Introduction to Indoor Environmental Quality

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ASHRAE members participating in the residential market should be committed to "advancing human well-being through sustainable technology for the built environment." Human well-being is intimately connected to indoor environmental quality. Both sit nicely within the human sciences. These two fields of study should be considered by practitioners as important as, if not more important than, any other metric within the study of architecture, buildings, and HVAC systems. In this segment on residential IEQ, members are introduced to current ASHRAE resources related to:

- Indoor sound quality (of which indoor vibration quality is related);
- Indoor thermal quality (of which indoor lighting quality is related); and
- Indoor air quality (of which indoor odor quality is related).

All six of the key IEQ sensory metrics listed above require a basic knowledge of:

- Human sciences (physiology and psychology);
- Building sciences (enclosure design and performance);
- Interior systems (finishing characteristics: color, composition, sound absorption, stability);
- Lighting systems (daylighting, shading, etc.); and
- HVAC system and equipment (utility of types,applications).

Indoor Sound Quality

ASHRAE Technical Committee (TC) 2.6, Sound and Vibration Control, is responsible in part for its content in Chapter 9, Indoor Environmental Health, in the *2017 ASHRAE Handbook—Fundamentals*; and Chapter 48, Noise and Vibration Control, in the 2015 *ASHRAE Handbook—HVAC Applications*. These resources discuss the sensing and perception of the sound quality in a space; and consider sources and causes contributing to auditory dissatisfaction.

Hearing is the process of converting sound waves originating from outside the ear into vibrations within the ear, and then into electrical signals transmitted to the brain. Sound waves are the oscillations in pressure

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above and below atmospheric pressure created by disturbances in the air. The frequency, in waves, is measured in cycles per seconds using units of Hertz (Hz). Sound waves create vibrations (vis-a-vis the ear drum) within the inner ear. These vibrations open up chemical receptor cells, which results in an electrochemical signal. The signals are then sent out via neurotransmitters and received by the brain through the auditory nerve. The brain interprets the signals as sound. Sound recognition capabilities develop before birth, and with experience, the brain at a below conscious level is constantly building an inventory of auditory signals associated with specific sources of noise. It is in conscious thought where recognition from memory identifies the difference between a child crying and a dog barking. Likewise, the brain can recognize the sounds associated with air velocity in a ducted HVAC system and that of water flowing in a plumbing pipe. Pressures in sound waves are scaled to ranges of decibels (db). A whisper for example is at approximately 20 db, a busy street at 70 db, and threshold of pain at 120 db.

Noise levels between 10 db and 50 db are considered acceptable in residential settings. Decibel levels must be evaluated and controlled at numerous frequencies to prevent unacceptable noise.[1] When noise from HVAC equipment becomes irritating—either because it is present all the time and/or it is loud—people will take steps to prevent that discomfort; they will turn it off, alter the source, or remove themselves from the cause so that it no longer remains annoying. Some measures to prevent sound discomfort could have negative effects on occupant indoor air quality or thermal comfort. Practitioners are encouraged to take the necessary step to mitigate noise and vibration in HVAC systems and familiarize themselves with equipment noise criteria (NC) ratings published by manufacturers.

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Indoor Thermal Quality

The committees responsible for assembling the body of knowledge on thermal comfort are TC 2.1, Physiology and Human Environment, and Standing Standards Project Committee (SSPC) 55, Thermal Environmental Conditions for Human Occupancy. These two committees explore and report on the thermal sensing of the indoor environment and resulting occupant perceptions and responses.

Recent work from SSPC 55 incorporates the influence of shortwave energy through windows on thermal perceptions. This solar effect on thermal comfort influences decisions related to enclosure performance, shading systems, window types, HVAC systems and thus energy use. Shortwave energy also connects lighting quality and thermal comfort. Since this energy form also plays a role in degradation of materials of construction into gases and particulate matter, it also connects thermal comfort to interior systems and indoor air quality.

Thermal comfort is also directly connected to HVAC systems and equipment, therefore, it is also related to noise and vibration concerns. As with other environmental factors, degrees of thermal discomfort influence occupant learning, productivity and sense of well-being. Wider indoor variations is of recent concern to those interested in natural ventilation and adaptive comfort and in the tension between homeostasis and alliesthesia. These being the body's desire for thermal balance (comfort) and the exercising of sensation though thermal imbalances (discomfort) in the same manner that an athlete works on their sense of physical balance by testing the limits of being out of balance.

Understanding the effects from building and HVAC systems, which regulate the heat dissipation rate from the human body, is important. The necessarily required total heat discharge for homeostasis and health varies between 330 Btu/h to 450 Btu/h (97 W to 132 W) at low to moderate activities; of which 225 Btu/h to 250 Btu/h (66 W to 73 W) is sensible heat. At low metabolic (MET) rates and air velocities, and low to moderate humidity, approximately 60% of the sensible heat is emitted as radiant energy, which is approximately 37% of total transfer.[2] Radiant being the dominant mechanism often comes as shock to those raised on air temperature as being the Holy Grail in regulating thermal comfort. It shouldn't be a surprise given that the emissivity of skin and clothing is such that they are effective enablers of radiant transfer.

Furthermore, it explains (in part) why enclosure performance is instrumental in controlling comfort through regulation of interior surface temperatures.[3]

In its simplest form, it is the average of the mean radiant temperature and air temperature [(MRT + t_{db})/2], which defines in thermal comfort vocabulary the operative temperature for the location of the occupant in the space. Operative temperature, humidity, air velocity, metabolic rate, and clothing values establish the general factors. Radiant asymmetry, temperature stratification, floor temperatures and drafts establish the local factors. The combination of these variables can be considered much like the solution to a Rubik's Cube. For ASHRAE Standard 55 compliance, the application of solutions in mechanically conditioned spaces is accomplished with an analytical method; or, in naturally conditioned indoor spaces, using an adaptive method. There is also a method for using elevated air speeds and a simplified but less flexible graphical method.

The integration of comfort metrics has been developed into a predicted mean vote (PMV) scale which results in a predicted percentage of dissatisfied occupants. This PMV is applied by practitioners in understanding levels of discomfort risk and is useful to architects, builders and their clients in achieving comfort targets for indoor spaces via choosing methods, materials of construction, and evaluating HVAC system types.

Indoor Air Quality

During a lifetime, a person breathes about 250 million L (66 million gallons) of air weighing about 300,000 kg (660,000 lbs).[4] Therefore, it is imperative that practitioners understand the significance of managing air quality. ASHRAE committees that are responsible for assembling the body of knowledge on IAQ include: TC 2.3, Gaseous Air Contaminants, TC 2.4, Particulate Air Contaminants, TC 2.9, Ultraviolet Air and Surface Treatment, and SSPC 62.2, Ventilation and Acceptable Indoor Air Quality in Residential Buildings. Additionally, practitioners should familiarize themselves with ANSI/ASHRAE Standard 52.2, *Method of Testing General Ventilation Air Cleaning Devices for Removal Efficiency by Particle Size* and ASHRAE Guideline 24, *Ventilation and Indoor Air Quality in Low-Rise Residential Buildings*. ASHRAE has official position statements dealing directly or indirectly with indoor air quality, which are available online at no cost. These committees, standards, guidelines, and position statements explore and report primarily on the sensing of the indoor environment through respiration processes; thereby, resulting in occupant perceptions and responses. Absorption through skin and digestion of airborne pollutants are also considered.

IAQ elements can be described as pollutants, contaminants, and toxicants depending on their presence, affects, and effects. They typically exist as particulates or gases/vapors/aerosols. For example, odors from bio-effluents and hydrogen sulphide are considered irritants as would be some dusts and microbial. Some of these elements can trigger physiological responses such as sneezing or coughing.

These human responses can be effective at removing or neutralizing irritants caught in the cilia and mucosa found in the nasal and throat passages. VOCs, ozone, NO_2, bacteria, and pollens are also in the irritant category. Residents with asthma or allergies may have more aggressive responses that can impair the occupant; includes contraction of air passageways and nasal congestion leading to breathing difficulties, hives, itching, and watering eyes. Carbon monoxide, lead, formaldehyde, and endotoxins from bacteria are known toxicants; and polycyclic aromatic hydrocarbons (PAHs), radon, asbestos are known causes of cancers related to air quality.

Particulate matter between 2.5 and 10.0 microns are found in the upper respiratory tract. Particulates less than 5.0 microns can migrate down into the bronchial passageways (with 2.5 microns travelling even deeper into the lungs); these then contribute to airflow blockages and macrophage responses such as what happens with asbestos and its resulting mesothelioma. Those less than 1.0 micron—such as bacteria, viruses and spores—can cause infections and inflammations. They become lodged in the air sacs of the lungs (alveoli); the smallest viruses and toxins from particulates (for example) are capable of permeating through the air/lung barrier (alveolar membrane) into the bloodstream.

Once airborne, contaminates and toxicants enter the bloodstream, the body's internal defense mechanisms are activated. One such response is the production of white blood cell types whose job is to locate and neutralize the foreign body. Once in the circulatory systems the waste product is then filtered, detoxified, and removed through the spleen, liver and kidneys. Those contaminates that cannot be metabolized, neutralized, or removed are known for contributing to morbidity and mortality.

Conclusions

Residential design practitioners cannot ignore the human sciences. They need to "act with care and competence using and developing up-to-date knowledge and skills" in this field of study. With over 56,000 members worldwide—and a lengthy and global history of research, education, outreach and standards development—ASHRAE has a tremendous knowledge bank to share with the housing community for the purposes of, "advancing human well-being through sustainable technology for the built environment."

IEQ Resources for Residential Practitioners

ASHRAE Guideline 10, *Interactions Affecting the Achievement of Acceptable Indoor Environments.*

ASHRAE Guideline 24, *Ventilation and Indoor Air Quality In Low-Rise Residential Buildings.*

ASHRAE Technical Committee 2.3, Gaseous Air Contaminants and Gas Contaminant Removal Equipment, https://tc0203.ashraetcs.org.

IAQ Position Papers at https://www.ashrae.org/about/position-documents:

- Airborne Infectious Diseases (Updated February 2017);
- Combustion of Solid Fuels and Indoor Air Quality in Primarily Developing Countries (Updated February 2017);
- Environmental Tobacco Smoke(Updated July 2016)
- Filtration and Air Cleaning;
- Indoor Air Quality (Updated July 2014); and
- Limiting Indoor Mold and Dampness in Buildings (Updated January 2016).

ASHRAE TC 2.4, Particulate Air Contaminants and Particulate Contaminant Removal Equipment, https://tc0204.ashraetcs.org.

ASHRAE TC 2.1, Physiology and Human Environment, https://tc0201.ashraetcs.org.

ASHRAE TC 2.6, Sound and Vibration Control, http://ashrae-tc26.org.

ASHRAE TC 2.9, Ultraviolet Air and Surface Treatment, https://tc0209.ashraetcs.org.

ASHRAE SSPC 55, Thermal Environmental Conditions for Human Occupancy, http://sspc55.ashraepcs.org.

ASHRAE SSPC 62.2, Ventilation and Acceptable Indoor Air Quality in Residential Buildings. http://sspc622.ashraepcs.org.

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2. Nilsson, P.E. (Ed). 2003. Achieving the Desired Indoor Climate, Energy Efficiency Aspects of System Design. Studentlitteratur, Lund.

3. Bean, R. 2017. Exposing Architectural Landmines with Online Thermal Comfort Tools. ASHRAE BPA 2017, Seminar 5: Advanced Tools and Strategies for Performance-Based Design Exploration.

4. RCP. 2016. "Every Breath We Take: The Lifelong Impact Of Air Pollution." Royal College of Physicians. Report of a Working Party. London: RCP. ■