Introduction

From the outset, buildings simply use a lot of energy. According to the Energy Information Administration, they represent 30-40% of all energy usage in the world. Therefore, the future of our environment is intrinsically linked to buildings and their design. Furthermore, 60-90% of our time is spent indoors. Our quality of life is thus defined by our lives inside, which are critically dependent on the quality of the air within. The following article addresses indoor air quality with a focus on the design issues associated with the topic. It will begin with identifying the key contaminants and the sources thereof, then move on to target problem areas in building design where these contaminants originate, and finally discuss solutions to deal with them. Since building ventilation is intrinsically linked to indoor air quality, a separate section on ventilation systems follows, along with a discussion of each type of contaminant’s historical association with sick building syndrome (SBS). SBS is used to describe acute symptoms felt by building occupants that can not be attributed to any other source than time spent in the building.

Ventilation and emissions

There are a few key relationships and principles that should guide design choices with respect to indoor air quality, typically abbreviated as IAQ.

When we look at the inside of a building, the composition of the air within depends upon the emissions into that space. The concentration of any element in the air is a function of how quickly a source is producing emissions, and how quickly the emitted substances are removed from the space. This can be expressed by the equation: Concentration (mg/m$^3$) = Emission Rate (mg/h) / Ventilation Rate (m$^3$/h).

The emission rate depends on the size of the source (Area in m$^2$) and the rate at which a unit area of the source is emitting (mg/m$^2$ h$^{-1}$). The equation above provides a good beginning on which to base design principles. It shows that there are two key ways to address indoor air quality. The first focuses on controlling the sources of the emissions. The second concentrates on using ventilation systems to remove the emissions themselves. Aside from benefits to IAQ, an efficiently operating, clean ventilation system can also reduce energy consumption.

Ventilation involves bringing in outdoor air to replace the air that is already in the occupied space. The ventilation rate measures how fast “uncontaminated” air is being introduced into the space.
Key contaminants and sources

When discussing sources of emissions, the key aspects to consider are: where they come from, what they are, and then how to eliminate, isolate, or reduce their presence. These sources originate from outdoor air, the building envelope, moisture, certain building materials, building services and equipment, and particularly HVAC systems.

Volatile Organic Compounds (VOCs)
Sources: building materials such as wood, carpets, furnishings, finishes, paints, sealants. Formaldehyde is a key VOC found commonly in wood products such as particle board, plywood and other types of products glued together.

Radon
Sources: Soil (foundations in basements), asbestos building construction materials, lead paint (particularly in older homes), and water.

Microbial contaminants
Source: Fungi, bacteria, and viruses that grow in moist areas.

SO$_2$, CO, NO$_x$, O$_3$, and particulates
Sources: Outdoor air and indoor combustion

How to eliminate, isolate, and reduce contaminants

Ventilation: The most effective means of ventilation is to provide a local exhaust (identify the sources and place an exhaust in the immediate vicinity, e.g. a bathroom fan). For sources that cannot be locally controlled, the indoor air will be diluted by that from the outdoors. One of the key ways to achieve this dilution is displacement ventilation, which supplies outdoor air to the floor. As activities progress within the building, heat sources such as humans warm the air around them. As this air rises it can be displaced by fresh air from outside. The air at the top can then be exhausted or filtered mechanically.

Air Filtration/Cleaning or outdoor air: As mentioned above, sometimes the source of pollution is the outdoor air itself, which makes filtration essential. An air filter allows air through, but traps dust and other large particulates.

Sinks: These use a material, such as a filter or air cleaner, that absorbs harmful chemicals. In other words, a sink works in a way that is the opposite of a source, taking in chemicals from the air and storing them.

A closer look at moisture

Sometimes the most important contaminant with respect to the indoor environment is moisture, particularly in humid climates. The existence of outdoor moisture is not a reason to avoid ventilation, and the solutions to moisture problems are highly dependent on climate. The issue of moisture becomes most pertinent when living matter (e.g. mold) begins to grow. Buildings provide warmth, food, and moisture, creating a perfect environments for bugs, mold and rot. There are multiple strategies for dealing with moisture. The first is simply to live with it, building with moisture tolerant materials and practices.

The second strategy is to build with absorbent materials and, more importantly, assemblages that have more drying than wetting potential. The third is to use mechanical dehumidification. The best way to deal with the issue of Indoor Air Quality is to design, build, commission, operate, and maintain the entire system from the beginning. Basic standards must be followed, but they represent only the bare essentials. The American Society for Heating Refrigeration and Air-Conditioning Engineers (ASHRAE) has recently published a design guide specifically for ventilation, called Standard 62.1. This guide moves a step beyond defining minimum requirements to the realm of establishing “best practices”.

![Figure 2: Mold Growth due to Moisture](image1)
![Figure 3: Lead Paint](image2)
![Figure 4: Ground Soil](image3)
![Figure 5: Smog in Beijing](image4)
Problems and solutions

In order to produce safe, healthy, low-maintenance buildings, IAQ must be considered throughout the planning, construction, commissioning and operation processes. A building should not be occupied until products have cured (off-gassed), and ventilation systems have been tested.

One way to address this issue is to suggest and enforce operational schedules for purging during off-hours and periods when the building is unoccupied. This is especially critical after maintenance, cleaning, polishing, etc.

To deal with the problem of moisture in building assemblies, the building should limit the penetration of liquid water and condensation on building surfaces. To achieve these goals, appropriate pressurization of the building, control of indoor humidity, and careful choice of building materials are all important considerations.

Poor outdoor air quality is an issue that affects indoor air. With this in mind, the proper siting of intake vents is absolutely essential, along with tight control of outdoor entry.

Fouled ventilation systems are another source of poor indoor air quality. This is generally caused by moisture or dirt in air-handling systems and deposition or erosion on HVAC surfaces. The solution to this issue is to provide adequate access for maintenance and inspection in the design of the building.

Inadequate ventilation rates are often targeted when air quality is poor. All combustion equipment must be properly ventilated and the building designed for the local capture (exhaust) of point sources. Ensuring that the exhaust systems installed do not leak and maintaining appropriate pressure balances within the building are both necessary for healthy operation.

If there is ineffective filtration/air-cleaning, the quality of the air will be inadequate as well, no matter how much air is being flushed into and out of the building. Therefore, the design of the building must not only achieve adequate air ventilation rates but also provide for adequate filtration and air cleaning.

A closer look at ventilation

In general, one can divide ventilation into three broad categories: mechanical, natural, and infiltration.

Mechanical ventilation is generally achieved through the use of an Air Handling Unit (AHU) which conditions and circulates the air going into the building. An AHU typically has a large blower with a variable flow rate that distributes the air, and can include heating or cooling capability when needed in conjunction with a boiler or chiller. Chillers are found primarily in large commercial buildings, while boilers are found in both residential and commercial buildings. Almost any AHU will include a filter, which is generally the first component installed in the unit. Common filter types include: low-MERV (MERV is a rating system describing the performance of an filter with respect to its ability to capture various sized particles), High-Efficiency Particulate Air (HEPA) filters, and electrostatic filters. AHU’s in colder climates often include humidifiers and provide for the exhaust of indoor air and intake of outside air. Heat recovery ventilation systems are designed to include heat exchangers, which can increase efficiency and decrease energy consumption. Forced ventilation can also be achieved with fans, which are generally more localized near the source of contaminants, like an exhaust fan within a bathroom or near a source of combustion such as a stove, for example. Fans are common components of both residential and commercial construction. Natural ventilation, on the other hand, is achieved without mechanical assistance, either through operable windows or through temperature and pressure differences within a space.

Infiltration is the addition of outdoor air into an indoor environment through cracks and other unsealed openings within the building. Buildings are generally designed with the expectation that infiltration will occur, at least to some extent, for the provision of outdoor air to the indoor environment.

Seppanen (Helsinki University of Technology) and Fisk (Lawrence Berkeley National Laboratories) performed a very interesting cross-sectional study investigating the occurrence of Sick Building Syndrome (SBS) in relation to various ventilation systems. The authors found that, relative to natural ventilation, air conditioning with or without humidification was linked to statistically higher (30%-200%) instances of Sick Building Syndrome symptoms. They also found an association between SBS and air conditioning systems, as opposed to simple mechanical ventilation, but with less consistency. The findings indicate
that HVAC systems do as much harm as good when improperly installed and maintained. The authors provide multiple hypotheses to explain their findings:

Pollutants are either emitted by HVAC components themselves, or by ductwork and surface contaminants which are then distributed by the AHU’s. HVAC systems have the potential to be microbiologically contaminated and the authors indicate that HVAC systems that have not been cleaned have a significant link to upper respiratory complaints. Conclusion: All HVAC components must be thoroughly cleaned on a regular basis, otherwise they may do more harm than good. HVAC systems may draw outdoor pollutants indoors and distribute those pollutants throughout the building. Conclusion: The proper placement of outdoor intakes (e.g. far from sources of combustion or allergens) is critical in healthy building design.

Ventilation rates are lower in mechanically ventilated buildings (particularly those with air-conditioning systems) than in those that are naturally ventilated. Unfortunately, there is very little data concerning ventilation rates within naturally ventilated buildings and those rates are obviously dependent upon user performance and the number of windows open within the building. Conclusion: Design for ventilation rates that meet or exceed ventilation rate codes.

Recirculation distributes pollutants from a source throughout the building. On the other hand, the recirculation will also tend to dilute the concentration of contaminants close to the source and is almost always combined with air-filtration, which reduces overall levels of contamination. Conclusion: Always couple air recirculation with air filtration.

High air velocities in mechanically ventilated rooms tend to increase the drying of mucous membranes and thus the reporting of related symptoms. Conclusion: Make sure the HVAC system is designed to code with respect to air velocities in the vicinity of workers.

Conclusion

Considering IAQ from building commission throughout the design process is absolutely essential. A building can be designed to function perfectly, but commissioning must verify that the design has been executed. This means that all building materials should be selected with IAQ in mind, particularly interior finishes. It also means selecting the appropriate HVAC system, establishing a project schedule, managing construction to preserve IAQ, and providing high quality Operations and Management training. IAQ must be a part of the design process from the very beginning. Moisture in the envelope and assemblies must be limited, along with exposure to outdoor contaminants. Mechanical systems must be kept clean and dry at all times, and indoor sources of contaminants must be addressed just as seriously as outdoor sources. Ventilation, filtration, and air-cleaning systems should be sized and designed for each specific site. Other ventilation design criteria include proper ventilation rates, recirculation in conjunction with filtration, the careful placement of outdoor intakes, and design for comfortable air velocities near occupants.

Notes


Figures

Figure 1: http://www.linz.at/english/tourism/3394.asp
Figure 2: www.waterdamagefortworth.com
Figure 3: flickr.com/photos/editor/2279584745/
Figure 4: http://cheap-dirt.biz/Top%20Soil%201.JPG
Figure 5: http://2008gamesbeijing.com
Figure 6: www.buildinggreen.com
Figure 7: stallionsecurity.com.au/site_files/images/
Figure 8: http://www.woodlands-glenshiel.co.uk/
Figure 9: http://www.sage-earth-sciences.com/
Figure 10: Ibid.

Biography

Max Sherman received his B.S. in both chemistry and physics from the University of California, Los Angeles. He then moved to the University of California at Berkeley, where he received his PhD in Physics, completing his thesis on Air Infiltration in Buildings. From his graduation from Berkeley to the present time, Sherman has worked for the Lawrence Berkeley National Laboratory. He is currently employed at LBNL as a Senior Scientist within the Energy Performance of Buildings group. In the last two decades he has served in various leading positions within the California Institute for Energy Efficiency.

He is an active member of the American Society for Heating Refrigeration and Air-Conditioning Engineers (ASHRAE), the American Society of Testing and Materials (ASTM), The American Society for an Energy Efficient Economy (ASEEE), the International Energy Agency (Buildings and Community Systems), the International Standards Organization, the American Physical Society, and the American Association for the Advancement of Science.
1.7 Indoor Air Quality through Design