INDOOR AIR QUALITY

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Contents

Summary

The issues of indoor air quality are complex and can be directly influenced by a number of system and building parameters. There are no universal solutions for every problem since there are numerous potential contaminant sources. They may originate from indoors and have a direct impact on indoor environmental quality, or they may originate from outdoors and be transferred by a mechanical or natural ventilation system or even by infiltration, into the building. The most common indoor contaminants are the Volatile Organic Compounds (VOCs), microbiological contaminants, and various gases or chemicals originating from human activity and equipment. Outdoor dust, pollen, and gases can also enter into the building. Poorly implemented energy conservation strategies and sealing of buildings have progressively caused serious indoor air quality (IAQ) problems that have become known as the sick building syndrome. Occupant health complaints and illnesses have been monitored in different use buildings around the world. The increased awareness of IAQ issues has led to a large number of IAQ improvements in various building practices, from eliminating the use of building materials like asbestos to the design, operation, and maintenance practices of ventilation systems. However, addressing and dealing with IAQ problems must be a continuous effort. Ventilation systems when properly designed, installed, operated, and maintained can secure proper IAQ conditions at acceptable energy consumption. Existing ventilation standards set the grounds for properly handling these complex issues.

1. Introduction

The US Environmental Protection Agency (EPA) has called Indoor Air Quality (IAQ) the number one environmental health concern of the 1990s. In the past, control of indoor air quality was achieved by rather natural means. Most buildings had considerable infiltration to allow for sufficient dilution of contaminants, natural ventilation could easily provide good quality fresh outdoor air, and indoor pollutants were rather limited, while in large commercial buildings when mechanical ventilation systems were used, excessive amounts of outdoor air were often used. However, efforts to reduce energy consumption led to tight buildings and reduced amounts of outdoor air. Even when mechanical ventilation is used to provide the necessary amount of ventilation, achieving acceptable IAQ also depends on the system's characteristics from the design stage down to the operating conditions (i.e., location of air intakes, construction practices, accessibility for maintenance, and proper cleaning of equipment to avoid microbial growth). On top of all this, lack of understanding of the importance and problems associated with IAQ, the need for contaminant control, and associated health risks, gave a mistaken sense of security.

In our days, poor outdoor air quality, particularly in urban locations, created problems of poor indoor air quality if not properly treated. Pollen, dust, car emissions, and other contaminants are often directly brought into the building through the ventilation system. A major contribution to contaminants comes from indoor sources that have increased both in concentration levels and number of different sources. New materials, processes, and equipment were brought into buildings. These include the use of chemicals in cleaning solvents for office equipment (for example, photocopiers and laser printers) and emissions from building materials and furniture (for example, formaldehyde foam insulation, increased use of carpeting, manufactured wood products, and adhesives that release chemicals to the air over time). Although the same contaminants can be traced in the outdoor environment, indoor concentrations can be high enough to threaten human health. The heating, ventilating and cooling (HVAC) system itself may also provide grounds for the multiplication of microorganisms that can grow, for example, on the duct work or filters, and be imported into the building as they become airborne and finally reach occupied spaces.

Several events gradually started making headlines, attracting the attention of the scientific and technical community, and they contributed in an unfortunate way to the increased public awareness about the rising problems of IAQ. Some of these events include:

- Numerous complaints of odor and acutely irritating symptoms were received from owners of urea-formaldehyde foam-insulated houses;
- Hundreds of outbreaks of illness among occupants of new or recently remodeled offices, schools, and other public access buildings were reported;
- Questions were raised in the late 1970s about the presence of friable asbestos in public buildings and related disease;
- Radon was traced in millions of homes in the United States, Canada, and Northern Europe and found responsible for 40% of lung cancer in Sweden and 10% in the United States;
- Pneumonia-like symptoms known as Legionnaires Disease were caused by a bacterium, *Legionella pneumophila*, which was detected in air handling systems.

The increased awareness of IAQ issues has led to a large number of IAQ improvements in various building practices, from eliminating the use of building materials like asbestos to the design, operation, and maintenance practices of ventilation systems. Progress has not been without paying a high price though, both in monetary costs and even human lives. The worst case scenarios have become reality with the serious impairment of human health as a result of IAQ problems encountered in buildings, including to the loss of human lives as a result of the legionella disease.

Addressing and dealing with IAQ problems is a continuous effort. Usually, the indoor conditions in buildings that were constructed some time ago differ significantly from the same type of building when new. This is due to various indoor and outdoor factors, for example: indoor volatile organic compound (VOC) emissions from different exposed building materials and other sources (e.g. furniture and flooring materials); from the building materials of the structure of the building that eventually migrate indoors by absorption and condensation, or through cracks and similar damages in the building structure; and outdoor pollutants. Therefore, it is normal for the indoor air quality of a building to alter with time, depending on the initial selection of material, maintenance, use patterns, and type and condition of building materials. Similarly, the performance of the ventilation system and its components may also deteriorate with time, depending on the contaminant load and maintenance.

Poor IAQ is recognized to be a major cause of health problems to building occupants. Indoor air can be contaminated by building materials, human activities, outdoor pollutants, ineffective ventilation, and malfunctioning of central heating and cooling systems (due to inadequate maintenance), ultimately resulting in what is known as "sick building syndrome." To eliminate or reduce contaminants to acceptable levels, it is necessary to either remove the specific contaminant (by physical or chemical means), or to dilute the air until the concentration is too low to be considered a potential hazard, at least based on current knowledge and according to the existing standards and regulations.

Indoor air can be characterized as of "acceptable" quality when it contains no known contaminants at harmful concentrations and a substantial majority of people exposed to it do not express dissatisfaction or develop ailment over time. The quality of indoor air is a result of a complex relationship between the:

- various contaminant indoor sources;
- ventilation rate;
- dilution of indoor contaminants with outdoor air; and
- air quality of the outdoor environment.

2. Sick Buildings

Building-related IAQ problems and their effects on building occupants are usually referred to as either "Sick Building Syndrome," "Tight Building Syndrome" (TBS), or "Building Related Illness " (BRI). Since 1965 there has been an increasing recognition of SBS, which must have been present even before that time, but which had not been yet recognized as such.

A building manifests SBS when:

- complaints of certain symptoms associated with acute discomfort persist at frequencies significantly greater than 20% over time;

- the causes of the complaints are not recognizable; and
- a substantial percentage of complainants report immediate relief upon exiting the building.

Some of the most characteristic health symptoms associated with SBS and reported by the occupants include several or most of the following: mucous membrane irritation, eye irritation, headache, odor, skin irritation/rash, sinus congestion, cough, sore throat, shortness of breath, abnormal taste, dizziness, fatigue, nausea, wheezing, and hypersensitivity. These symptoms or different combinations thereof, are the primary symptoms of SBS defined by the World Health Organization (WHO). The common practice for collecting the data from the occupants for their health related symptoms and complaints, is circulating a questionnaire. It includes about 30 symptoms that the occupants can select if they believe they are caused as a result of their indoor environment. Self-administered indoor climate questionnaires have been proven effective instruments when analyzing SBS problems in workplaces and dwellings, with acceptable validity and reliability.

Several studies have been conducted following this type of an approach. Representative results are illustrated in Figure 1. One study was performed in Hellenic office buildings located in Athens with data coming from a total of 476 employees in naturally and mechanically ventilated offices. The other study was based on data coming from 4373 employees from office buildings throughout Europe.

Naturally ventilated buildings (solid line), Mechanically ventilated buildings (dashed line). Health Symptoms - A: Eye irritation; B: Headaches; C: Disturbed concentration; D: Dizziness; E: Drowsiness; F: Unusual Fatigue

Health Symptoms - A: Lethargy; B: Blocked nose; C: Dry throat; D: Headache; E: Eye irritation; F: Dry skin

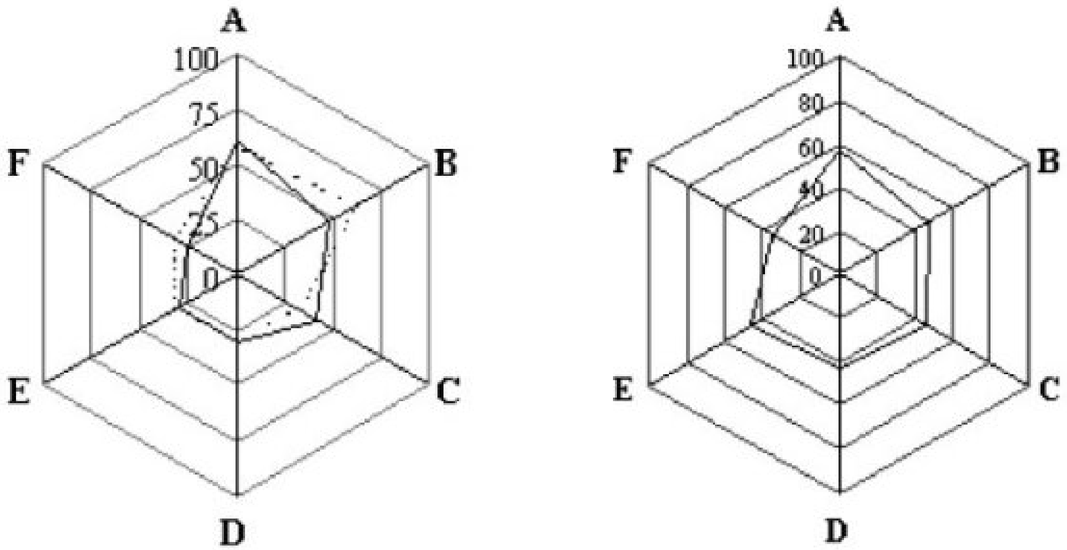

Figure 1. Star distribution for the percent of reported symptoms by employees in office buildings, in Athens (left) and throughout Europe (right).

Data from another study in Norway based on a population of 2197, investigated the differences in reported frequency of health complaints among different occupational groups, and between men and women. Figure 2 illustrates the results in relation to gender. The highest prevalence of health complaints was reported as being from the working environment. The results indicated an increased frequency of self-reported health complaints among women, allergic individuals, and persons working in schools, kindergartens, health care institutions, hotels, and offices.

Health symptoms - A: Hard irritation etc. B: Headache; C: Tiredness; D: Throat irritation;
E: Eye irritation; F: Face dry / irritation

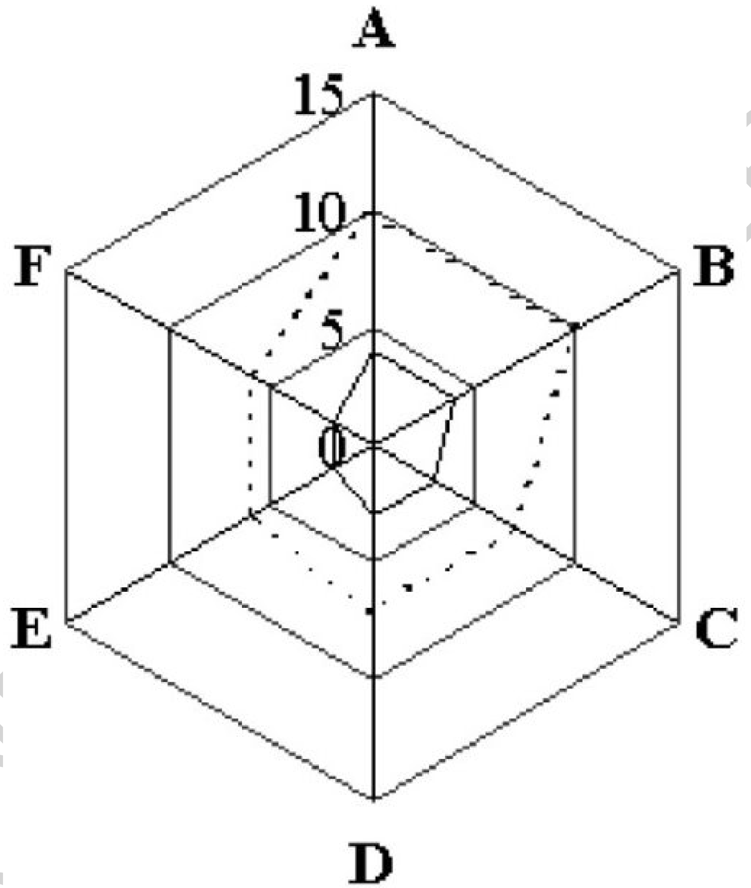

Figure 2. Star distribution for the percent of reported symptoms by employees in various type of buildings in Norway, from men (solid line) and women (dashed line).

The frequency of work related symptoms has been investigated by the EPA in the United States. The first (Frequency A), defines frequent as any occurrence in the past four weeks, and the second (Frequency B), defines frequent as at least 1-3 days per week in the last four weeks. The results are illustrated in Figure 3.

Health symptoms - A: Headache; B: Dry, itching or irritated eyes; C: Unusual tiredness, fatigue or drowsiness; D: Stuffy or runny nose, or sinus congestion; E: Sore or dry throat; F: Dry or itchy skin

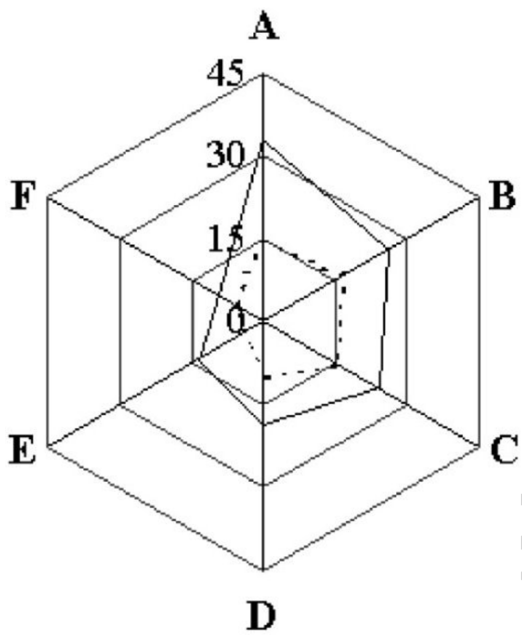

Figure 3. Star distribution for the percent of reported symptoms by employees in various type of buildings in the United States, for different frequency of occurring symptoms, Frequency A (solid line) and Frequency B (dashed line)

Most of the times, occupant complaints are dismissed as acute sensitivity in certain individuals, job-related stress or dissatisfaction, or psychosocial factors. Although these factors can play a role in the perception of indoor conditions and the occupant's assessment of indoor environmental quality, careful investigations have shown that the symptoms are usually caused or exacerbated by indoor air contamination. Immediate relief upon leaving the building is strong evidence of building-related problems.

According to an investigation of 44 office buildings throughout Europe, natural and mechanical ventilated buildings have the lowest levels of symptoms, and sealed air-conditioned buildings the highest. The mean Building Symptoms Index (BSI) varies from 1.53 to 5.25 depending on the ventilation system, as shown in Table 1.

Ventilation System	BSI range
Natural	1.53–3.57
Mechanical	1.25–3.76
All air system	2.12–5.25
Local induction unit	3.05–4.76
Central induction unit	2.69–4.92

Table 1. Building Sickness Index (BSI) by ventilation group.

Many buildings can be "problematic," but not "sick." The term "problematic building" in relation to the indoor conditions, should be referenced to buildings where the occupants are not satisfied with the prevailing indoor conditions. The term "sick building" should be used for buildings that exhibit several problems, although it is not a prerequisite that each parameter (i.e., concentration of different pollutants) exceeds the corresponding limits, and some may be generally within acceptable levels. The combination of even relatively low concentrations of pollutants can initiate a chain reaction and problems that may lead to the development of specific health symptoms. In a typical office building, there may be over 300 different chemical substances, the majority of which are at very low concentrations. Some of them, though, can cause problems even at concentrations that are difficult to be measured.

Health symptoms for SBS buildings are common in office buildings, while they are not particularly high in residential buildings. For example, according to studies carried out in Sweden, about 40% of males and 60% of females had at least one symptom every week, directly related to sick buildings, during their employment over a period of three months. At least two-thirds of these symptoms are related to the indoor environment. Exactly who will be influenced and eventually develop the symptoms related to SBS depends on various parameters, for example gender and sensitivity to allergies, those related to the working conditions and psychology of the people, as well as the characteristics of the building and the indoor environment. The majority of the problems occurred in buildings constructed or renovated after the mid-1970s. Other parameters that influence the development of health symptoms are the quantity and quality of the outdoor air, the use of office equipment in the space (e.g. photocopiers or humidifiers), and cleanliness.

The causes of the SBS are sometimes difficult to determine, although according to probable causes identified in numerous investigations and actually verified in case studies, they range from exposure to specific indoor and outdoor pollutants and sources, inadequate ventilation, work related stress, air ionization, and poor indoor thermal conditions. Inadequate ventilation has been identified in many cases as the main parameter.

For example, during one of the most comprehensive studies of its kind, a total of 356 public access buildings for which illness complaints had been reported, were investigated over a ten year period by the National Institute of Occupational Safety and Health (NIOSH) in the United States. The most common complaints that were reported included eye irritation (81%), dry throat (71%), headaches (67%), and fatigue (53%). The major building problems are attributed to inadequate ventilation (50%), chemical contamination (34%), and microbial contamination (5%). Inadequate ventilation was also identified as a major source of IAQ problems in 68% of 94 Canadian buildings investigated by the Canadian Health and Welfare Department. An increase in the supply of outdoor air has often reduced occupant complaints.

Poor IAQ can prove a significant financial burden. For example, the EPA has reported that in the United States the annual cost for health treatment of illnesses caused by indoor air pollution exceeds US$1 billion. The impact of these illnesses on reducing the performance of the work force is estimated to exceed US$5 billion. The final total cost of indoor air quality related illnesses, including compensations, sick leave, medical care, etc., is estimated to be close to US$60 billion in the United States. The World Health Organization (WHO), estimates that the cost related to the illnesses caused by SBS is about 0.5–1% of GNP. By improving the indoor air quality, it would be possible to avoid the occupants' health related problems, and improve living conditions and even overall employee performance.

In some cases, instead of trying to improve the indoor conditions and actually solve the IAQ problems in buildings where people live and work, there seems to be an "alternative" approach, using medicine. It appears that this "solution" has been found preferable in the quest for an answer to these serious problems. It is of interest to note that the expenditures for the research on antiallergenic medicines is about 100 times more than the budget allocated for research on the indoor environment, indoor air quality, and health, according to published information for Sweden and the United States.

An additional hidden and indirect cost of poor indoor air quality may result from lawsuits by employees working in buildings that have developed the SBS against those who are responsible for handling these problems or who have caused them. Handling this kind of problem involves engineers, scientists, medical doctors, and lawyers. This high number of directly or indirectly involved different disciplines also illustrates the magnitude and complexity of the problem.

Following this trend, during an ASHRAE annual meeting on indoor air quality there was a special meeting for lawyers in order to discuss related topics with the engineers involved in this field. The absolute minimum that is necessary to be implemented in order to minimize the consequences from such problems is to enforce the relevant standards and codes, and to closely follow any new developments.

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Biographical Sketch

Constantinos A. Balaras, Ph.D. Born in Athens, 1962. Married, one son. Mechanical engineer, researcher at the National Observatory of Athens, IERSD, Group Energy Conservation. Ph.D. and M.S.M.E. from Georgia Tech., B.S.M.E. from Michigan Tech. Active in the areas of energy conservation, thermal and solar building applications, renewable energy sources, analysis and numerical modeling of thermal energy systems, HVAC systems. Previous affiliations with the University of Athens, Central Institute for Energy Efficiency Education, Protechna Ltd, Technological Educational Institute of Pireaus, British-Hellenic College, American Standards Testing Bureau Inc., American Combustion Inc., Georgia Institute of Technology, Hellenic Shipyards Co., Georgia Power Co. Participated in various European and national research projects, as a project manager and scientist in charge, including projects on energy renovation of office and apartment buildings, HVAC systems in hospital operating rooms, solar absorption heat pump, solar control, passive cooling, regional development of renewable energy sources. Private practice includes electromechanical design and installation projects for new constructions and renovations of residential and office buildings, and a small size industrial building. Member of the Hellenic Technical Chamber (Chartered Mechanical Engineer), EUR ING, Hellenic Society of Mechanical - Electrical Engineers, Hellenic Society of Heat and Power Cogeneration, Hellenic Forum for the Dissemination of Renewable Energy Sources (ELFORES), ASHRAE (Inititating representative and president of Hellenic Chapter 1999-2000), ASME (Member of the Governing Board ASME Greek Section), ISES. Author and co-author of over 35 papers in international Journals and 50 papers in Conferences, chapter contributions in 9 scientific books and numerous technical project reports. Guest editor for a special issue of the Journal Energy and Buildings; Invited Reviewer of papers for the Journal of Solar Energy; Invited Technical Assessor for the European Architectural Competition Living in the City and Working in the City (under the auspices of the European Commission); Member of The Scientific Research Society; Pi-Tau-Sigma, Honorary Mechanical Engineering Fraternity.