Current State of the Science: Health Effect and Indoor Environmental Quality
Clifford S. Mitchell, Junfeng (Jim) Zhang, Torben Sigsgaard, Matti Jantunen, Paul J. Lioy, Robert Samson and Meryl H. Karol

Presented by Snezana Djordjevic
EOH 2504 Principles of Environmental Exposure
In this article, indoor pollutants have been reviewed along with their relating issues such as source characterization, exposure assessment, health effects associated with indoor exposure and intervention research relating to indoor environments.

In the past problem of indoor environment quality (IEQ) focused on indoor constituents (primarily particles, bioaerosols, and chemicals) and comfort factors temperature, air flow and humidity, but recently it has begun as a complex between building occupants and an array of physical, chemical, biological and design factors.

Advances in source characterization enable a better understanding of how chemicals are transported and processed within the spaces and the role that other factors such as lighting and building design may play in determining health. Ability to measure exposure remains the challenge particularly for the biological agents. Researches are also examining the effect of multiple exposure as well as the effects of exposures on vulnerable populations such as children and the elderly.
Source characterization

Outdoor air pollutions is a dynamic system in which the physical and chemical process affecting the accumulation of pollutants in the atmosphere are constantly changing, largely driven by complex meteorology and photochemistry.

The usual approach of modeling indoor air pollution treats the indoor environment as a static box in which physical and chemical transportation of indoor air pollutants are absent or negligible. On this way estimates are made for primary indoor air pollutant concentration but secondary pollutants are ignored.

In-depth studies of indoor air have shown that the concentration of agents in indoor air is a function of outdoor concentration, indoor source strength, removal and deposition rate within the structure, indoor mixing and chemical reaction
**Indoor production:**
Primary sources of indoor pollutants include fuel combustion for cooking, heating and lightening; tobacco smoking; bioeffluents from humans and animals; floor and wall coverings; synthetic paints, glues, polishes, and waxes; pesticides; and building products. Also release of gases from solvent used indoors or from water that is used daily, by products (e.g. chloroform). Concentration of many volatile organic compounds (VOCs) are higher indoors than outdoors because of the use of many types of synthetic materials.

Secondary sources refer to indoor chemistry that transform a set of indoor pollutants, emitted from primary sources or transported from outdoors, to a new set of indoor pollutants.

**Outdoor-to-indoor transport**
Pollutants of outdoor origin can be transported indoors via building openings and cracks. Attempts have been made to estimate the fraction of measured indoor concentration contributed by outdoor air due to the outdoor to indoor transport process.

One study, the Exposure of Adult Urban Populations in Europe Study (EXPOLIS) compared concentration of ambient particulate matter smaller than 2.5 micrometers PM2.5, its 16 elemental constituents and black carbon, 30 VOCs, and carbon monoxide among urban adult population in seven European cities. The proportion of outdoor PM found indoor for PM2.5 averaged 0.64 for residential structure, 0.47 for workplaces, and 0.35 for subsample of office buildings constructed after 1990. Although attempts have been made to differentiate PM of outdoor origin from PM of indoor origin, analyses have been complicated because the fraction of indoor species contributed by outdoor air depends not only on outdoor concentration but also on home-specific parameters including air exchange rate (AER) typically expressed as air exchange per hour, indoor generation rate, removal rate and house volume. Models of indoor PM exposure have been developed to account for both indoor and outdoor sources, as well as mixing, transport, and removal (Georgopoulos et al. 2005; Nazaroff 2004)

One of the chemical which outdoor-to-indoor transport considered unimportant is ozone (O3). O3 like PM is regulated in the United States as a criteria pollutant. Weschler at al. (1989) showed that indoor exposure to ozone can easily surpass outdoor exposure. Under high AERs indoor O levels can be 50-70% of outdoor levels. Indoor O3 concentration of 20ppb may not be sufficient to cause health concern but this ozone level can drive a complex set of indoor chemical reactions.
**Indoor-to-outdoor transport**

Since the late 1970s, the air tight design of buildings, driven mainly by energy conservation, has resulted in reduced AERs. Ventilation is necessary to reduce concentration of pollutants generated indoors, but is also necessary to reduce the time available for chemical reactions among indoor pollutants. Based on approximately 4,590 measurements of residential AERs conducted across the US, Pandian et al. (1998) reported that its magnitude are undesirable for removing air pollutants that originate indoors and are low enough for certain reactions to occur. (Mean, median and SDs of AERs were 0.55, 0.42, and 0.47 air exchange per hour, for the northeastern region and 0.71, 0.62, and 0.56 ach for the southeastern region.

**Indoor chemistry**

Pollutants can be removed from indoor air through both physical and chemical processes. Physical processes include phase change, adsorption or absorption, or dissolving in water or organic films. Indoor chemistry are reactions involving indoor pollutants, occurring either in the gas phase or on the surfaces. These chemical reaction processes represent sinks for the primary indoor pollutants and sources of secondary indoor pollutants.

The most extensively studied gas-phase reactions are oxidation reactions involving O3 and free radicals. O3 can react with nitric oxide, nitrogen dioxide, and unsaturated organic compounds (terpenes, terpenoids, unsaturated fatty acid) to yield reactive intermediates, the hydroxyl radical (OH), the nitrate radical (NO3) and oxygenated organic compounds. Reactions of ozone with NO2 form the NO3 radical that further reacts with VOCs, leading to the formation of indoor nitric acid. The NO3 radical can also react with NO2 to form dinitrogen pentaoxide N2O5 that undergo hydrolysis, another pathway of nitric acid formation (Weschler et al. 1992). Unstable products of the ozone-terpene reactions include reactive intermediates and the hydroxyl radical.
PM indoor formation relating with O3 reactions is difficult to characterize. It is because 25% of indoor PM2.5 could not be explain with known sources (Wallace 1996) and indoor particles can vary with the variation of outdoor summertime fine particles.

A second type of indoor chemistry involves surface reactions. Indoor surface maybe ideal for substance sorption and water condensation. Surface water film can react with indoor NO2, a mayor product of natural gas combustion, to form nitrous acid (HONO) and nitric acid (HNO3). Ozone reacts with unsaturated VOCs contained in surface coatings at a faster rate than when it reacts with the same compounds in the gas phase (Reiss et al. 1995). Indoor surfaces including building materials, wall cavities, ducts, skin, clothing, dust and airborne particle are very diverse and are very determining factor of indoor surface chemistry. Building material contain a large number of reactive constituents that can be released into the indoor air along with secondary products, including terpenoids, aliphatic aldehydes, phthalates, phenol, mono- and dicarboxylic acids and various photoinitiators. Photoiniciators can undergo decomposition to generate free radicals and some precursors of odorous products (Salthammer et al. 2004)

Indoor oxidation chemistry has increased over the past several decades because ozone levels, the use of unsaturated VOCs have been on the rise and AERs have been decreasing.
Exposure Assessment

Studies suggest that indoor environmental measurements provide a better estimate of personal exposure than outdoor monitoring of VOCs, but neither indoor nor outdoor environmental sampling is a good predictor of personal exposure (assessed by personal sampling and blood VOC concentration) (Sexton et al. 2005). Exposure assessment for biological agents is more challenging than for the particulate and chemical exposure. New and more accurate identification methods to indentify molds are under development. Even if fungal and mold species can be identified more accurately in the environment, there are jet no reliable markers of human exposure or dose for these and other biological agents: some effort are under way to assess exposure using chemical markers or immunologic markers (Schmechel 2006; Sebastian et al. 2005)

Health Effects

Mediating responses to a wide variety of environmental stressors

- **Particulate matter (PM)** has long been linked to both acute and chronic health effect, including asthma, cardiac disease and to potentiate the effect of common allergens, promoting IgE production. Recent investigations have focused on possible effects on heart rate variability (Magari et al. 2002; Pope et al. 1999). PM, especially products of combustion, has also been linked to the development of cancer although the exact relationship is still under investigation (Vineis and Husgafvel-Pursiainen 2005). The contribution of indoor PM to hospital admission and mortality have yet to be fully explored. (Bell et al. 2004; Morris 2001).

- **Chemicals** in the built environment include semi-VOC and VOC, pesticides and some chemicals produced during combustion. There is interest also in the health effect from plastics and plasticizers. These plasticizers may be related to allergic diseases in children (Bornehag et al. 2004b, 2005; Oie et al. 1997). The relationship of VOCs to asthma, particularly in children, remains controversial. Study in Australia found that the ratios for asthma increased with increasing concentration of VOCs (benzene, toluene, ethylbenzene and xylene) but study in the United Kingdom did not. (Venn et al. 2003)
**Biological agents** – Allergy to indoor agents can cause frequent and severe health problems, especially in children. Animal allergens are found commonly indoors, even where animals are not present. The levels of cat and dog allergens in school floor dust were associated with the number of pupils with animals at home. There is a large literature on the health effects of biological agents found in damp indoor environments (Bornehag et al. 2001). Molds were associated with a number of conditions including hypersensitivity pneumonitis in susceptible persons, but evidence is still insufficient to conclude that such an association exists. Long-term experimental exposure studies on a larger number of subjects would be needed to rule out an effect of mold exposure (Meyer et al. 2005). Molds can produce toxic metabolites known as mycotoxins and there are about 400 of them, mostly produced by species occurring on food. Many of the molds found indoors are similar to those on food. *Stachybotrys chartarum* is a species that produces toxic compounds when grown on building or in the house material. Research on the chemistry of *Strachybotrys* toxin is progressing to identify the chemical properties of species occurring in indoor environments. Species of *Chaetomium* and *Aspergillus vesicolor* are also potential producers. The clinical effect of mycotoxins have been alleged to include respiratory, neurologic, immunologic, dermatologic, gastrointestinal, and irritant effects, among others (Kuhn and Ghannoum 2003; Laumbach and Kipen 2005). There remains a lack of consensus regarding the systemic effect of mold exposure. One of the limiting factors in this research is reliable, validated markers of exposure to either molds or the mycotoxins. Other biological hazards associated with indoor environments include bacteria, viruses, and other organisms.

**Interactions and multiple exposure** - Health effects are often related to multiple exposure and many experimental interventions affect more than one exposure and agent. Exposure to O₃ and NO₂ have been shown to increase airway epithelial cell cytokine production (Spannhake et al. 2002). These findings and others suggest the possibility of additional benefits to interventions that reduce cumulative exposures to several pollutants compared with interventions focusing on only one exposure.
Building Design and Health

Physical and design characteristics of built structure (lighting, heating, noise, design) may create additional exposure that might contribute to health. Evidence indicate as that suppression of melatonin by nocturnal artificial lighting may play a role in breast and colon cancer development (Pauley 2004; Stevens 2005). There is a growing literature on school design and injury prevention.

Conclusion

Exposures in the indoor environment are the result of complex interactions between the structure, building systems, furnishings, the outdoor environment, and building occupants and their activities.

More research is needed on the interactions of multiple exposure and the risk to certain populations.

Research is also needed on better measures of dose, particularly for biological agents.
Limitations

- 25% of indoor PM2.5 cannot be explained with the known sources - contribution from outdoor PM has to be explored
- PM and development of cancer is still under investigation
- PM have been shown to increase cardiovascular mortality but the specific mechanism by which this occur has yet to be clarified
- The relationship of VOCs to asthma, particularly in children, remains controversial - different studies have shown different associations
- There is not enough evidence regarding the systemic effect and mold exposure - limiting factors of reliable validated markers of exposure to either molds or mycotoxins
- Indoor and outdoor exposures are often regulated differently