14].

3.3.5. Bioaerosols

Bioaerosols refer to biogenic agents that are airborne. Many bacterial and viral diseases are spread by direct contact between individuals or indirectly as a result of droplets in air which are produced by talking, sneezing and coughing. It can also transmit through the HVAC system. The main biological factors causing building related sickness are mould, fungi, bacteria, viruses, protozoa, pollens, house dust mites, insect pests, algae, pigeions and rodents. These pollutants may cause symptoms like stuffy nose, dry throat, chest tightness, lethargy, loss of concentration, blocked, runny or itchy nose, dry skin, watering or itchy eyes or headaches in sensitive people[15].

Legionnaire's disease is a contagious disease that generally occurs as pneumonia. Exposure to contaminated cooling towers, drinking water, cooling systems, and humidifiers are the reasons that have been attributed to its outbreak.

IV. CONCLUSION

It is evident from this study that in most cases, IAQ problems are either directly associated with the HVAC systems or these systems could be a remedy to the problem. The major problems associated with the HVAC systems have been identified as inadequate ventilation, inside contamination, microbiological contamination, polluted outside air supply, and inadequate filtration. The importance of good design, commissioning, operation and maintenance strategies for the HVAC systems is well accepted for good IAQ in the building environment. Further, IAQ investigations can be carried out in some selected buildings, in India, that may include the building inspections, building occupants questionnaire surveys, parametric measurements, and interviews with operation and maintenance personnel.

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