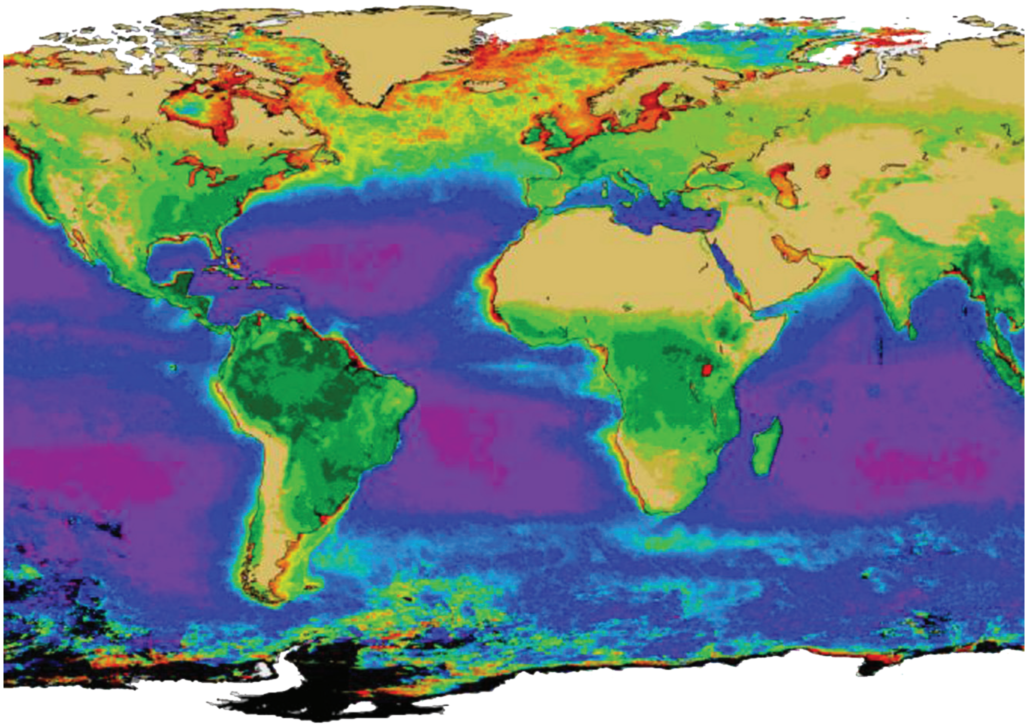
Standards of Human Comfort

Relative and Absolute

Michael Boduch and Warren Fincher



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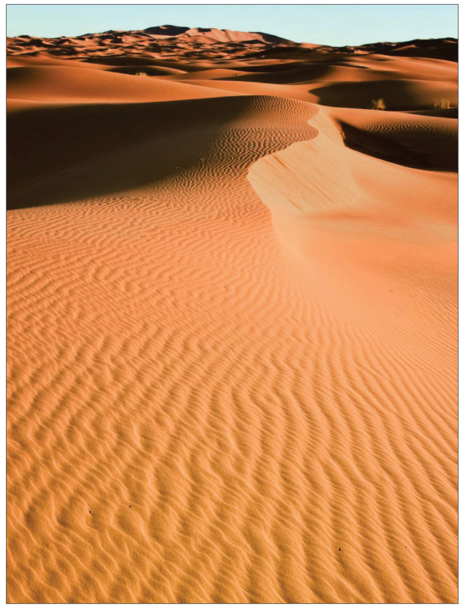


Figures 01 and 02. Humans maintain comfort levels in very diverse climates.

For something so desirable, comfort can unfortunately be a nebulous concept. The room that makes one person put on a sweater can make another wish they were in shorts, and some people focus better in contemplative silence while others need ear-splitting music simply to get motivated. In these differences, however, is the kernel to understanding the nature of comfort: that it is phenomenological.

Our interface to the world is through our senses: touch, sight, hearing, smell, and taste. Each one of these senses can lead to a greater or lesser degree of comfort, and they can act independently or in concert. For instance, our sensation of cold can be so overwhelming that we literally shut down our bodily functions, yet at other times we will tolerate discomfort for a pleasurable experience, such as standing in the rain and mud for a concert. Indeed we are more likely to be in agreement on the absence of comfort.

While discomfort is about approaching extremes, comfort is primarily about determining ranges. Various organizations, such as American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE), the International Organization for Standardization (ISO), and the European Committee for Standardization (CEN) have each written publications that establish these ranges in detail. Yet while these standards provide a set of conventions that can be approached as targets, the experience of comfort remains a product of our senses.

Thermal Comfort

Temperature is the most significant component to the experience of comfort in a space. Our bodies perform within an internal temperature range much narrower than external temperatures. In the process our bodies' metabolism generates heat, which must dissipate into the surrounding air or surfaces.

When external temperatures are high, this process becomes more difficult and we may overheat or feel warm. When external temperatures are low, the rate of heat loss becomes more rapid, and we may feel uncomfortably cold.

Surfaces of a Room. When assessing thermal comfort in a confined space, we must examine both the general temperature in the room, as well as the uneven distribution of heat in the room. Typically when people refer to temperature, they mean the temperature of the air; however, our experience of thermal comfort depends on more than simply air temperature. The mean radiant temperature entails averaging the temperatures of each surface in the room. Combined with the air temperature this produces an overall measure, the mean operative temperature. However, even this measure has its limitations, as how close a person wil be to a particular surface is usually variable, and in these cases different surfaces will dominate at different times.

Differences in temperature within a room or across a body can create a sense of discomfort (see Figure 03). When temperatures from different surfaces diverge, we sense a surface as radiating heat or "giving off" cold. When the ceiling is the contrasting surface, we note discomfort when the ceiling is greater than 9˚ F (5˚ C) warmer or 25˚ F (14˚ C) colder than the other surface temperatures in the room. We allow a greater divergence of wall temperature from alternate surfaces temperature before we sense discomfort, 41˚ F (23˚ C) for warmer walls and 18˚ F (10˚ C) for cooler walls.[1] As well, a vertical air difference from our feet to our head shouldn't exceed 5.5˚ F (3˚ C),[2] otherwise the high temperature gradient highlights one part of the body as feeling notably warmer or colder than the other.

Relative Humidity. While temperature is the most important factors in generating a phenomenological sense of thermal comfort, many other climatic factors contribute. Relative humidity plays a large part in conjunction with temperature to provide a sense of discomfort. High levels of relative humidity can work against the evaporative cooling effects of sweating and leave the body prone to over-heating. Further, high levels of relative humidity in inclement winter weather produce a greater sense of cold.[6]

Relevant Publications

ASHRAE Standard 55 [3]
ISO 7730 [4]
EN 15251 [5]

Human beings are sensitive to slight temperature changes, yet cannot perceive differences in relative humidity levels within the range of 25% and 60%, which is the primary reason that this range is often cited as the baseline.[7] If relative humidity falls outside this range, there are notable effects. When relative humidity gets too high, discomfort develops, either due to the feeling of the moisture itself,[8] which is unable to evaporate from the skin, or due to increased friction between skin and clothing with skin moisture.[9] When relative humidity gets too low, skin and mucous surfaces become drier, leading to complaints about dry nose, throat, eyes, and skin.[10] In particular, discomfort in working environments, which are prone to significant eyestrain, such as an office with a computer, is exacerbated (see Figure 04).[11]

Velocity of Air. Air velocity plays a role in the perception of thermal comfort. In hot weather, as the body tries to cool itself, the flow of air across the body will assist

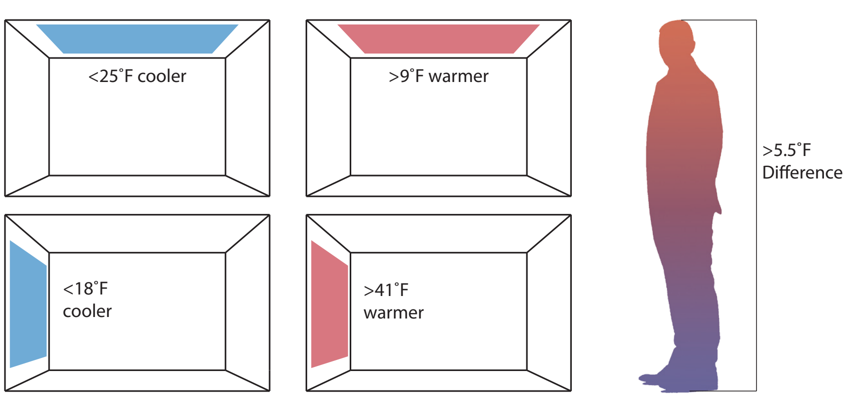


Figure 03. Allowable temerpature variances

evaporative cooling from sweating. When air has a high relative humidity, the air next to the sweating body may become saturated with moisture, but by moving the air next to the body away and bringing in fresh, lower-humidity air, the evaporation of sweat can continue. Mechanisms of convection can further move the heat generated by metabolic processes from the skin and into the surrounding air. All this leads to continued cooling, and the higher the velocity of air, the more effective is the process.

As helpful as airflow can be in warm and humid conditions, it can be problematic in others. In cool settings, the same processes of evaporative cooling and convection, which play a key part in cooling the warm body, may cool the inhabitants beyond their levels of comfort. Aside from the cooling effect of airflow, the air speed itself can cause discomfort (see Figure 05). Generally, airflow slower than 100 feet per minute feels either pleasant or goes unnoticed. Higher than that, and the flow of air can within an enclosed space can provoke distraction (up to 200 fpm) and annoyance (above 200 fpm).[12]

The Role of Color. As a further complication, temperature is not completely determined by our sense of touch. The presence of particular colors found in a space can influence our perceptions of temperature as well as climatic qualities. Experiments reveal that rooms painted in hues between blue or green can feel colder than rooms with red or orange walls by as much as 7ºF (3ºC).[13]

Metabolism. The biggest source of difference in perception, however,

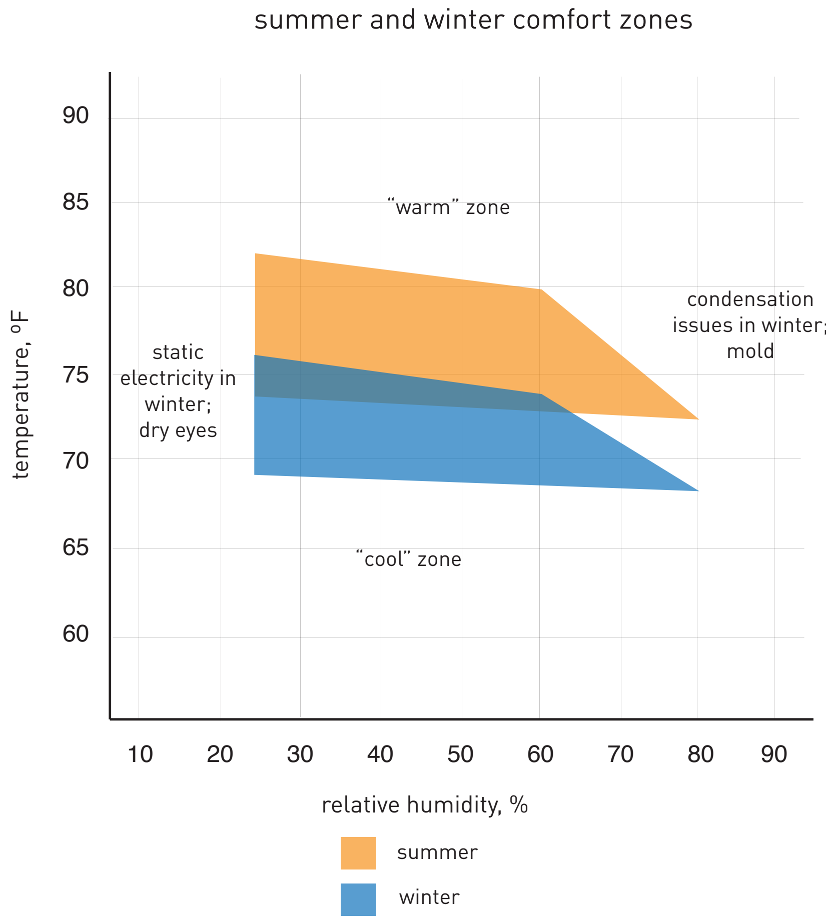


Figure 04. Comfort zones for summer and winter.

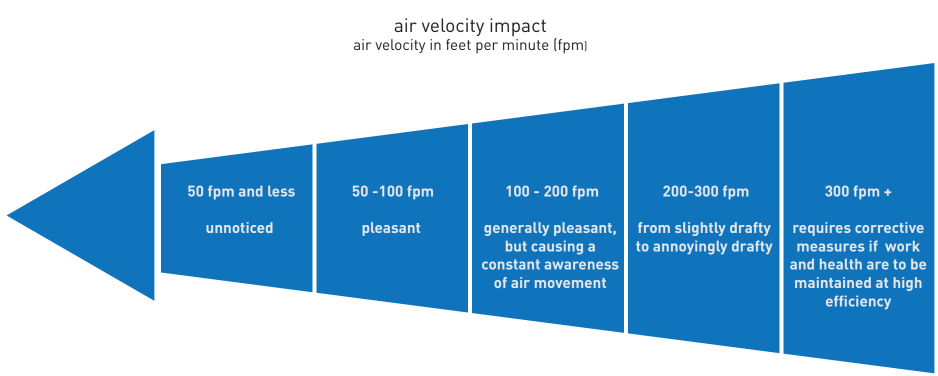


Figure 05. Air Velocity Impacts.

may be our individuality. Our bodies generally do a terrific job at regulating temperatures, but each body has a different metabolism that can change over the course of years or in the space of a day. Our metabolisms differ based on long-term factors such as genetics and sex, medium-term factors such as seasonality, and short-term factors such as exercise or diet. And metabolism even changes based on external temperature, further making complex attempts to definitively anticipate an experience of thermal comfort by the designer, leaving the inhabitant of the architectural space to engage in a variety of individualistic solutions for regulating the body.

Visual Comfort

Visible light is that portion of the electomagnetic spetrum that permits humans to see. It is just a small band of the total spectrum, as indicated in Figure 06. Light has particle properties and wave properties, and when considered as a wave, it has a frequency that is tied to color.

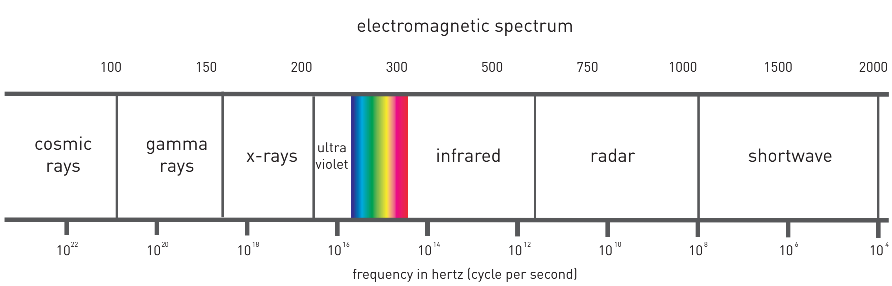
When light strikes a surface, its energy is either transmitted, abosorbed, or reflected. The color of a surface represents the frequency of the spectrum reflected back to the observer. A surface that is white has most of the spectrum reflected back equally, whereas one that is black has had most of the energy absorbed.

The main focus on visual comfort has traditionally been light levels, contrast, and glare, and upon these there is agreement on many principles. The first is the more intense the task, the brighter the light required. This is the main reason operating rooms are much brighter than offices, which are in turn much brighter than living rooms (see Figure 07). The second pertains to contrast: the greater the contrast, the easier the comprehension. This is why almost every publication uses black text on white paper. The final point is that glare is undesirable, as it makes it difficult to see the object of attention.

Parameters of Light Intensity. Each of these issues has been solved to some degree. For instance, tables exist that indicate desired light levels for different types of use, contrast ratios of 1:3 to 1:10 foster concentration but still allow perception of surrounding items, and glare can be reduced with light from multiple sources. What is interesting, however, is how these items are only part of the story of visual comfort, and how sometimes it may be desirable for each of these answers to be subverted.

Role of Other Senses in Interpreting Visual Cues. One problem is that though we receive light solely with our eyes, our perception is often conflated with a reaction occurring concurrently to our other senses. For instance, the light that falls from the sun is simultaneously perceived with the warmth on our skin, which most find a pleasurable experience. Likewise, the light that falls from a fluorescent tube may be associated with the background hum of the electrical ballast that produces it, which most find undesirable. There have been no studies that prove that office light leads to less productivity, yet indeed almost uniformly we believe this to be so.

Color. There are also other effects beyond light levels, contrast, and glare. Color pertains to a particular frequency of light, and color can have an effect on one's comfort. Though it is has not been established whether the influence is from the color itself or derived from cultural and historical associations, people react differently to various segments of the spectrum. For instance, gambling has been shown to increase under red light.[14] Another consideration is whether the light is steady or flickering, as flickering light tends to create eyestrain.[15] When watching a television or a computer screen, the refresh rate, or how often the image changes, can have a dramatic effect



Firgure 06. Visible Light and the Elecomagenetic Spectrum

lux required for appropriate illuminance

50	100	150	200	300	500	750	1000	1500	2000
rarely used interiors for movement and little detail	occasional interiors for movement and casual seeing	occasional interiors with n detail but some risk to others	occuied interiors for visual tasks with some detail	visual tasks moderately easy with high contrast or large size	visual tasks moderately difficult or color judgment required	visual tasks difficult (small, low contrast)	visual tasks very difficult (small, low contrast)	visual tasks extremely difficult ,optical aids and local lighting may help	visual tasks exceptionally difficult ,optical aids and local lighting will help
tunnels, walkways	corridors, changing rooms, auditoria	loading bays, medical stores, plant rooms	foyers and entrances, turbine halls, dining rooms	libraries, sports and assembly halls, teaching spaces	general offices, engine assembly, kitchens, labs	drawing offices, ceramic decoration, meat inspection, chain stores	general inspection, electronic assembly, gauge and tool rooms, supermarkets	fine work and inspection, hand tailoring, precision assembly	assembly of minute mechanisms, finished fabric inspection

Figure 07. Illuminance levels for room use

on comfort.[16] Yet the very fact that the light of a candle flickers is also what creates its sensual mood.

Which is a reminder that visual effects are perhaps the most phenomenological of all the comfort categories. When entering St Petri in Klippan, Sweden, a 1960's church by Sigurd Lewerentz, the first impression is one of complete darkness. The hollowness of the place, followed by the slow dripping of the baptismal font, is what draws you into the main space before your eyes adjust. Each of the laws is broken — blindness on entry, nonexistent contrast issues, glare from the church windows as you turn the corner. Yet, as demonstrated here, the strategic use of normally undesirable lighting can phenomenological enhance the occupation of space.

Auditory Comfort

Sound is created by waves of compressed air that we perceive with our ear. There are many objective properties that contribute to how we measure sound based on its wave nature. For instance, the density of air impacts how fast a sound moves across a space. The distance between waves, both in terms of a linear distance as well as time, gives a sound its pitch. Sound also embodies energy, with the magnitude of air compression leading to an experience of volume.

Parameters of Human Hearing. The perception of sound by the human ear stands between thresholds of both frequency and magnitude. The range of pitches humans can hear lies between 20 and 20000 Hz.[17] As the body ages, however, the range of frequencies our ears can sense begins to diminish, and the ear requires more energy (measured as higher decibels) in order to hear each pitch. Thresholds of sound pressure also exist for the human ear. Measured in decibels, we can generally hear sounds as quiet as 0 db, and 130 db generally stands at the commencement of pain, though this can depend on the pitch.[18] The combination gives us the phenomenological experience of loudness.

Loudness. Volume does not correlate strictly with the magnitude of sound pressure. At any given pitch or sound frequency, we will experience higher levels of sound pressure as louder tones, which seems intuitive. However, if the sound pressure remains constant but the frequency changes, the human ear will experience the sound as increasing or decreasing in volume non-linearly and can be measured in Phons.[19] (see figure 08). Notably, the human ear is most sensitive in the range of frequencies used in the human voice. Thus, for aural comfort, there is little need to boost the energy found in sound frequencies in the range of the human voice – indeed, there may be a need to suppress sources of sound in this range so that the obfuscating or “masking” of the human voice within a cacophony of similarly-pitched sounds does not occur. This may be one reason why it is possible to tolerate high levels of sound coming from trains or cars as background noise, but still be distracted by the sound of a boisterous crowd at a nearby bar.

Noise. Along with having trouble delineating the human voice from background sound, which is the most common definition of “noise,” the listener responds with annoyance from a number of other auditory qualities.[20] Sounds with higher frequencies and a higher sense of loudness are more prone to elicit annoyance. People prefer continuous noise and broadband sounds over intermittent noise and pure tones. People generally regard sounds perceived as non-stationary or as locationally ambiguous as more disconcerting than sounds with a locatable source. And sound that is extraneous but still perceived as information-bearing causes more annoyance than the same quality of sound perceived as unintelligible.

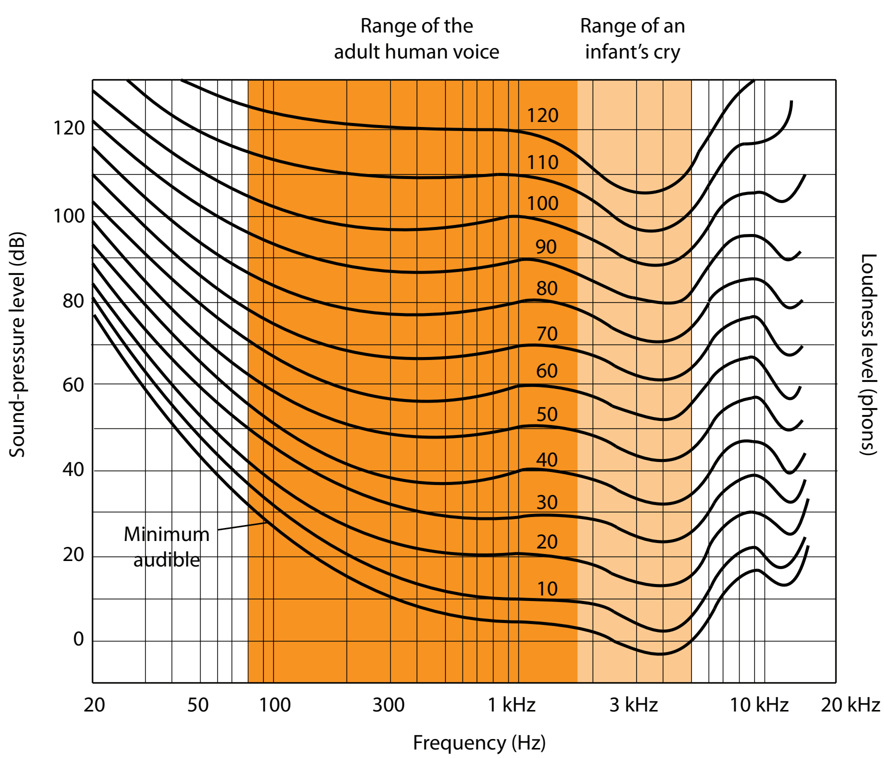


Figure 08. Phons and the effect on the human ear

Olfactory Comfort

Olfactory experiences of space are not usually recognized within discussions of human comfort, but nonetheless the presence of smell can deeply affect our experiences in one location or another. The smell of flowers and grasses, dust, exhaust, baked goods, bleach, each suggests a particular setting and perhaps even specific memories of places and events.

Indication of Hazards. Certain smells, such as that of smoke and exhaust, indicate the presence of harmful substances, and proper air change in a space can evacuate both the pathogen and the unfavorable smell. Many smells may promote headaches and may play an important role in triggering migraine headaches.[21] Along with headache-inducing smells, many restaurants have banned perfumes for allergy reasons.

Promoting Behaviors and Emotions. At first it may appear that the absence of all odors may seem ideal. Yet other businesses, such as Starbucks, are so concerned with smell that they will retool their machines and processes to ensure that the scent identified with their product is not lost.[22] Research has also shown that linkages do not even need to be direct — consumers will buy more cards, for instance, if it is nearer a candle.[23] Scents can also direct emotional responses. In order to calm patients undergoing an scan with an MRI device, the rooms housing the machines are often lightly scented with vanilla. Thus strategic use of scents within a space can promote desired behaviors and emotional states, promoting a phenomenological sense of comfort, even if not consciously recognized as such.

Hygienic Comfort

Sometimes our senses fail to alert us to discomfort, and this will happen with issues of air quality. A myriad of negative impacts -- ranging from coughs or headaches to severe illness -- will happen with little or no advance warning from our senses. A report by the National Institute of Occupational Safety and Health (NIOSH) states that 20% of complaints received are concerned with air quality, and of those 50% were due to inadequate ventilation.

The air we inhale can simply be nauseous, such as stale, moldy air. Unfortunately, it is often worse. Formaldehyde, a toxic and carcinogenic chemical, has been one of the most troublesome compounds. It is a volatile organic compound (VOC), which means it vaporizes at room temperature. As such, formaldehyde poses a health threat as it off-gases. Asbestos is another hazardous building material that, when aerosolized, has been proven to promote mesothelioma and lung cancer. Though the detrimental forms of asbestos are no longer in use, it was commonly used in the first half of the twentieth century as an insulating material, and asbestos continues to be found in the extant building stock.

Sick Building Syndrome (SBS) is the term used for conditions that occur when occupants spend too much time in a building that is loaded with contaminants, such as gases and vapors, odors, aerosols, viruses, bacteria, spores and fungi. The situation is exacerbated when air refresh rates are low either due to tight confines or lack of circulation.

Preventatives and remedies to poor air quality include filtering air, maintaining sufficient air replacement and ventilation rates, and appropriate sealing of any openings to unfiltered air or gases, including subterranean spaces. As well, poor maintenance of air quality equipment can limit their efficacy.

But somestimes this is difficult, as in an airplane. Traditionally fresh air was taken near the engines, but as jet engine technology has matured, air intakes have become compromised and the quality of the external air pulled into the aircraft has deteriorated. HEPA filters help, but air quality is still traditionally low. Recently new filtration systems have been developed using “cold plasma” technology, which creates a high voltage to strip electrons from some of the molecules in a gas, which in turn ionize the suspended particulates in the air into charged particles which are consequently trapped in the filter.[24] Reports suggest that this new system can kill 99.999% of pathogens in a single pass, and even on a short flight of about one hour, the cabin air will pass through the filters approximately 30 times. Conceivably these technologies could be used in buildings as well.

Different countries have developed various scales for expressing outdoor air quality. In all cases, a correlation is made between the concentration of particulates in the air and the probable impact on an individual’s health status. While the air quality index (AQI) used by the U.S. Environmental Protection Agency only gives general descriptions about air quality ranging from “good” to “hazardous,” the AQIs of Canada and most developed Asian countries link a particulate density with expected health problems. The limitations of these AQI arise from the small set of pollutants measured, usually carbon monoxide, ground-level ozone, sulfur dioxide and gross dust particulates.

indoor contaminants	allowable air concentration levels
carbon monoxide (CO)	< 9 ppm
carbon dioxide (CO2)	< 800 ppm
airborne mold and mildew	simultaneous indoor/outdoor readings
formaldehyde	< 20 $\mu g/m^3$ above outside air
total VOC	< 200 $\mu g/m^3$ above outside air
4 phenyl cyclohexene	< 3 $\mu g/m^3$
total particulates	< 20 $\mu g/m^3$
regulated pollutants	< national ambient-air quality standards
other pollutants	< 5% of TLV-TWA

Figure 09. Acceptable concentration levels

Indoor air quality is measured against two primary factors: a sense of comfort from the air and no ill-effects to inhabitants' health, inclusive of both the phenomenological as well as the physical.[25] When speaking of indoor air particulates, we may include odors, irritants, toxic particulate substances, biological contaminants and radon/soil gases. Odors may or may not be problems for the inhabitants of a space, but the other four categories are by definition hazardous to human health if present in high enough concentrations for certain durations. Irritants may result from building materials, office equipment and service equipment. Toxic particulate substances includes such items as asbestos, and biological contaminants are comprised of viruses, bacteria, fungi, and algae. Some gases, such as radon and methane, enter a building through contact with the soil. Radon departs from most of the soil-released gasses in that radon produces radiation due to its tendency toward rapid decay.

Figures

Cover Photo: http://www.play-montreal.com/?p=170 (accessed 10 December 2009)

Figure 01: iNfinity Trading, www.tradinginfinity.com/images/sahara_main.jpg (accessed 19 October 2009).

Figure 02: Flickr, www.flickr.com/photos/peterkelly1/326403399 (accessed 19 October 2009).

Figure 03: Fincher, Warren and Micheal Boduch, developed from American Standards of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) *Standard 55-2004* (Atlanta: ASHRAE, 2004), 7-8.

Figure 04: Boduch, Michael and Warren Fincher, developed from American Standards of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) *Standard 55-2004* (Atlanta: ASHRAE, 2004).

Figure 05: Boduch, Michael and Warren Fincher, adapted from Vitory Olgyagy, *Design with Climate: Bioclimatic Approach to Architectural Regionalism* (Princeton University Press, 1963).

Figure 06: Boduch, Michael and Warren Fincher, adapted from Benjamin Stein, et. al., *Mechanical and Electrical Equipment for Buildings* ,10e (Hoboken, New Jersey: John Wiley and Sons, 2006), 460.

Figure 07: Boduch, Michael and Warren Fincher, adapted from CIBSE, 1994, *Code for Interior Lighting* (London: Charted Institution of Building Service Engineers, 1994.)

Figure 08: Boduch, Michael and Warren Fincher, adapted from Benjamin Stein, et. al., *Mechanical and Electrical Equipment for Buildings* ,10e (Hoboken, New Jersey: John Wiley and Sons, 2006), 736.

Figure 09: Boduch, Michael and Warren Fincher, adapted from Sandra Mendler, *The Greening Curve: Lessons Learned in the Design of the New EPA Campus* (Research Triangle Park, North Carolina: U.S. Environmental Protection Agency, 2001.)

Notes

Note 01. American Standards of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) *Standard 55-2004* (Atlanta: ASHRAE, 2004), 7.

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Note 05. EN Standards, *Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics* (Pilsen, Czech Republic: EN Standards, 2007).

Note 06. J. Roset, et. al., "Learning About Humidity in Thermal Comfort," Universitat Politecnica de Cataluyna, http://www-fa.upc.es/personals/jroset/esun-058.html.

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Note 12. Vitory Olgyay, *Design with Climate: Bioclimatic Approach to Architectural Regionalism* (Princeton University Press, 1963.)

Note 13. Johannes Itten, *Elements of Color* (John Wiley and Sons, Hoboken), passim.

Note 14. "The Role of Light and Music in Gambling Behavior: an Empirical Pilot Study." *International Journal of Mental Health and Addiction* (Springer, New York: 2009).

Note 15. New Buildings Institute, *Advanced Lighting Guidelines*, 2003 Edition (New Buildings Institute, White Salmon, Washington), 2-15.

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Note 21. E.L. Spierings, A.H. Ranke, P.C. Honkoop, "PPrecipitating and Aggravating Factors of Migraine Versus Tension-Type Headache," *Headache* 41 (2001): 558.

Note 22. Julie Jargon, "At Starbucks, It's Back to the Grind," *Wall Street Journal* (17 June 2009).

Note 23. Deborah J. Mitchell, Barbara E. Kahn and Susan C. Knasko, "There's Something in the Air: Effects of Congruent or Incongruent Ambient Odor on Consumer Decision-Making," *Journal of Consumer Research* 22(2): 229-238.

Note 24. "Breathing More Easily," *The Economist* (17 September 2009).

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