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# THE INDOOR AIR QUALITY OBSERVATORY (OQAI): a unique project to understand air pollution in our living spaces

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Combustion deodorizers contribute to indoor air pollution  
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Head of the Indoor Air Quality Observatory (OQAI) in the Health & Comfort directorate of the Scientific and Technical Center for Building (CSTB) in France, Corinne Mandin has a background in chemical engineering and holds a doctorate in biology and health sciences. She works in the field of human exposure to chemicals, especially in buildings.

The OQAI was formed in 2001 to research air quality and comfort in living spaces. Its work is financed by the French ministries responsible for housing, the environment and health, the Environment and Energy Management Agency (ADEME) and the Agency for Food, Environmental and Occupational Health & Safety (ANSES).

The mission of the CSTB, which has scientific and technical oversight of the OQAI, is to ensure the quality and safety of buildings. It supports stakeholders in the transformation of buildings, together with environmental, energy and digital transformation. It is active in five key areas: research and consulting, assessment, certification, testing, and the dissemination of knowledge. Its areas of expertise cover construction products, buildings, and their integration into the town and district.

Over the past 10 years, indoor air quality has become a major component of environmental health. In France, the Indoor Air Quality Observatory (OQAI) runs national campaigns to measure indoor air pollution in homes, schools, office spaces and health care or medical-social establishments. After presenting the pollutants concerned and their health effects, this article summarizes the main outcomes of the OQAI's national campaigns in three types of environments: dwellings, classrooms and offices. It then focuses more specifically on the relationships between indoor air quality and energy performance, as making the building envelope more airtight to reduce energy loss can lead to reduced air exchange, resulting in a deterioration in indoor air quality. Although further research is necessary to improve our understanding of the airborne substances present in buildings and of their health effects, there are already good practices and tools that can be implemented to improve indoor air quality in our living spaces.

## INTRODUCTION

That indoor air quality represents a health issue is no longer in question. In 2014, the French National Agency for Food, Environmental and Occupational Health & Safety (ANSES) and the Indoor Air Quality Observatory (OQAI) estimated the number of new cases of illness and deaths per year in France linked with six indoor air pollutants at around 28,000 and more than 20,000 respectively. This represents a cost of around €19 billion. Modern lifestyles effectively lead the population to spend the majority of their time in indoor environments where a large number of pollutants may be present.

In response to the need for deeper understanding and to better direct government policies and improvement solutions, the OQAI conducts research on new pollutants and investigates new problems.

## POLLUTANTS THAT DEGRADE INDOOR AIR QUALITY AND THEIR EFFECT ON HEALTH

The sources of air pollution in buildings are numerous. Typically, indoor pollutants are categorized by type: chemical (semi-volatile and volatile organic compounds or VOCs, inorganic gases), biological (viruses, bacteria, molds, pet allergens, mite allergens) or physical (particulates, asbestos fibers, artificial mineral fibers, electromagnetic fields). Indoor pollution may also be described according to the three types of sources typically recognized: i) external pollution (air or ground in the case of radon, or soil contaminated by past or present industrial activity), ii) building constituents (construction materials and floor, wall and ceiling coverings) and fixtures, and iii) the occupants themselves (bioeffluents, smoking, cleaning, DIY, personal hygiene, etc.).

The respective contribution of each of these sources to indoor concentrations is difficult to determine, due not only to the specific characteristics of each space and its occupants' habits, but also to the variability over time of indoor concentrations and chemical reactivity phenomena leading to the formation of secondary pollutants. For example, terpenes are chemical substances mainly used in indoor cleaning and deodorizing products, which can react with ozone from outside and lead to the formation of formaldehyde and ultrafine particulates. Temperature and relative humidity also play a role by encouraging materials to release emissions into the indoor air.

Indoor air pollution constantly changes over time. New practices such as electronic cigarettes or 3D printing generate new forms of pollution. Additionally, some substances now banned from sale may still be present in buildings. This is the case with polychlorinated biphenyls (PCBs), for example, which were used in sealants in the 1970s and are frequently detected in the air in buildings constructed during that period. The same may be said of lindane, which was used as an insecticide in timber frames and head lice treatment shampoo, and is still often detected in indoor air. Ahead of the next national campaign to measure indoor air quality in French dwellings starting in 2020, the OQAI has updated its directory<sup>1</sup> of substances that may be present in indoor air. The list includes substances that have either: i) previously been detected in air or dust deposited on the ground, ii) previously been measured in an environmental chamber in emissions from construction materials or consumer products, or iii) been recorded in the composition of materials and products used in buildings. In total, 2,741 substances have been collated, including 1,715 new substances compared with the OQAI's last compilation of indoor air pollutants in 2010.<sup>2</sup>

The health effects of indoor air pollutants are just as varied as the pollutants that cause them. They range from mild annoyance linked to odors to serious effects such as lethal poisoning due to carbon monoxide, asthma, cancer, cardiovascular illnesses and reproductive problems. Poor indoor air quality may also be associated with headaches, nausea, and irritation of the eyes, nose and respiratory tract.

While some associations between substances present in indoor air and health effects are well established (as is the case with asbestos fibers and mesothelioma, or radon and lung cancer), the effects of a large number of other pollutants have not been clearly identified and remain merely suspected. Moreover, determining health effects can be made more complex by several features: effects are sometimes delayed; exposure is often to weak doses or occurs through various routes, including the ingestion of dust deposited on surfaces and skin contact, as well as inhalation; and these effects may be cumulative, synergic or antagonistic due to the mix of substances present.

Currently, concerns regarding indoor pollution are centered on endocrine disruptors, pesticides (especially near crops), biocontamination (for example, the dispersion of viruses in buildings in the case of flu pandemics) and nanoparticulates. These particulates are less than 100 nm in diameter and may be incorporated into construction materials and consumer products to give them particular properties, for example to strengthen or preserve. While studies are revealing the troubling implications of particulates of this size for respiratory health,<sup>3</sup> questions remain about how they are emitted into indoor air during use of said materials and products, or through their decomposition.

## CURRENT STATE OF POPULATION EXPOSURE IN BUILDINGS

As the number-one indoor environment in terms of time spent, dwellings were the subject of the OQAI's first national campaign in 2003-2005. More than a hundred chemical, physical and biological parameters were recorded over one week, in a sample of 567 randomly selected dwellings representative of the stock of primary residences in mainland France. This campaign showed that some pollutants, such as formaldehyde, particulates, and certain phthalates and polycyclic aromatic hydrocarbons were systematically present in the dwellings. Air pollution in dwellings is not homogeneous, however, and different pollution profiles were identified. Additionally, 10% of French dwellings are multipolluted: they simultaneously present several chemical pollutants in very high concentrations. Conversely, 40% of dwellings are considered lightly polluted, as they showed concentrations lower than or equal to the median levels of the sample for almost all the pollutants studied.

1 Directory due for publication in early 2020.

2 <https://www.oqai.fr/fr/campagnes/la-hierarchisation-des-polluants>

3 Review of evidence on health aspects of air pollution – REVIHAAP Project. World Health Organization, Regional Office for Europe, 2013.



Indoor air quality measurement in a private home - ©OQAI-CSTB

Examination of the concentrations recorded alongside the characteristics of the buildings, their location, their occupants and their lifestyles identified factors leading to degradation of indoor air quality. For example, in single-family homes, the presence of a connecting garage increases concentrations of benzene and toluene in the rest of the dwelling. These substances are emitted by vehicles (exhaust gases and fuel tanks) and DIY products that may be stored in the garage. Cooking, care and hygiene (showers, drying laundry) activities may contribute to high humidity in the building, which favors the growth of molds. Behavior with regard to opening windows and the state of mechanical ventilation systems also play a role in indoor air quality.

*Almost one in two new or recently renovated dwellings is contaminated by molds, most often invisible*

After dwellings, schools are the location frequented second most often by children. In schools, the high density of furniture, use of products for activities (glues, paints, markers, etc.) and frequent cleaning of the premises may have repercussions on indoor air quality and represent distinctive features of these buildings in comparison with dwellings. In addition, the use of chalk, proximity to major highways, and children's high activity level (which causes dust deposits to become airborne) are all factors that contribute to particulate pollution in classrooms. All these distinctive features prompted a national measurement campaign, carried out by the OQAI between

2013 and 2017 in a sample of 301 randomly selected nursery and elementary schools representative of schools in mainland France.

The vast majority of schools conformed to the regulatory guideline values on indoor air quality available for formaldehyde and benzene,<sup>4</sup> and the threshold values requiring additional investigation and notification of the departmental prefect were never exceeded. Nitrogen dioxide, a marker of external atmospheric pollution where there are no combustion sources in the school buildings, was undetected in a quarter of schools. However, the results of this national campaign did highlight four points for consideration. Firstly, fine particulate pollution is omnipresent, with indoor concentrations higher than the World Health Organization's (WHO) guideline values in 96% of schools. Some pollutants were present in the air in 100% of classrooms, including phthalates, which are used as plasticizers; polycyclic aromatic hydrocarbons, produced by combustion, including from road traffic outside; and lindane. The presence of lead in deteriorating paint was observed in concentrations above the regulatory limit of 1 mg/cm<sup>2</sup> in 15% of schools. Lastly, 40% of schools had at least one classroom in which air renewal was unsatisfactory with regard to occupation, with a confinement index equal to 4 or 5 out of 5.

<sup>4</sup> French Decree 2011-1727 of December 2, 2011 relating to indoor air guideline values for formaldehyde and benzene.





Indoor air quality measurement in a classroom  
©OQAI-CSTB



Indoor air quality measurement in a workplace  
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With statutory indoor air quality monitoring in place in nurseries and schools, the next step is to prepare for subsequent deadlines and identify the relevant parameters for monitoring other spaces open to the public. To this end, the public authorities have commissioned the OQAI to perform surveys in three types of establishments specifically targeted for the 2023 deadline: accommodation for senior citizens, and long-term care units and centers for disabled children and adults. Approximately 100 randomly selected establishments are currently being studied (2019-2020) to obtain preliminary data on indoor air quality and comfort in these spaces.

## FOCUS ON INDOOR AIR QUALITY IN OFFICE BUILDINGS AND ITS RELATIONSHIP WITH PERFORMANCE AT WORK

In office spaces, specific sources and activities, such as the presence of printers and photocopiers and regular use of cleaning products that may produce volatile organic compounds (VOCs), raise the question of a specific kind of indoor pollution in these buildings. In this context, considering that a large part of the active population spends a significant amount of time in these spaces, the OQAI mounted a national measurement campaign between 2013 and 2017. Measurements of VOCs and aldehydes (19 compounds studied), particulates from 10 nm to 1 µm in diameter, temperature, relative humidity and carbon dioxide (CO<sub>2</sub>) were taken in 129 office buildings, two-thirds of which were randomly selected, with the remaining third included on a voluntary basis. Five workspaces were measured in each building.

Initial data analysis showed overall weak indoor concentrations of the substances under investigation. The median concentration of formaldehyde was 14 µg/m<sup>3</sup>, lower than the median concentrations in dwellings and schools. High concentrations of limonene (>100 µg/m<sup>3</sup>)

were recorded in 5% of offices. Similarly, concentrations of benzene above 10 µg/m<sup>3</sup> were occasionally observed, and were in almost every case linked to an equally high concentration in outside air in dense urban areas. Some offices (7%) were multipolluted, with all compounds under investigation present in higher concentrations than across the sample as a whole. Analysis is continuing to identify the contributory factors to poor indoor air quality in certain office spaces.

Poor indoor air quality in office spaces is associated with reduced worker performance. Numerous studies have been conducted under controlled conditions. They showed that temperature, air renewal rates, noise and lighting could have an effect on how quickly and/or accurately some tasks were performed. These factors were also associated with the number of incidents of short-term sick leave. A French study examining this relationship in real-world conditions took place as part of the European project OFFICAIR<sup>5</sup>. The aim of this project (2011-2014) was to study air quality and comfort in new or recently renovated office buildings in Europe. Coordinated by the OQAI in France, the study showed that while personal characteristics remained the primary factors determining performance at work, indoor concentrations of xylenes and ozone recorded during the summer could have an effect.<sup>6</sup> For this project, occupants of the offices surveyed were asked about their perception of their workspace, with the main causes of discontent among the 1,190 respondents in the 21 French buildings surveyed being: noise made by other occupants (54% of dissatisfied people), dry air (48%) and confined air (46%). Of health symptoms attributed to the building, headaches were most frequent (31% of respondents), followed by dry eyes (27%), watering or itching eyes (21%) and dry or irritated

<sup>5</sup> Study cited in the article by Fabien Squinazi; 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.

<sup>6</sup> Mandin C., Boerstra A., Le Ponner E., Cattaneo A., Roda C., Fossati S., Carrer P. 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;565-574.



Investigation of the links between the perception of air quality, comfort and health effects in indoor environments - ©OQAI-CSTB

throat (21%).<sup>7</sup> The ability to control the indoor environment (temperature, lighting, etc.) promoted a more favorable perception of it. Similarly, the existence and effectiveness of a complaint management procedure is associated with a more favorable perception of air quality and comfort, and with a reduction in perceived health effects noted inside and attributed to the building.

## NECESSARY RECONCILIATION OF HEALTH AND ENERGY CHALLENGES

As buildings are currently among the priorities for energy savings, the OQAI is paying special attention to air quality and comfort in new and refurbished buildings. In short, improvement in the energy performance of buildings, which comes largely from making the building envelope more airtight, should not be to the detriment of indoor air quality. The OQAI therefore started a program<sup>8</sup> in 2012 to study indoor air quality and comfort in new or recently renovated buildings. Results so far pertain to 72 dwellings and show concentrations lower than or equivalent to those observed in French dwellings in 2003-2005, with the exception of three chemicals: hexanal, alpha-pinene and limonene. The factors associated with these higher indoor concentrations appear to be linked not to the buildings' energy performance, but to the presence of wood (frames, floors, furnishings and insulation) and cleaning products<sup>9</sup>. In the same sample, active fungal growth was present in 47% of dwellings, compared with 37% for housing stock in 2003-2005, which means almost one in two new or recently renovated dwellings is contaminated by molds, most often invisible. In buildings under construction, the elimination of unwanted air leakages while the mechanical ventilation system is not yet in operation and the windows are kept

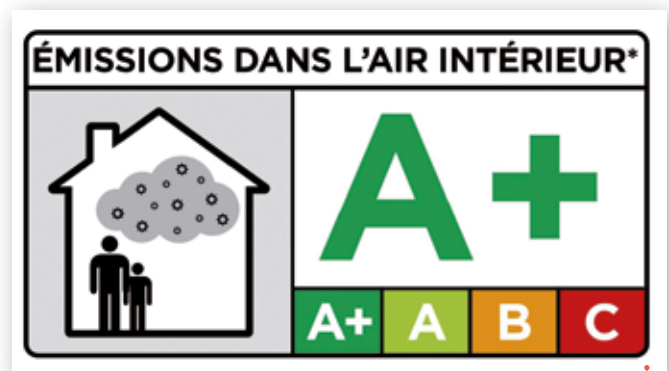
closed, combined with the reduction in material drying times, may explain high humidity when the building is made weatherproof/airtight<sup>10</sup> and the presence of molds in the acceptance phase. In renovated buildings, the failure to consider ventilation when making the building envelope more airtight limits the egress of moisture generated by the occupants and their activities, and thus encourages the growth of molds.

The increase in radon concentrations in renovated dwellings also demands attention. In France, extensive measurement campaigns in geographical areas with high ground radon emission potential showed that homes in which windows had been replaced for energy-saving purposes contained statistically significantly higher radon concentrations than homes in which windows had not been replaced<sup>11</sup>. Similar observations were made in other countries (Switzerland, Finland, Lithuania and the United States).

## POSITIVE STEPS AND WAYS TO ACHIEVE GOOD INDOOR AIR QUALITY

Although further research is necessary to improve our understanding of the airborne substances present in buildings and of their health effects, there are already good practices and tools that can be implemented immediately to improve indoor air quality in our living spaces.

Improving indoor air quality firstly involves using low-emission products and materials. Since September 1, 2013, construction and decoration materials (wall, floor and ceiling coverings, paints and varnishes, insulating materials, etc.) marketed in France must be labeled with their potential VOC emissions. This labeling is based on emissions of 10 different VOCs and of volatile organic compounds overall ("total VOCs"). Four classes indicate the emissions level, ranging from "A+" (the product emits no or very few VOCs) to "C" (the product emits a large quantity or has not been evaluated).



Label indicating the volatile organic compound emissions class of a material or product for construction or decoration

7 Mandin C, Boerstra A, Le Ponner E, Roda C, Fossati S, Carrer P, Bluysen P. Perception de la qualité de l'air intérieur, du confort et de la santé dans les espaces de bureaux, et relations avec les caractéristiques techniques des bâtiments. French section of OFFICIAIR project, Part 1. Environnement, Risques & Santé 2017;16:553-564.

8 <https://www.oqai.fr/fr/campagnes/fonctionnement-du-programme-oqai-bpe>

9 Derbez M., Wyart G., Le Ponner E., Ramalho O., Ribéron J., Mandin C. Indoor air quality in energy-efficient dwellings: levels and sources of pollutants. Indoor Air. 2018;28:318-338.

10 Installing the roof, and fitting doors and windows

11 Le Ponner E., Collignan B., Ledunois B., Mandin C. Déterminants des concentrations intérieures en radon dans les logements français. Environnement, Risques & Santé 2019;18:33-40.

In the absence of labeling when choosing products, it is important to follow the usage instructions, which often call for increased ventilation of the area when using products. It is also important to avoid storing products that might emit VOCs in living spaces, ensure proper ventilation of the storage areas if necessary, and lastly, to take care when using harmful, inflammable, corrosive or toxic products (look for hazard symbols on the labels).

*The large-scale observation of occupied building stock is a unique tool for developing and adjusting government policies, motivating professionals and raising awareness among the general public*



Hazard pictograms on chemical products - ©INRS

Other actions are also necessary to ensure indoor air quality. Regular cleaning of the building's equipment and combustion appliances for heating and hot water production is necessary to limit the emission of pollutants such as carbon monoxide. Management of water damage, water ingress and rising damp is also essential to limit the presence of moisture and growth of molds.

The second set of actions to improve indoor air quality concerns air circulation and ventilation. As pollutants cannot be avoided completely, the air should be renewed to remove them. Ventilation systems should be properly sized, installed and maintained. Air inlets should never be blocked. The intake valves for mechanical ventilation systems should be away from any external sources of pollution (road traffic or vent from underground parking if on a wall, air cooling tower or chimney if on a roof). Filters should be cleaned and replaced regularly. A gap of 2 cm should be left under doors to allow air to circulate. The website <https://www.batiment-ventilation.fr> contains details in French of the standards and guides on evaluating the ventilation in residential and commercial buildings.

Lastly, the use of air purifiers is the final solution to consider. Great care is required when introducing these devices into buildings, whether as part of ventilation systems, integrated into the materials or as standalone appliances. The effectiveness of these systems and their safety (non-emission of by-products) remain to be determined. In a 2017 investigation, the French National Agency for

Food, Environmental and Occupational Health & Safety (ANSES) concluded that current scientific knowledge cannot demonstrate the effectiveness and safety of indoor air purifiers that work on the principles of catalysis or photocatalysis, plasma, ozonation or ionization.<sup>12</sup> Traditional mechanical filtration of particulates at the ventilation system's air intake or using a standalone appliance is effective if the device is correctly and regularly maintained.

## CONCLUSION

The large-scale observation of occupied building stock is a unique tool for developing and adjusting government policies, motivating professionals and raising awareness among the general public. Our knowledge of the pollutants present in indoor air has progressed greatly in recent years, and major advances have been made in reducing exposure to some chemicals. Further research is necessary, all the more so given that building techniques are constantly evolving and new questions are being raised due to new uses and products. More research is also needed in connection with climate change and the reemergence of asbestos issues as buildings are renovated to be more energy efficient. At the same time, private companies are tackling the problem to integrate it into the act of constructing and operating buildings. The increasing development of miniaturized, connected sensors to measure certain pollutants should make it possible to monitor indoor air quality on a massive scale, and thus alert people to take action in the event of pollution. As indoor air quality has become a performance indicator for buildings, it is becoming increasingly central to society's concerns and expectations around health protection.

### For more information:

<http://www.oqai.fr>

The publication "Qualité d'air intérieur, qualité de vie : 10 ans de recherche pour mieux respirer," published by Éditions CSTB in 2011 to mark 10 years of the OQAI.

<sup>12</sup> <https://www.anses.fr/fr/content/%C3%A9purateurs-d%E2%80%99air-int%C3%A9rieur-une-efficacit%C3%A9-encore-%C3%A0-d%C3%A9montrer>