MANAGING INDOOR AIR QUALITY TO PROTECT OCCUPANT HEALTH

Docteur Fabien Squinazi,
Former director of the Paris Hygiene Laboratory
Member of the French Public Health Council (HCSP)
Member of the scientific board of the French Observatory on Indoor Air Quality (OQAI)
Medical biologist

Replacement of a ventilation filter

Fabien Squinazi is a medical biologist, former hospital biologist, former director of the Paris Hygiene Laboratory and former head of the Environmental Health and Hygiene Bureau at Paris City Hall. He is a member of various commissions at the French Ministry of Health (French High Council for Public Hygiene, Living Environments section, Buildings group – health; technical panel on lead; expert panel on clinical waste) and at the French Health and Safety Agency (expert panel on air environments and working groups). Dr. Squinazi also sits on the scientific board of the French Observatory on Indoor Air Quality (OQAI) and the "Environmental Risks" commission of the French Public Health Council (HCSP), and is a corresponding member of the National Academy of Pharmacy (6th environmental health section) and of several non-profits involved in the following areas: environmental health, High Environmental Quality (HQE) for buildings, asthma and allergies, prevention of atmospheric pollution, prevention and study of clean room contamination, air environment occupations. He has published several articles and books on air quality and water quality.

Deterioration in indoor air quality can lead to various diseases linked to the growth of microorganisms or the presence of pollutants and allergens. Other collective non-specific symptoms affecting various bodily functions (ENT, ocular, respiratory, dermal, neurological) can occur in a building, then disappear when the people affected leave the building. In both cases, a medical and environmental investigation may identify clinical aspects and search for sources of pollution or faults in the ventilation system. The audit results and interpretation of the observed concentrations compared with reference values may provide information to help understand the problems encountered. Various tools are currently available to control and assess indoor air quality during the construction or renovation of a building, and while it is operational. Three main categories may be identified: 1/ preventative measures taking account of sources of pollution from both inside and outside the building and the ventilation system, 2/ protocols for measuring various parameters on at the delivery stage and in operation, and 3/ measurement tools providing continuous information on indoor air quality.

THE EMERGENCE OF SICK BUILDING SYNDROME

Indoor air refers to non-industrial closed indoor environments, including dwellings, establishments open to the public, care and education settings, health care and medical-social establishments, and means of transportation. Living, staying, visiting, studying or working in these indoor environments can lead users or occupants to report discomfort or health issues.

The French health authorities are increasingly faced with "epidemics of unexplained symptoms" occurring in workplaces and public buildings such as schools and hospitals. These collective non-specific syndromes, commonly known as "Sick Building Syndrome," are distinct from specific illnesses linked directly to the building (building-related illnesses), which form a uniform clinical picture of objective clinical or biological abnormalities for which a doctor can identify one or multiple agents[1]: infectious diseases (legionellosis, colds and flu, tuberculosis), immunological diseases (hypersensitivity pneumonitis) and allergic disorders (allergic rhinitis, asthma, eczema, contact urticaria). The agents concerned are bacteria, viruses, fungi, actinomycetes, molds and allergens from dust mites, cockroaches, pets, etc.

Sick building syndrome differs from building-related illness in that it causes various non-specific symptoms, which may differ from one person to another, even during the same episode. People may present multiple relapses, especially upon returning to the place where their symptoms began. Symptoms are generally subjective, in that clinical examination of affected people reveals no objective abnormality and the results of any additional examinations are normal. Complaints may involve different organs and are often polymorphic. Each person may present different clinical signs, which fall into five categories:

1. Symptoms affecting the mucous membranes and upper respiratory tract: eyes (irritation, dryness, tingling, itching, burning sensation, watering), nose (irritation, dryness, congestion, sneezing, nosebleeds), or throat (irritation, dryness, husky or altered voice, coughing);
2. Symptoms affecting the lower respiratory system: tightness in the chest, wheezing, shortness of breath, asthma attacks, etc.;
3. Symptoms affecting the skin, such as dryness, itching, eruptions, sensations of burning or pressure on the face, dry or red facial skin;
4. Symptoms affecting the central nervous system, causing fatigue, difficulty in concentrating, drowsiness, heavy head, headaches, light-headedness, dizziness or nausea;
5. Symptoms of external discomfort (unpleasant odors, altered taste).

1 Institut de Veille Sanitaire. Diagnostic et prise en charge des syndromes collectifs inexpliqués. Technical guide. 2010

The signs of discomfort or symptoms experienced inside a building characteristically improve after leaving the location concerned, primarily affect vulnerable people, and promote clinical exacerbations in people already affected by allergic, respiratory, ocular or dermal disorders.

THE MULTIFACTORIAL ORIGIN OF SICK BUILDING SYNDROME

Numerous scientific publications[2,3] record associations between certain environmental or psychosocial factors and the onset of these symptoms. However, several authors[4,5] agree that all these factors may play a role without any single factor being sufficient to explain the health phenomena observed. Therefore, we speak of "multifactorial pathology"[6] that combines:

- Environmental factors: the presence of indoor pollutants such as volatile organic compounds including aldehydes, particulates and fibers, nitrogen dioxide, ozone, and molds associated with damp; ventilation defects, uncomfortable temperature, insufficient humidity, inappropriate lighting, overcrowding, etc.
- Individual risk factors: immune system predisposition, pre-existing skin dryness, wearing of contact lenses;
- Psychosocial factors: overly distant management or overly controlling management that restricts employee autonomy, workload-related stress, difficult relationships with line managers or colleagues, boring work, lack of privacy.
- The relative influence of these different factors may change over time, especially if the initial problem brings on an attack when the first attempts at management fail to relieve the reported symptoms. Numerous social factors are likely to make the attack worse.

Aside from consequences that can be highly detrimental to health, sick building syndrome also causes a deterioration in performance, not only in office staff, but also in children in the school setting.

2 Burge P.S. Sick building syndrome. **Occup Environ Med**. 2004;61:185-190

3 WHO. Indoor air quality: biological contaminants. WHO regional publications. European series no. 3. WHO, 1990:1-54.

4 Mendell M.J., Fisk W.J. Is health in office buildings related only to psychosocial factors? *Occup Environ Med*. 2007;64(1):69-70.

5 Baker D.B. Social and organizational factors in office building-associated illness. *Occup Med*. 1989;4(4):607-24.

6 Lahtinen M., Huuhtanen, Reijula. Sick Building syndrome and psychosocial factors – a literature review. *Indoor Air*. 1998;4;71-80.

COMFORT, HEALTH AND PERFORMANCE AT WORK IN OFFICE BUILDINGS

An audit carried out in office blocks in the Île-de-France region by the Society of Occupational Medicine of western Île-de-France and the Paris Hygiene Laboratory[7] enabled improved definition of employee complaints, based on a self-completed medical questionnaire distributed to employees when they visited the occupational physician. Two studies performed in 1994 and 1995 collected 4,276 questionnaires in winter and 2,152 in summer. The results were as follows: half the people surveyed complained of symptoms linked to their building: nose (25%), eyes (24%), throat (19%), headaches (17%), skin (12%), difficulties in concentrating (10%), abnormal fatigue (8%). The study also revealed several sources of dissatisfaction: building temperature (complained of by 60% of respondents), air quality (58%), noise (42%) and lighting (35%). A second study, using the same format, but this time performed at the national level over the winter of 1996-1997 with 3,953 employees, confirmed these results.

The European OFFICAIR project[8], which ran from 2010 to 2014 and involved 1,190 respondents, highlighted the same sources of dissatisfaction, but in different proportions: temperature (35%), air quality (38%), noise (44%) and lighting (27%). In a subsample of five buildings[9], the relationships between indoor air quality and work performance testing were studied. It was shown that individual variables such as age and being in receipt of medical treatment remained the main determinants of performance at work. It was also found that indoor concentrations of xylenes and ozone could influence employees' reaction times during the summer. Additionally, in both summer and winter, satisfaction in terms of noise and the ability to control the indoor temperature increased the occupants' self-reported productivity.

In the United States, the study by Professor Fisk and colleagues[10] compared the costs of a non-optimal indoor environment (in terms of absenteeism, for example) with the costs of improving that environment. According to the different scenarios considered, the benefits could be as high as $17 billion per year for American offices as a whole.

7 Squinazi F., Lanfranconi I., Giard A.M. Confort et santé dans les bâtiments climatisés. Proposition d'un auto-questionnaire à utiliser par le médecin du travail. Documents pour le Médecin du Travail. 1994 ;60(4):341-352.

8 Bartzis J. et al. European collaborative project OFFICAIR. On the reduction of health effects from combined exposure to indoor air pollutants in modern offices. 2014

9 Mandin C., Boerstra A., Le Ponner E., et al. Qualité de l'air intérieur et confort dans les espaces de bureaux, et relations avec la performance au travail. French section of OFFICAIR project, Part 2. Environnement, Risques & Santé. 2017;16(6):565-74.

10 Fisk W.J., Black D., Brunner G. Benefits and costs of improved IEQ in U.S. offices. Indoor Air. 2011;21:357-67.

CLASSROOM AIR QUALITY AND CHILDREN'S SCHOLASTIC PERFORMANCE

In 2007, Pawel Wargocki and David Wyon[11] carried out two summer interventional studies of the environment in two classrooms in a Danish school occupied by children aged between 10 and 12 years.

The authors observed that reducing the temperature from 25 °C to 20 °C improved performance in two arithmetical exercises and two language-based exercises similar to school work. The performance improvement was mainly due to the increase in the children's response speed. Other positive impacts were that the students' perception of the temperature changed from "slightly too hot" to "neutral" and they reported significantly fewer headaches at the lower temperature. A panel of adults entering the classrooms just after the children had left also noted a cooler and more acceptable environment at the lower temperature.

In addition, doubling the flow rate of fresh air per person from 5 to 10 liters per second improved students' performance by 15% for four arithmetical exercises, increasing response speed while generating almost no errors.

A similar European study[12] in 1996, involving 800 students in eight schools, showed that students' scores in concentration tests dropped as confinement (measured by carbon dioxide level) increased.

These results show that introducing the means to avoid rises in temperature and increase ventilation could improve students' school results.

11 Wargocki P., Wyon D.P. The effects of moderately raised classroom temperatures and classroom ventilation rate on the performance of schoolwork by children. *HVAC&R Research*. 2007;13(2):193-220

12 Myhrvold A.N., Olsen E., Lauridsen O. Indoor Environment in Schools—Pupils' Health and Performance in regard to CO_2 Concentrations. *Indoor Air. The Seventh International Conference on Indoor Air Quality and Climate.* 1996;4:369-371.

THE ENVIRONMENTAL AUDIT: A MEANS OF IDENTIFYING AND DEFINING ISSUES RELATED TO INDOOR AIR QUALITY IN BUILDINGS

An environmental audit is initiated when the nature of building or redevelopment work makes it likely to affect the environment. The environmental audit is rooted in a double approach[13].

- **A medical approach,** identifying non-specific symptoms or diseases associated with the presence of agents in the affected premises. Meeting with medical experts, managers, clerical and technical staff, followed by chronological analysis of the facts, should allow identification of the factor causing the symptoms, the timing of the symptoms (duration and frequency) and the number of people affected. There may be perception of a particular odor, disruption of the environment by the work (noise, dust, alterations regarded as harmful), general concern triggered by a sick person in the group, etc. Certain contextual factors can also promote reporting: an environment perceived as having deteriorated (for example, a nearby building site or poor workstation ergonomics), a strained sociological situation (underlying social conflicts, poor working conditions, difficult reporting relationships, defective management structures, etc.), unusual physical or psychological stress (relocation, performance reviews, restructuring, difficult economic situation, the prospect of downsizing, etc.).
- **A technical approach,** including a visit to the premises concerned and any annexes, looking for potential sources of pollution. The assessment must take into account potential emissions from construction materials; wall, floor and ceiling coverings; technical equipment (furniture, fuel-burning appliances, heating and air-conditioning systems, computing equipment); products for cleaning, personal hygiene, DIY, deodorizing, etc. It will involve searching for any damp stains, damaged surfaces or the presence of mold. The effectiveness of the building's air recirculation system will be checked (windows and doors, natural or mechanical ventilation system). Potential external sources in the vicinity should also be identified, such as a cooling tower, parking lot, industrial or artisanal activity, or even a building constructed on a potentially polluted site.

Based on the information gathered during the environmental audit and on medical advice received, a strategy is defined for measuring physical, chemical or microbial agents in the air, materials or surfaces. An external reference measurement and/or control environment near the affected premises may provide useful points for comparison.

13 French standard PR NF X 43-406: December 2018. Air quality – Strategy for environmental audit following a report. Building in residential, educational or office use.

For example, the following parameters will be measured, depending on the suspected sources of pollution:

Carbon monoxide	Faulty heating and hot water appliances, tobacco smoke, external urban pollution including from nearby road traffic
Volatile organic compounds	Construction or decorating products (wood-derived products; floor, wall and ceiling coverings; primary installation products, fillers and adhesives; paints and varnishes), furnishings, cleaning and dry-cleaning products, tobacco and e-cigarette smoke, external urban pollution including from nearby road traffic (fuel, service stations, parking lots), proximity to industry and incinerators, possible earlier soil pollution on the site, asphalt or bitumen, fires
Benzene	Tobacco smoke, burning of scented candles and incense, fuel-burning heating, fuel (proximity to a service station or parking lot)
Formaldehyde	Smoking and vaping, rough timber and wood-derived boards with formaldehyde-based binder (particle board, fiberboard, OSB, etc.), solvent based paints, materials containing formaldehyde without diffusion barrier treatment, cleaning and treatment products (phytosanitary or for pest control), burning of incense and scented candles, tobacco smoke
Ozone	Laser printers, photocopiers, electrostatic air purifiers
Nitrogen dioxide	Various types of fuel burning including gas burning; poorly sealed fume extraction ducts; urban pollution including from road traffic; air intake near road traffic, parking lot or garage
Particulates	Dirty or deteriorated ventilation system, fuel burning, tobacco smoke, proximity to a construction site, external urban pollution including from road traffic, proximity to industry, polluted outdoor air (including with pollen)
Artificial mineral fibers	Glass wool, rock wool, slag wool
Radon	Construction materials, soil in potential radon zones (fissures, porosity, joints, pipeline paths)
Airborne fungal flora	Indicator of the quality of air filtration by air treatment systems, internal source of damp (water damage, leaks, condensation) or mold growth
Airborne bacterial flora	Environmental indicator of the effectiveness of air recirculation, cleanliness of the premises and ventilation/air conditioning systems
Dust mite allergens (for allergic patients)	Bedding, box spring, textile floor and wall coverings, curtains, sofas, plush toys
Legionella pneumophila	Internal water and air-cooling distribution systems

Sensors can continuously measure some types of indoor air pollutants

Systematic measurements are also taken of temperature, humidity and carbon dioxide:

- Measurements of temperature and relative humidity over a period of at least 24 hours (eight days if possible) provide information on ambient conditions in the environment under investigation. These parameters demonstrate both the building's comfort conditions for occupants and the level of chemical emissions from the various materials and products present within the building.
- Carbon monoxide measurements give an indication of air recirculation in the building. Depending on the occupancy and non-occupancy patterns of the premises, this may bring to light any nychthemeral fluctuations[14] and variations between weekdays and the weekend.

In interpreting the measurement results, it is useful to compare them with reference values. Several factors must be considered when selecting the reference value for a given substance: the type of environment in which the measurements were taken, the length of time for which people mentioned in the report were exposed (was it acute exposure for a short time, or continuous, chronic, long-term exposure?) and the duration of measurement.

In a context where the aim of the investigations is to protect the health of occupants, the selection of reference values for the environment under investigation should initially be made as follows: 1/ regulatory values, if any have been defined; 2/ air quality reference values (VRAI) suggested by the French Public Health Council; or 3/ indoor air guideline values (VGAI) from the French Environmental and Occupational Health & Safety Agency (ANSES) or WHO guideline values or toxicity reference values (TRVs). For substances for which no reference values are available, informative values from studies representative of the environment under investigation may be used.

Ultimately, the audit must provide details of suggested actions.

ACTION LEVERS FOR PREVENTION AND REMEDIAL MEASURES

Given the health issues, but also environmental and economic challenges it represents, management of indoor air quality has become a major prevention issue for organizations involved in the construction, renovation and operation of buildings.

Different action levers for prevention and remedial measures have emerged in response to these challenges.

1. NEW OR RENOVATED BUILDING: PROJECTS BY ALLIANCE HQE-GBC FRANCE

In 2013, Alliance HQE-GBC France[15] published a document concerning the rules for evaluating indoor air quality on acceptance of a new or renovated building (that is, at the moment ownership passes to the contracting client, before the occupants move into the building)[16]. A practical guide[17], published in June 2017, presents the five key stages for integrating, completing and enhancing indoor air quality measurements on acceptance: program planning, building design, tender document preparation, construction and handover.

Several other works focus on the worksite phase, a sensitive stage in the process of constructing or renovating a building.

On the subject of regular monitoring of indoor air quality in buildings at every stage of their life cycle, in a 2018 methodology report, Alliance HQE-GBC France proposed a set of rules for evaluating indoor air quality in an operational building[18]. This report forms part of the organization's commitment to quality of life in a sustainable built environment. The parameters measured, whether physical, chemical or microbial in nature, are compared with reference values to detect any technical faults within the operational building.

14 Variations that occur within a period of 24 hours, especially those relating to day and night.

15 Alliance HQE-GBC is the professional alliance for a sustainable built environment. It brings together unions, trade federations, companies, local authorities and individuals from the construction, development and infrastructure sectors.

16 Alliance HQE-GBC. Protocole HQE PERFORMANCE : Règles d'application pour l'évaluation de la qualité de l'air intérieur d'un bâtiment neuf ou rénové à réception. 25 pages. June 2015 edition.

17 Alliance HQE-GBC France. Mesurer la qualité de l'air intérieur des bâtiments neufs ou rénovés : 5 étapes clés pour intégrer, réaliser et valoriser des mesures à réception. Practical guide. 36 pages. June 2017.

18 Alliance HQE-GBC France. Le bâtiment durable pour tous. Règles d'application pour l'évaluation de la qualité de l'air intérieur d'un bâtiment en exploitation. 29 pages. 2018

The basic on-acceptance protocol and priority parameters when in operation may be supplemented by additional parameters if the preliminary survey reveals other potential sources of pollution, such as damp problems, a potentially polluted site, or changes to the external environment (for example, new high-rise construction or changes in traffic flows).

2. CONTINUOUS MEASUREMENT SENSORS

Recent years have brought the development of continuous measurement sensors for some types of pollutants (particulates and volatile organic compounds, including formaldehyde and nitrogen dioxide), carbon dioxide, temperature and relative humidity. This development allows us to envision progress along three major lines:

- Improved study of the dynamics of concentrations;
- Better understanding of occupants' exposure to different pollutants;
- Appraisal of emissions-producing activities and/or aeration practices and/or ventilation system function.

Feedback highlights certain failings in the design, realization and/or operation of ventilation systems, which cause deterioration in indoor air quality

The information obtained may enable detection of a pollution event (significant variation in the concentration of a parameter, either over an extended period – 1 to 2 hours – or temporary, but chronic and repetitive) and/or monitoring of its concentrations over time (trend monitoring) linked with emissions-producing activity and/or air recirculation in the premises (aeration and/or ventilation).

However, it should be remembered that the information obtained from these sensors has its limits: sensors provide socalled "indicative" measurements, or an "objective estimate" of indoor air quality. The use of sensors to manage indoor air quality within a building or raise awareness among its occupants cannot therefore be a measuring tool in isolation; it must be combined with technical information on the ventilation systems, occupancy of the premises and occupants' activities during the measuring period[19]. The considerable quantity of data accumulated over time must be interpreted in light of this information to enable decisions that are useful and effective for the occupants.

3. VENTILATION: A LINK TO BE STRENGTHENED

The importance of air recirculation appropriate to the occupancy of the premises should be emphasized. An effective and well-maintained ventilation system brings in fresh air and provides occupants with the oxygen they need, supplies fuel-burning appliances with the oxygen required to work properly, regulates the building's humidity and prevents the growth of unwanted microorganisms and pests (mold, dust mites, cockroaches), reduces the transmission of infective agents, eliminates odors and the physical and chemical pollutants that accumulate, limits exposure to soil pollutants (radon, volatile chemical substances) and, ultimately, improves human performance.

Feedback received highlights certain failings in the design, realization and/or operation of ventilation systems, which cause deterioration in indoor air quality and excessive humidity, which in turn leads to mold growth. The design phase of a new or renovated building must take account of the external environment's impact and adapt the ventilation system to the occupants and their activities. The expertise of a ventilation specialist is valuable during the design and construction of the ventilation system. In the building acceptance phase, inspection of the ventilation system ensures it has been installed correctly. Lastly, in the operational phase, the assurance of controlled ventilation flow rates guarantees the effective recirculation of air.

It would be worthwhile reopening the debate on regulatory ventilation flow rates, which were defined in the 1980s in France (through regulations on dwellings, the standard regional health regulations for public buildings or the labor law on office buildings), with regard to occupants' expectations of comfort and the air quality in buildings.

4. INDOOR AIR PURIFICATION SYSTEMS

In recent years, technical air purification solutions have appeared on the market. These are either air purification appliances based on the filtration or destruction of indoor air pollutants (by photocatalysis, ionization, etc.), or functionalized materials that trap and neutralize pollutants such as formaldehyde or use photocatalysis.

Precautions should be taken with certain technologies; the French national health and safety agency recommends carrying out tests of their effectiveness and safety (given the potential emission of by-products resulting from the incomplete decomposition of pollutants) in real-world conditions to raise awareness, especially among asthma patients, of the potential risks from reduced air quality when using certain purification appliances[20]. Asthmatic patients in particular should be made aware of the possible worsening of their condition when using such appliances, especially those that use essential oils and those that may produce ozone.

It would be worth compiling all medical, technical and metrological data on these appliances in a national database as an aid to health care professionals and organizations involved in construction.

19 Alliance HQE GBC France. Place des capteurs de mesure en continu de la qualité de l'air intérieur lors de la réception ou l'exploitation d'un bâtiment. Framework paper

20 French Agency for Food, Environmental and Occupational Health & Safety (ANSES). Identification et analyse des différentes techniques d'épuration d'air intérieur émergentes. 2017