INDOOR AIR QUALITY MONITORING AND CONTROL

A. Buekens and **K. Schroyens**
Department of Chemical Engineering – CHIS 2, Vrije Universiteit Brussel, Belgium

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Summary

Since the 1960s and 1970s health care has been a matter increasing concern with people having sick building syndrome (SBS) characterized by headaches or other complaints of unspecified origins. These include among other things fatigue, headache, lethargy, dizziness, nausea, irritation of mucous membranes, eyes or respiratory system, allergic reactions and sensitivity to odors. SBS thus addresses a situation in which occupants of a building experience acute health effects that seem to be linked to time spent in a building, but no specific illness or cause can be identified. The complaints may be localized in a particular room or zone, or may be widespread throughout the building.

While specific causes of SBS remain unknown, the following causes have been cited frequently as contributing factors to the complaints typical for sick building syndromes. These elements may act in combination or may supplement other complaints such as inadequate temperature, humidity, or lighting:

- Inadequate venting of the habitat or space;
- Dust accumulations at the entrance or in the filters of the ventilation system, serving as a breeding ground of microorganisms or as a source of other agents;
- Allergens and irritants;
- Tobacco smoke;
- Solvents, or other exhalations from coatings, glues, carpets, etc. (Volatile Organic Compounds - VOCs);
- Mineral fibers (see *Control of Particulate Matter in Gaseous Emissions*);
- Radon;
- Electromagnetic fields.

SBS is often more prevalent among asthmatics, since they are already sensitized to common indoor allergens. In 1982 the World Health Organisation formally recognized the SBS condition.

1. Indoor Air Quality

Indoor Air Quality (IAQ) generally refers to the quality of the air in e.g. an office, hospital, or domestic environment. Alternative terms include Indoor Environmental Quality (IEQ) and "Sick Building Syndrome." Complaints about IAQ range from air smelling odd to more complex, almost intangible perceptions, where air quality insidiously causes illness and lost work time. IAQ complaints possibly derive from a large number and variety of possible sources, causes, and varying levels of individual sensitivity. IAQ concerns have increased since energy conservation measures were introduced in homes and office buildings during the 1970s, minimizing the infiltration of outside air and thus contributing to the buildup of indoor air contaminants.

Ventilation system deficiencies, overcrowding, tobacco smoke, microbiological contamination, outside air pollutants, and emanations from materials and equipment in the office can all cause problems. Related problems include comfort problems due to improper temperature and relative humidity conditions, poor lighting, and unacceptable noise levels, as well as adverse ergonomic conditions, and job-related psychosocial stressors. Typical symptoms may include headaches, unusual fatigue, itching or burning eyes, skin irritation, nasal congestion, dry or irritated throats, and nausea.

The American Industrial Hygiene Association provides brochures and fact sheets for consumers and professionals on IAQ in the homes, in workplaces, on carbon monoxide, molds, lead, and how to hire an IAQ consultant.

Environmental health comprises those aspects of human health, including quality of life, that are determined by physical, chemical, biological, social, and psychosocial factors in the environment. It also refers to the theory and practice of assessing, correcting, controlling, and preventing those factors in the environment that can potentially affect adversely the health of present and future generations.

2. Origins

More and more people spend most of their time indoors, often ninety percent or more. Some surroundings, activities and exhalations may pose specific problems, e.g.:

- at home: cooking, biomass heating, smoking, household chemicals, exhalations from furniture, carpets, upholstery;
- at the office: ozone from copiers, from heating, ventilation, and air conditioning (HVAC) systems;
- in hospitals: pathogens.

Over the years, construction industry has increasingly focused on energy efficiency and comfort, providing central heating and cooling systems. Both home and office construction has minimized heating or cooling losses by making buildings more airtight. At the same time, more synthetic materials are being used for furniture, clothing, fabrics, cleaners, detergents, and preservatives.

These trends have created buildings where exposure to dust, vapors, and gases through inhalation has gone beyond what historically has been the case. Inadequate ventilation may be at the origin of the problem. New houses are insulated and sealed so well that no fresh air enters any more, without passing through technical systems, involving heating, cooling, filtration. Moisture builds up, creating a perfect breeding ground for molds!

Problems are often a result of operating or maintaining a building in a manner that is inconsistent with its original design or prescribed operating procedures. Sometimes indoor air problems are a result of poor building design or of occupant activities, such as smoking, cooking, or heating.

Also, some types of building materials emit vapors that are harmful or discomforting (exhalations) to many people. Such conditions eventually make a house sick.

Some common factors associated with SBS include air-conditioned offices with large open plan areas and low levels of staff control over ventilation, heating and lighting; poor design and maintenance of building services; poor standards of general repair; and poorly organized office cleaning services job-related factors include routine clerical work and working with display screen equipment. The causes of SBS are unknown but a number of factors are likely to be involved combining in different ways in different situations. These include both physical, environmental factors and job related factors.

Attention now focuses on three common, but distinct generic causes of SBS:

- Combustion Products.
- Biological Factors.
- Volatile Organic Compounds. (see *Condensation, Control of Carbon Monoxide and Volatile Organic Compounds*)

2.1. Major Combustion Pollutants

Malfunctioning or inappropriate use of heating devices (stoves, fireplaces, and ill vented space heaters) may produce pollutants at harmful levels within living surroundings. The most common combustion pollutants in the homes are:

- Carbon monoxide (CO), a dangerous asphyxiant,
- Nitrogen dioxide (NO_2) and sulfur dioxide (SO_2), which are both irritants.

Carbon monoxide is a potential killer. Its properties and detection are treated in *Condensation, Control of Carbon Monoxide and Volatile Organic Compounds*. The problem of tobacco smoke is more complex and will be treated further.

2.2. Biological Air Pollutants

Biological Air Pollutants are to be found everywhere. Some examples are: dander, molds, dust mites, pets and people carrying germs, parasites and other agents. Biological contaminants include pollen, bacteria, viruses, and molds. These contaminants can breed in stagnant water, which can be accumulated in humidifiers, drain pans, and ducts, or can be collected on ceiling tiles, insulation, or carpets. Discolored walls may indicate molds. Biological contaminants can cause fever, chills, cough, chest tightness, muscle aches, and allergic reactions. One indoor air bacterium, Legionella pneumophila, can cause a broad spectrum of diseases, from mild cough and fever (Pontiac fever) to a serious pneumonia (Legionnaire’s Disease). One of the most deadly pathogens is the mold Stachybotrys that produces mycotoxins.

Three types of human diseases can derive from these biological pollutants:

- Infections, in which pathogens invade human tissue;
- Hypersensitivity diseases, which involve specific activity of the immune system; and
- Toxicosis in which biologically produced chemical toxins cause direct toxic effects.

In many cases, SBS may be related to microbial contamination in buildings.

People having multiple chemical sensitivities may be able to smell toxins and also manifest allergic reactions to toxins, viral particles, and fungal mold spores originating from the air ducts (heat and air conditioning) of a sick building. High relative humidity, inadequate exhaust of bathrooms or kitchens, humidifiers, drip pans under cooling coils, air conditioners, flooding, and components of HVAC systems are all potential grounds for breeding of biological air pollutants.

2.3. Volatile Organic Compounds

At room temperature many different VOCs are exhaled from certain solid and liquid materials. A wide array of such potential sources, like formaldehyde, solvents, cleaning agents, paint strippers, pesticides, and benzene exists in the homes and the offices. . Scents, hair sprays, fragrances in personal care products or in cleaning and maintenance products, household products such as finishes, rug and oven cleaners, paints, thinners, dry cleaning fluids, exhalations from some copiers and printers, glues and adhesives, markers, manufactured wood products, carpeting, upholstery and photo solutions are among common commodities that may emit VOCs. Often described as a pleasant, *new* smell, the related VOCs can cause headaches, nausea and irritate eyes, throat and nose. Research shows that some VOCs can cause chronic and acute health effects at high concentrations, and some are known carcinogens. Some individuals show acute reactions when exposed to low or moderate levels of multiple VOCs.

A major irritant is formaldehyde, which is found in resins and glues, in finishes, plywood, paneling, fiberboard and particleboard, and in some of the backings and adhesives for carpets. The urea-formaldehyde foam insulation is no longer used, although buildings, which had the blown foam in the 1970s, may still have VOCs from the insulation. New installations, carpet, wall coverings, paint, or construction can all heighten problems with VOCs.

Methylene chloride is used in some household products, such as paint strippers; perchloroethylene is used in dry cleaning.

Chemical contaminants can also derive from outdoor sources, such as motor vehicle exhausts, plumbing vents, sewers, and building exhausts. Pollutants and smells can enter the building through poorly located air intake vents, windows, and other openings, deriving from nearby garages, bathrooms, and kitchens. Pollutants can be more abundant in winter, when air renewal rates are restricted. VOCs, especially in carpets or inside cupboards, can easily be detected by their odor. Indoor levels of VOCs can accumulate much higher levels than is possible outdoors.

Table 1 presents some typical pollutants in customer items.

Pollutant	Found In
VOCs	Carpet, Paint, Fabric
Mold & Mildew	Air Conditioner, Humidifier, Heat Ducts
Nitrogen Dioxide	Wood-burning Stove & Fireplace Smoke
Formaldehyde	Resin-based Particleboard, Fiberboard, Cabinets, Countertops, Carpet, Fabric
Radon Gas	Seeps Through Cracks in Foundation
Particles	Carpets, Ducts

Table 1: Some examples of Pollutants in Customers Items

2.3.1. Formaldehyde

Formaldehyde is found in insulation material, particleboard, plywood, office furniture, carpet glues, various plastics, synthetic fibers in rugs, upholstery and other textiles, pesticides, paint and paper. It is also emitted from electric stencil-cutting machines and is present in tobacco smoke. Levels of emission increase with temperature.

Formaldehyde is a colorless gas with a pungent odor. At two - three ppm it will irritate the eyes, nose and throat of most people exposed to it, but many are affected at much lower levels. At four - five ppm the irritation is worse and is accompanied by drowsiness, loss of memory, sneezing and skin rashes. At 10-20 ppm there is severe breathing difficulty and burning eyes, nose and throat. Formaldehyde increases the risk of several types of cancer, and has also been shown to cause poor sleep, impaired memory, and lack of concentration, nausea and menstrual irregularities.

The occupational exposure limit in the UK is two ppm, twice as high as the permissible level in the USA of one ppm, which has an action level of 0.5 ppm. In Sweden and Germany the maximum permissible indoor level is 0.1 ppm. People who have become sensitized to formaldehyde have adverse reactions whenever it is present, even in very small amounts. Concentrations as low as 0.01 ppm have been associated with eye irritation.

2.3.2. Arene (Aromatic) hydrocarbons

Common aromatic hydrocarbons are benzene, C_6H_6, toluene $C_6H_5CH_3$ and xylene $C_6H_4(CH_3)_2$. They are basic substances in petrochemical industry and frequently found in industrial products. Benzene is an important petrochemical intermediate and present in automotive and aviation fuel. Toluene is used as a solvent e.g. for paints, rubber and pharmaceuticals. Xylene occurs in three forms, *ortho*-xylene, *meta*-xylene and *para*-xylene and is used as thinner, solvents for inks, rubber, gums and adhesives, paint removers and as a fuel component. ;

Aromatic hydrocarbons are always present in combustion products, including cigarette smoke, given their relatively high thermal stability at elevated temperature.

Benzene is the most toxic of these three aromatic hydrocarbons. The American Conference of Governmental Industrial Hygienist (ACGIH) prescribes a Threshold Limit Value (TLV) of:

- 0.5 ppm for a Time Weighted Average (TWA),
- 2.5 ppm for a short term exposure limit (STEL) and
- a ceiling limit of 8 ppm.

The TLV (Threshold Limit Value) for toluene is 50 ppm and for xylene 100 ppm and the STEL (Short Term Exposure Limit) for toluene or xylene is 150 ppm. The Occupational Safety & Health Administration (OSHA) permissible exposure limits (PEL) are PEL-TWA 1 ppm for benzene, 200 ppm for toluene and 100 ppm for xylene.

Benzene is classified by ACGIH as a confirmed human carcinogen and has been substituted in many products, often with toluene or xylene. If feasible, benzene should be substituted with a less hazardous material. Toluene is classified as an occupational reproductive hazard.

When using benzene or xylene, it is recommended to avoid skin contact by wearing gloves. Industrial ventilation may be necessary to control employee exposure to any one of the discussed aromatic hydrocarbons. Respiratory protection can range from a half mask air-purifying respirator with organic vapor cartridges, to a self-contained breathing apparatus, depending on the air concentration. An industrial hygienist should evaluate the specific operation to determine the appropriate type of respiratory protection.

2.3.3. Pesticides

Pesticides may be used to kill fungi, beetles, fleas, ants, booklice, rodents, and plant and timber pests. The treatment is sometimes carried out during working hours, with little apparent concern for the health of the people working at their desks. They may be added to air-conditioning and ventilation systems to reduce biological contamination. Pesticides can also be used as wood preservatives, but often leach out into the air over a number of years.

The hazards of pesticides depend on their chemical constituents and include cancer, fetal damage, liver and neurological damage, skin problems, and irritation to the eyes and respiratory system.

2.4. Tobacco Smoke

Environmental tobacco smoke (ETS) is a mixture of particles emitted from a burning cigarette, pipe, or cigar, and smoke exhaled by the smoker. Smoke can contain any of more than 4,000 compounds, including carbon monoxide, formaldehyde, and carcinogenic and strongly irritant compounds. Exposure to ETS is often called "passive smoking." A study (1992) of the Environmental Protection Agency (EPA) concluded that lung cancer deaths in nonsmoking adults are attributable to ETS; it also causes eye, nose, and throat irritation, affects the cardiovascular system and causes chest pain. Infants and young children whose parents smoke in their presence are at increased risk of lower respiratory tract infections and are more likely to have symptoms like coughing, wheezing, and excess phlegm. Children with asthma are especially at risk from ETS.

The EPA estimates that exposure to ETS increases the number of asthma episodes and the severity of symptoms in 200,000 to 1 million children annually. Secondhand smoke may also cause thousands of non-asthmatic children to develop the disease each year. A number of organic markers may represent the concentrations of environmental tobacco smoke (ETS) in both field and chamber studies, namely:

- nicotine,
- carbon monoxide (CO),
- 3-ethenylpyridine,
- nitrogen oxides,
- pyridine,
- aldehydes,
- acrolein,
- benzene,
- toluene, and
- several other compounds.

Respirable suspended particulate (RSP) matter, solanesol, N-nitrosamines, cotinine, chromium, and potassium are also used, as markers for particle phase constituents of ETS. The elemental cadmium has been also suggested as a good marker.

But most commonly, RSP, CO and nicotine are utilized as markers of ETS, aldo nicotine and RSP concentrations have potential problems. Nicotine is found primarily in the gas phase (90 %), making it a poor particle marker. Sine it is strongly basic it is removed from indoor environments at a faster rate than particle-phase nicotine, underestimating exposure to the particle phase of ETS. RSP is problematic as a marker of ETS since it could come from other sources. Still, it is widely used as a marker of ETS since the elevated RSP level is significantly higher than that from other sources.

Tests were undertaken using the INDOORTRON facility at the US Joint Research Centre to investigate the impact of various ventilation rates on the air concentration of ETS-components and evaluate human exposure to ETS in indoor environments. Preliminary evidence indicates that changes in ventilation rates during smoking do not have a significant influence on the air concentration levels of e.g. CO, NO_x, aromatic compounds, nicotine, suggesting that higher ventilation rates would not lead to a meaningful improvement of indoor air quality.

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Biographical Sketches

Alfons Buekens was born in Aalst, Belgium; he obtained his M.Sc. (1964) and his Ph.D (1967) at Ghent University (RUG) and received the K.V.I.V.-Award (1965), the Robert De Keyser Award (Belgian Shell

Co., 1968), the Körber Foundation Award (1988) and the Coca Cola Foundation Award (1989). Dr. Buekens was full professor at the Vrije Universiteit Brussel (VUB), since 2002 emeritus. He lectured in Ankara, Cochabamba, Delft, Essen, Sofia, Surabaya, and was in 2002 and 2003 Invited Professor at the Tohoku University of Sendai.

Since 1976 he acted as an Environmental Consultant for the European Union, for UNIDO and WHO and as an Advisor to Forschungszentrum Karlsruhe, T.N.O. and VITO. For 25 years, he advised the major industrial Belgian Bank and conducted more than 600 audits of enterprise.

Main activities are in thermal and catalytic processes, waste management, and flue gas cleaning, with emphasis on heavy metals, dioxins, and other semi-volatiles. He coordinated diverse national and international research projects (Acronyms Cycleplast, Upcycle, and Minidip). Dr. Buekens is author of one book, edited several books and a Technical Encyclopedia and authored more than 90 scientific publications in refereed journals and more than 150 presentations at international congresses. He is a member of Editorial Boards for different journals and book series.

He played a role in the foundation of the Flemish Waste Management Authority O.V.A.M., of a hazardous waste enterprise INDAVER, and the Environmental Protection Agency B.I.M./I.B.G.E. He was principal ministerial advisor in Brussels for matters regarding Environment, Housing, and Classified Enterprise (1989). Since 1970 he has been a Member of the Board of the Belgian Consumer Association and of Conseur, grouping more than a million members in Belgium, Italy, Portugal, and Spain.

He is licensed expert for conducting Environmental Impact Assessments (Air, Water, Soil) and Safety Studies regarding large accidents (Seveso Directive).

Kathleen Schroyens has studied Industrial Engineer in Chemistry (1998) at the KAHO – Ghent.

Since 1999 she is working as scientific collaborator at the Chemical Engineering department of the Vrije Universiteit Brussel. Kathleen Schroyens is collaborating in projects for the European Union (MINIDIP, Haloclean) and The Flemish Government, AMINAL, preparing an inventory of all waste or product streams, derived from thermal processes that are contaminated with dioxins, performing (succinct) risk analysis and devising the measures required in order to monitor and control such streams'. She is also a collaborator in smaller assignments concerning dioxins emissions of MSWI and other industrial plants.