Impacts of building designs on indoor air quality in developing countries: Review

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Abstract: The design, physical layout, mechanical systems, equipment and space usage are all essential elements that can affect indoor air quality (IAQ). The air distribution system requires particular attention, such as identifying ways of outdoor air gets in, filtering air and checking the circulation of air throughout the buildings. However, most of the buildings constructed in developing countries are based on the beauty (attraction) of design, cost feasibility, number of rooms to be rented, and others factors without giving attention to IAQ. This resulted in indoor air pollution, which results in increasing health problems, reducing productivity due to discomfort or increased absenteeism, creating negative publicity that could put rental properties at a competitive disadvantage, and opening potential liability problems. As a result, this review is needed to provide basic information about the Indoor Air Pollution that is related with outdoor air intake by opening windows and doors in mistaken direction and other problems related with the building design. The designers/contractors, owners, occupants, and any health related organizations and institutions can use this information as base line to keep indoor air quality of buildings and construction of new buildings.

Key words: Air distribution, air pollution, building design, indoor air quality.

INTRODUCTION

Air pollution can be conveniently categorized as being either particulate (dust) or molecular (gas). Particles can be induced into the body and respiratory systems through breathing. Gas or molecular pollution also enters the body in breathing air, but it is able to penetrate beyond the lungs, into the bloodstream and around the entire body. Although these entities are invisible, bulk pollution is clearly visible in many forms, including; vehicle emissions, factory chimneys, dust raised by speeding cars and cigarette smoke (Farr, 2010).

The content, type, cause for and form of Indoor air pollution varies between developed and developing countries, and between urban and rural areas. In developing countries, indoor air pollution results from burning of biomass (woods, barks, twigs, crop residues and charcoal in rural areas) and charcoal burning for heat and cooking purpose in urban areas. Most of the times in rural areas of developing countries like Ethiopia; kitchen

is not separated from living room/house. This in other words results in smoke and particulate matter from burning of fuel wood, which will cause lung-related health problems like asthma and lung cancer.

In developed countries, indoor air pollution results from “chemicals" and "new substances" (formaldehyde, insecticides and phthalates). However, secondhand tobacco smoke is a pollutant common to both developing and industrialized countries. For example, dust and organic particles are more common in agricultural areas and mites or fungal contaminants in closed, unventilated urban dwellings. The local climate conditions should also be taken into consideration, as they have an impact on architecture (building materials used, structure, room distribution and characteristics), and particularly on the ventilation of the dwelling. Not only this, but also the vulnerability to indoor air pollution varies with age. Children inhale more pollutants per kilogram of body weight than adults do, because airways are narrower, irritation can result in proportionately greater airway obstruction. Children in urban areas spend most of their time indoors, which means that their primary exposure to air pollution may come from air inside homes and schools rather than outdoors (WHO, 2005). There are numerous situations in homes and schools which may result in possible exposure to contaminants, such as second-hand tobacco smoke, spraying of insecticides, accumulation of pollutants in carpets, poor quality air and others (WHO, 2008).

Poor air quality causes adverse health effects in large populations, both in developed and developing countries. The largest exposures to health-damaging indoor pollution occur in the developing world than the developed countries (Palanivelraja and Manirathinem, 2009). According to HEI (2013), the ambient particulate matter pollution ($PM_{2.5}$) in 2010 contributed to 3.2 million premature deaths worldwide. However, indoor air quality (IAQ) is a major concern to businesses, schools, building managers, tenants, and workers because it can impact the health, comfort, well-being, and productivity of the building occupants (OSHA 2011). According to WHO (2008), the level of social and economic development is linked closely to determinants of indoor air pollution (IAP).

SIGNIFICANCE/NECESSITY OF THE REVIEW

The design, physical layout, mechanical systems, equipment and space usage are all essential elements that can affect air quality. The air distribution system requires particular attention, such as identifying ways of outdoor air gets in, filtering air and checking the circulation of air throughout the buildings (TSI, 2013). However, most of the buildings constructed in developing countries are based on the beauty (attraction) of design, cost feasibility, number of rooms to be rented, access/nearness to main street, number of staffs to be accommodated in one room, ease of movement inside the building and portions to be included. In other words, no attention is given to identify and manage the major sources of indoor air pollution. The attention is needed to identify the direction of prevailing wind which blows air mixed with smoke and particulate matter from vehicles, industries, metal works, landfill, and chemicals from agriculture and/or horticulture, and mining. As a result, this review is needed to provide basic information about the indoor air problem related with outdoor air intake by opening windows and doors in mistaken direction of the building design. The designers/contractors can use this information as base line when they plan to construct new buildings.

CAUSES OF INDOOR AIR POLLUTION RELATED WITH BUILDING DESIGN

Many indoor air problems are the result of giving no attention to IAQ as a key issue at the very beginning of the design process. Basic design decisions related to site selection, building orientation, and location of outdoor air intakes and decisions on how the building will be heated, cooled, and ventilated are of critical importance to providing good IAQ (Ashrae, 2009). Efforts to achieve high levels of building performance without diligent considerations of IAQ at the beginning of the design process often lead to IAQ problems and represent missed opportunities to ensure good IAQ.

Construction materials and indoor equipments

The wide range of occupancies and activities in commercial and institutional buildings involve many different types of equipment and activities. IAQ problems have resulted from improper equipment operation, inadequate exhaust ventilation, and poor choices of materials used in some of these activities. The materials known for absorbing moisture from some building materials are known for source of Indoor air problems. For instance, When Asbestos containing materials are damaged or disturbed, they release asbestos fibers into the air. Airborne asbestos fibers pose an increased health risk for mesothelioma, lung cancer, and asbestosis (IAQMP, 2012). Lead can be found in paint and varnishes, and possibly other materials and items. When lead is released as dust or chips, individuals may inhale or ingest the lead. This can affect the nervous system, and young children are particularly susceptible (IAQMP, 2012).

The type of mirrors used for the construction of doors and/or windows play a great role in moisture content inside the room due to condensation, and also it results in

increment of room temperature due to lack /absence of attention given to the transparency of mirrors used for windows and doors. In other words, there are some mirrors which are known for high reflection of sun radiation resting on them. According to EBC1 (2016) News, most of the large buildings with doors and/or windows made of mirrors are highly reflecting to sun radiation, which was one of the causes of car accidents in the capital city of Ethiopia (Addis Ababa), as a result of eye irritation of drivers. Not only this, but also the higher reflection resulted in the increment of surface temperature in the city where report was made, which in other words, affect the temperature of indoor since there is air exchange between indoor and outdoor.

Moreover, some mirrors are known for their "Green House Effect". The type of color mirrors are painted with affects the transparency and absorption to sunlight energy. This is to mean that some mirror are transparent to short wave radiation coming from the sun and less transparent (translucent) for long wave irradiations reflected back from walls of building, floor, ceiling or from any materials inside the room. There is positive net energy inside the room, which will result in temperature increment that in other words results in indoor air pollution. Recent developments in construction materials have resulted in the use of more synthetics and composites, which can affect air quality. Radical changes in technology have led to innovations such as computers and photocopiers that provide greater efficiencies and time savings, but they can also affect the quality of indoor air (TSI, 2013).

A healthy indoor environment is one in which the surroundings contribute to productivity, comfort, and a sense of health and well-being. The indoor air is free from significant levels of odors, dust and contaminants and circulates to prevent stuffiness without creating drafts. Temperature and humidity are appropriate to the season and to the clothing and activity of the building occupants.

Microbial organisms

Excessive levels of moisture in building assemblies, particularly in the building envelope lead to IAQ problems. Such situations can lead to mold growth that can be very difficult to fix without major renovation efforts and costs (USEPA, 1991; Ashrae 2009). Microbial organisms, such as fungi (for example, mold) and bacteria can cause illness (such as allergies, asthma), costly damage, and discomfort. Microbes need moisture, a food source (such as drywall) and other particular conditions to grow (IAQMP, 2012). Moisture problems arise for a variety of reasons, including roof leaks, rain penetration through leaky windows, envelope design and construction defects such as low-permeability wall coverings in hot and humid climates, and poor building pressure control buildings (USEPA, 1991; Ashrae, 2009). These problems are largely avoidable but require an understanding of building moisture movement and attention to detail in envelope design and construction and in mechanical system selection, installation, and operation (IAQMP 2012).

Lack of commitment

Despite the building design problems, there are opportunities to improve the indoor air quality of building either by regular removal of wastes (residues of fruit or food, paper, volatile organic compounds), or planting plant species with dense crown on the side of pollution source. Making a commitment to good IAQ at the beginning of a project and maintaining that focus through design, and construction will result in a building that is more successful in meeting its design goals and achieving the desired level of performance throughout its life. However, all of the activities to improve indoor air quality need the commitment of individuals, occupants, organizations, different sectors, and owners. This is because of the reason that the community participation plays a great role in solid waste reduction by showing their willingness to use materials with no/or little waste, which results in a significant reduction in total waste generated (Alefu 2015). As a result of this, the total amount and composition of gases released (outdoor air, which is one of the major sources of indoor air pollution) from biodegradation of solid wastes is or can be reduced.

Poor outdoor air quality

The traditional means of dealing with IAQ is through outdoor air ventilation. While ventilation can be an effective means to dilute indoor contaminants, it assumes that the outdoor air is cleaner than the indoor air. In many locations and for many contaminants, this is not the case, and insufficiently treated ventilation air can actually make IAQ worse (Ashrae, 2009). Poor outdoor air quality includes regionally elevated outdoor contaminant levels as well as local sources, such as pollen, dust, fungal spores, industrial pollutants, motor vehicle exhaust from nearby roadways and contaminants generated by activities in adjacent buildings (USEPA, 1991; Ashrae, 2009). Some programs encouraging higher levels of building performance recommend increasing outdoor air ventilation rates, but such recommendations should be based on the consideration of the potential impacts of poor outdoor air quality. In urban areas of developing countries, most of the buildings are constructed without considering methods of filtering and/or reducing the total outdoor air mixture by plants or trees before they enter into indoor. Plants absorb different toxic chemicals on

their leaves and barks, and also they use carbon dioxide (carbon sink) for photosynthesis.

Inadequate ventilation rates

There are a variety of reasons for inadequate ventilation rates, including lack of compliance with applicable codes and standards, installation or maintenance problems that lead to the design ventilation rate not being achieved in practice, or space use changes without an assessment of the need for updated ventilation rates (Ashrae 2009; Osha, 2011). Also, system-level outdoor air intake rates may be adequate, but air distribution problems can lead to certain areas in the building being poorly ventilated.

Ineffective filtration and air cleaning

Filtration and air cleaning are effective means of controlling many indoor air pollutants, particularly those associated with poor outdoor air quality. Air filtration or air cleaning, therefore, can provide an important adjunct, and in some cases substitute, for outdoor air ventilation (Ashrae, 2009; Osha, 2011). This study focuses on treatment of filtration and air cleaning alternatives that, when properly administered and maintained, can improve both IAQ and energy performance.

EFFECTS OF INDOOR AIR QUALITY PROBLEMS

The quality of indoor air can and does impact productivity, personal comfort, building maintenance costs and even health and safety, either positively or negatively depending on how air quality is managed (Ashrae. 2009; TSI, 2013). Failure to respond promptly and effectively to IAQ problems has the following consequences (USEPA, 1991). These are:

1. Increasing health problems such as cough, eye irritation, headache, and allergic reactions, and, in some rare cases, resulting in life-threatening conditions (for example, legionnaire's disease, carbon monoxide poisoning).
2. Reducing productivity due to discomfort or increased absenteeism.
3. Accelerating deterioration of furnishings and equipment.
4. Straining relations between landlords and tenants, employers and employees.
5. Creating negative publicity that could put rental properties at a competitive disadvantage, and
6. Opening potential liability problems.

PREVENTING IAQ PROBLEMS RELATED WITH BUILDING DESIGN

Building owners, designers, and contractors can all benefit from an increased focus on providing good IAQ in their buildings (Ashrae, 2009). The relationships among building owners, management, staff, and occupants are an important factor in decisions that affect indoor air quality. The objectives of the major players in these relationships may be very different. Occupants want the building to be pleasant, safe, and attractive; if they are paying tenants, they also want to get the maximum use out of the space they rent for the least cost. Building owners and management want to maintain a reputation for providing quality property at reasonable cost, but also need to derive a profit. Facility staffs are often caught in the middle, trying to control operating and maintenance costs while still keeping occupants satisfied. Any IAQ management system will be successful only if it is organized to fit your specific building. It would not be appropriate for this document to prescribe any single approach. However, the skills associated with IAQ management activities will be identified to help building management decide who will be best able to carry them out. Education and training programs for staff and building occupants should be provided to ensure that new procedures are understood and adopted.

Preventive maintenance plays a major role in maintaining the quality of air, by assuring that the building systems are operating effectively and efficiently. Moreover, it helps to maintain a comfortable temperature and humidity in occupied spaces. According to IAQMP 2012, preventive maintenance means the routine inspection, adjustment, and repair of building structures and systems, including the heating, ventilating, and air conditioning system (HVAC), local exhaust, and flooring. According to US EPA (2014), 13.1% of Country's total budget was assigned for the achievement of its goal of addressing Climate change and improving air quality in 2015.

Managing buildings for good IAQ

There are two primary reasons to include IAQ considerations in the earliest stages of project planning (Ashrae, 2009).

1. Avoiding problems that occur when IAQ is treated as an afterthought and
2. Allowing consideration of alternative design concepts that involve decisions made early in the design process.

Incorporating IAQ at the very beginning of conceptual design gets a number of key issues before the design team, enabling them to make informed decisions that will affect the project through the construction and occupancy

phases. The phrase “protection is better than cure” best fits this concept. The IAQ of building is affected by:

1. The owner’s expectations for IAQ in the building,
2. Outdoor contaminant sources in or near the site,
3. The activities expected to occur in the building (and the contaminants that might be associated with these activities),
4. The characteristics of the occupants (e.g., their age range and health status, as well as the possibility of short term visitors that may have very different expectations than occupants who will remain in the building for a long time), and
5. The approaches used to heat, cool and ventilate the building.

According to IAQMP 2012, managing a building for good indoor air quality involves reviewing and amending current practice and establishing new procedures on activities like:

1. Operate and maintain HVAC equipment: keep all equipment and controls in proper working order, keep interior of equipment and ductwork clean and dry.
2. Oversee activities of staff, tenants, contractors, and other building occupants: These activities are; smoking, housekeeping, building maintenance, shipping and receiving, pest control, and food preparation and other special uses.
3. Maintain communications with occupants: Get complaints about IAQ problems from occupants.
4. Educate staff, occupants, and contractors about their responsibilities in relation to indoor air quality.
5. Identify aspects of planned projects that could affect indoor air quality and manage projects so that good air quality is maintained: Some of these are redecorating, renovation, or remodeling, relocation of personnel or functions within the building, and new construction.

Building evaluation

Buildings should be evaluated regularly for their ventilation systems and the maintenance activities. However, the intensity and frequency of evaluation depends on the purpose of the building used for. For instance, School buildings can be evaluated every year (IAQMP, 2012). The ventilation evaluation is related with the air intakes, air filters, condensate areas, coils, cleanliness, mechanical rooms, dampers, controls, air movement, and exhaust. Whereas, the maintenance evaluation is related with the building supplies, dust control, floor cleaning; drain traps, moisture, and combustion appliances. The variety of unique features in their design and usage (for example, apartment buildings, hospitals, schools, shopping malls) make a wide range of IAQ problems possible. In apartment buildings, for example, each residential unit can produce cooking odors and the operation of kitchen exhaust fans is generally outside the control of building management.

CONCLUSION

Many design decisions that can lead to poor IAQ are made in the early phases of design and are difficult to modify or correct later on. Early design missteps can be avoided if IAQ is put on the table as a key design issue at the start. The problems that can be avoided are inadequate space for mechanical equipment, limiting access for inspection and maintenance, and selection of interior finishes that can lead to high levels of volatile organic compound (VOC) emissions or to moisture problems in the building envelope.

RECOMMENDATIONS

In order to reduce the negative effects of building designs in indoor air quality, the owners should discuss some issues about indoor air quality with contractors before the construction. As a result, engineers should get some information from environmentalists and foresters about techniques of incorporating buildings with vegetations in controlling the entrance of polluted air into indoor and the direction of continuous source of pollutants before the construction. In addition to this, different sectors like road construction authority, engineers, environmentalists, foresters, municipal workers and others should work together in order to maintain indoor air quality of buildings.

Conflict of Interests

The author has not declared any conflict of interests.

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