The indoor air quality observatory - outcomes of a decade of research and perspectives

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ABSTRACT

For over a decade now, the OQAI — Observatoire de la qualité de l'air intérieur [French observatory for indoor air quality] — has been leading research into indoor air quality and occupant comfort in living spaces: housing, schools, offices, leisure spaces. The objective is to gain insight into patterns of pollution and occupant discomfort in order to root out the causes, evaluate the health risks, and issue policy recommendations.
Further to a national-scale survey on dwellings, OQAI has launched two new national-scale campaigns focused on indoor air quality and comfort in schools and office buildings. A national system for collecting indoor air quality and occupant comfort data on newly-built or retrofitted energy-efficient buildings has been deployed since 2013. The OQAI also continues to press ahead with its work on indoor air quality indexes and participate to the evaluation of the health-impact of emerging pollutants such semi-volatile organic compounds.

KEYWORDS

Indoor air quality, comfort, population exposure, national-scale survey

1 INTRODUCTION

The French observatory for indoor air quality (OQAI) has the mission to gain insight and inventory knowledge on indoor environments in order to evaluate and control the health risks tied to chemical, physical or biological pollutants in indoor living spaces. Through an array of actions and initiatives, the OQAI helps drive improved air quality and occupant comfort in the national building stock as part of a wider energy efficiency policy. Founded in 2001, it is public founded by three French ministries — Housing, Environment and Health — in collaboration with ADEME [French environment and energy management agency] and ANSES [French agency for food, environmental and occupational health and safety]. Operational mobilization and scientific coordination is led by the CSTB [Scientific and Technical Centre for Building].
The governance of OQAI is organized around three main boards: a Supervisory Board defining and coordinating OQAI research strategy, ensuring the OQAI stays independent and immune to lobbying and promoting open accountability; a Scientific Advisory Board ensuring quality and scientific cogency across all OQAI research; an Advisory Panel whose mission is to canvass opinion and feedback from organizations and institutional stakeholders potentially impacted by OQAI research projects and help identify specific issues or situational

contexts. CSTB is the fieldwork operator appointed to handle OQAI programs leading and coordinating a network of scientific and implementing partners needed for OQAI to fulfil its missions.

OQAI currently manages six programs related to housing, living spaces and venues for children, office building, energy efficient buildings, decision support tools and information & communication.

2 THE AIR AT HOME: A NATIONAL INVENTORY

The first nation-scale survey conducted by OQAI on 2003-2005 was focused on the primary residences in mainland France. The aim of this survey was to have a first snapshot of indoor air quality (IAQ) in these occupied buildings and to sketch out a preliminary shortlist of the factors driving this indoor air pollution among building conditions (i.e. environment, building materials, equipment's, ventilation status, etc.) and household activities.

A total of 567 randomly selected primary residences were investigated. The target pollutants were selected from the indoor air pollutants shortlist originally established by the OQAI back in 2002 (Mosqueron et al., 2003; Kirchner, 2011) and revised in response to talks held by the OQAI Scientific Advisory Board, where certain biocontaminants featured high on the agenda: animal allergens, carbon monoxide, volatile organic compounds and aldehydes, particulate matter, radon and gamma radiation. Other parameters were collected such as carbon dioxide, temperature and relative humidity, exhaust airflow rates at air outlets in the houses specifically equipped with ventilation ducts.

This field campaign generated a snapshot giving the very first picture of the kind of air people breathe every day by people living in mainland French towns and cities. The vast dataset compiled (featuring over 650 variables) was distilled to yield the following lessons (Kirchner et al., 2009):

- indoor pollution has its own specific profile, where pollutant concentrations are often higher than outdoors;
- mould, which is a cause of allergies and respiratory disorders, is found in 37% of homes;
- 10% of homes are exposed to multiple pollution; up to 8 compounds were found at high indoor concentrations, confirming how different households face different pollution issues;
- formaldehyde is found in 100% of homes.

In France and across Europe, the pollutant distributions from the OQAI nationwide housing survey have been used to assess the health risk tied to numerous substances and to inform the risk management and prevention measures, such as for contextualizing existing guideline values.

A clear set of pollution factors emerged, including occupancy density, the presence of an attached garage, outdoor air and soil pollution, water damage, smoking, dry-cleaning clothing, and the use of air fresheners, candles or incense sticks. A 2009 report on ventilation levels in French housing stock highlighted that (Deroubaix et al., 2009):

- overall, looking at the entire building stock studied, room air change rate in housing is not dependent on the ventilation systems installed;

- the occupant – through his behaviour and building use, by opening windows for example – actually plays a role in shaping indoor air quality as important as the building's own technical performances and ventilation modes;

- 56% of housing equipped with mechanical ventilation do not meet the minimum air exchange rate requirements for buildings, thus highlighting the need to step up efforts on system scale-up, implementation and maintenance measures.

The research also identified a relationship between pollution and occupant health. There was a higher prevalence of respiratory symptoms (asthma and rhinitis) in homes exposed to pollution by one or more volatile organic compounds (Billionnet et al., 2011). The objective assessment of fungal contamination of the dwellings also extends previous results suggesting positive associations between exposure to molds and asthma and chronic bronchitis (Hulin et al., 2013).

The housing program is currently completed with a focus on household exposure to semi-volatile organic compounds (SVOCs). SVOCs such as phthalates, polybrominated diphenyl ethers, synthetic musks and polychlorinated biphenyls are attracting growing concern due to their ubiquitous presence and their potential adverse health effects, particularly endocrine disruption. The findings, once compiled, will be the first results obtained in France at housing stock scale.

As part of a wider overarching project named ECOS (cumulative indoor exposures to semi-volatile organic compounds in dwellings) co-coordinated by the EHESP and the CSTB, this project concerns data obtained from analyzing samples of indoor airborne particles and floor-settled dust collected over the course of two national-scale surveys: the OQAI-led 2003–2005 national campaign on indoor air quality in primary residences in mainland France; and the CSTB-coordinated 2008–2009 national "Lead in Homes" campaign on contamination by lead and eight other metals in the homes of children aged 6 months to 6 years. Pre-campaign groundwork phases of these studies provide solid assurances of their current feasibility. First, the substances of interest have been ranked and prioritized based on a review of air and dust concentrations reported in the scientific literature, and toxicity reference values (Bonvallot et al., 2010). Next, the EHESP [French school of advanced research on public health issues] developed dedicated analytical methods for the prioritized compounds (Mercier et al., 2014). Finally, laboratory tests on dust samples have made it possible to confirm zero breakdown of the analysed molecules during the freezing-phase step between collection and analysis (Blanchard et al., 2014). The analyses are underway (Mandin et al., 2014a, 2014b) and should be published early 2015.

3 LIVING SPACES AND VENUES FOR CHILDREN

No French study has yet emerged that gives the 'big picture' on indoor air quality and occupant comfort in schools at a national scale (Kirchner et al., 2011). What little information is available is generally limited to some pollutants such as formaldehyde or benzene. However, the fact is that indoor air pollutant concentrations can sometimes prove higher in schools than in other living spaces and venues, due to a combination of dense rates of

occupancy, frequent use of cleaning agents and classroom supplies like felt pens, rubbers, chalk, and so on, and very low air exchange.

The aim of the on-going OQAI nationwide campaign in schools is to gain key insight into air quality and occupant comfort in classrooms and dorms at nursery and primary schools, so as to propose appropriate solutions for improving the school indoor environment. The campaign is coordinated by the CSTB with technical mobilization and on-the-ground logistics support from an array of partner teams, field investigators and laboratories across France.

600 classrooms from 300 schools randomly-selected across mainland France are instrumented to measure a panel of pollutants: volatile or semi-volatile organic compounds, nitrogen dioxide, particles, metals, and allergens. Measurements and occupant questionnaire are also taken to document visual and acoustic comfort. In addition, walkthrough survey allows describing the building condition and occupation.

The results will be analyzed and unveiled in 2016. The new knowledge obtained will be processed to propose specific opportunities for improving school environments so that children get better protection and a better space in which to learn and grow.

4 OFFICES: NATIONAL-SCALE OFFICE BUILDING SURVEY

In France today, there is still a dearth of information on indoor air quality in office buildings and the perceived comfort levels of their occupants, yet studies in other countries show that there could be indoor pollution profiles and features that are specific to office environments. People spend significant amounts of time at the office, and the air they breathe can impact not just their health but also their on-job performance. Therefore, responding to demand from public authorities and environmental health and safety agencies, in 2013 the OQAI launched a national-scale office building survey (Mandin et al., 2012).

The data collection campaign, set to cover all of France, is running until 2016. It focuses on a sample population of 300 buildings, and is designed to representatively cover as many different office-space configurations as possible. The campaign is coordinated by the CSTB with technical mobilization and on-the-ground logistics support from an array of partner teams, field investigators and laboratories deployed across France.

The campaign will serve to provide a state-of-play inventory of office buildings in France in terms of both indoor environment quality and occupant comfort and health. The stakes and issues involved, given the amount of time much of the French population spends at the office, make the OQAI's new "office spaces" campaign a major step forward for occupational health risk assessment and prevention efforts.

Furthermore, with issues tied to reducing energy demand high on the agenda, especially in the building sector, the campaign extends to recording the energy efficiency of the office buildings surveyed.

The campaign is deployed in two phases:

- Phase 1, 300 office buildings, 2013 to 2015 including an all-day survey to: a) collect the data on the building, its envelope, facilities and immediate environment, b) measure various air quality parameters (volatile organic compounds, aldehydes, ultrafine particles, plus temperature, relative humidity and CO_2 concentrations); and c)

poll the occupants on their perceptions of in-building health and comfort. A team of 3 investigators is mobilized for this day-long effort.

- Phase 2, starting in 2016, focusing in on a subsample of 50 office buildings, to drill down deeper into the data collected during phase 1. Phase 2 will analyze a new subset of air quality parameters: fungal and bacterial contamination; man-made mineral fibres and asbestos fibres (if found under the phase 1 survey); and cat, dog, and mite allergens. Noise measurements and light levels will also be measured during the week-long field survey.

Phase 1 was launched in June 2013. The results will be analyzed and unveiled in 2016.

In the meantime, the early emerging trends in air quality and occupant comfort in new or recently-retrofitted office buildings will be published in 2014 under the European OFFICAIR project (www.officair-project.eu). The OQAI coordinated and led the French strand of this work, in 21 office buildings (Dijkstra et al., 2014; Mandin et al., 2014c).

5 ENERGY-EFFICIENT BUILDINGS: FULLY COMPREHENSIVE DATASETS ON ENERGY-EFFICIENT BUILDINGS

Since 2008, OQAI has launched a program dedicated to energy efficient building aiming at evaluate the indoor environment and occupants' habits in these new buildings with reinforced airtight envelope.

A first study was carried out in seven energy-efficient newly built houses before and during the houses' first year of occupancy (Derbez et al., 2014a). It provided the indoor concentrations of some pollutants such volatile organic compounds (VOCs), aldehydes and particles and made possible to find some hypotheses concerning the pollutants sources. The monitoring of IAQ and occupant comfort over time was extended by two supplementary years in two of these houses (Derbez et al., 2014b). IEQ was generally acceptable over time except when ventilation systems were shut down. The ventilation systems presented some shortcomings, including the failure to reach the designed exhaust air flow rate and induced occupant dissatisfaction. Regarding the measured pollutants, houses didn't present any specific indoor air pollution. The variability of indoor air quality over time was explained by the high emissions from the new building materials, products, and paints during the first months after completion and then more episodically by human activities during occupancy. Regarding the thermal comfort and even if occupants were globally satisfied, overheating and under heating were observed.

Based on this first experience, the OQAI is heading the deployment of a unique platform in France developed to collect indoor air quality and occupant comfort data in newly-built or freshly-refurbished buildings (Derbez et al., 2014c).

The objective is to populate a dedicated database with all available information on energy-efficient buildings. This is to be achieved by proposing a harmonized protocol targeted at the public-sector agencies and private-sector organizations tasked with measuring air quality in these buildings.

Within the framework of its "Energy-efficient buildings" agenda for action, the OQAI is deploying a data feedback and information sharing platform named "OQAI – ENERGY-EFFICIENT BUILDINGS". This platform is open to all public-sector agencies and private-

sector stakeholders with an interest in assessing indoor air quality and occupant comfort in buildings that meet the latest building regulations on thermal performance.

The purpose of this platform is to provide support tools for the deployment of new-build projects and decisions on thermal efficiency retrofit options, to help identify the steps to be taken and optimize the transitional retrofitting of existing building stock.

It is grounded in the principle of steadily building up a common pool of data, obtained through the deployment of a "harmonized measurement, collection and transfer protocol" developed by the OQAI with input from its network of science and technology partners.

This "harmonized protocol" spans the entire data collection and sampling strategy in order to systematically characterize a panel of indicators on indoor air quality and occupant comfort in energy-efficient buildings. The protocol-compliant data thus collected is transferred into a national reference database run by the OQAI, and the output provided to ministries and government agencies.

A hundred-plus operations are already on-going in several regions of France, notably under impetus from the PREBAT programme, thanks to backing from the ADEME [French environment and energy management agency] and local-level co-financers. These first-wave operations are deployed by AASQA [local air quality monitoring authorities], CEREMA [national technical centre for risks, environment, and infrastructure planning], INERIS [national institute for industrial environment and risks], universities, consultants, etc.

6 DECISION SUPPORT TOOLS

The development of decision support tools, such as indoor air quality indicators or predictive indoor air pollution models, is the focus of a dedicated OQAI action programme.

Since 2006, the OQAI has been leading work to produce composite indoor air quality indexes capable of giving an intuitive snapshot of the full range of indoor air pollution geometries, not just to yield a fresh information tool but also to facilitate building/facility management. The first step - compilation of an inventory of the air quality indexes available in France and the international arena in 2006 - showed that existing indexes associated occupant symptoms not just with indoor air quality but also the quality of the wider indoor environment.

In 2007, CSTB conducted a survey to gain insight on the perceived incentives and disincentives of using indoor air quality indexes among facility managers (residential, tertiary-sector and school buildings), institutional clients, and other key people. The conclusions suggested that indexes held potential for sparking awareness of the indoor air quality issue, which at the time was still poorly understood and plagued by misconceptions. Indexes were believed to be a way to gauge the scale of the problem, from both an environmental perspective and a health safety standpoint. However, they were also perceived as a threat carrying an array of risks, not just in terms of health but also on the social, psychological, economic and legal fronts, all of which could incur the liability of the building managers if the indexes are 'negative'.

In 2009, the OQAI developed an indicator to qualify the level of stuffiness of the air in a classroom (schools) or activity room (day-care centre) while children are present: index of air stuffiness in schools, acronymed "ICONE". ICONE takes into account both the frequency and intensity of CO_2, which are measured over a minimum period of one week while children are

present (Ramalho et al., 2013). The ICONE rating ranks stuffy air on a scale of zero to five: 0 is non-stuffy air (CO_2 concentration under 1,000 ppm 100% of the time) and 5 represents an extreme stuffy air condition (CO_2 concentration over 1,700 ppm 100% of the time). An indicator device was also developed in order to provide a visual cue at all times to allow management of open doors and windows to achieve the best balance between satisfactory indoor air quality and superfluous energy expenditure. OQAI is currently finalizing a new device to measure and visualize the air stuffiness in housing, after the final test results came in from trial-volunteer occupants.

Beside these developments, a first exploratory study assessing the social–economic cost of indoor air pollution in France has been conducted (Kopp et al., 2014). This research, led jointly with the Université Paris–Sorbonne, ANSES and the CSTB, was conducted on six pollutants: benzene, trichloroethylene, radon, carbon monoxide, particles and environmental tobacco smoke. Based on the method used, the French social cost of indoor pollution, described by the six pollutants, would be of the order of € 19 billion for one year. While these results have to be considered as a first estimation due to assumptions taken into account, it appears that the magnitude of these costs is significant and that the particulate matters make up a major part.

7 KNOWLEDGE FOR OUTREACH

OQAI-acquired knowledge and insight is widely extended through science outreach to industry and the wider public.

An illustrative example is the research used to construct the inventory of French and international data on indoor air quality, which is regularly updated and downloadable directly from the OQAI website (www.oqai.fr).

The OQAI also shares its knowledge through extension and outreach service programmes undertaken jointly with the building sector, the health community, and the wider public. The OQAI workshops offer a forum for various audiences to voice opinion on the issues covering topic areas: socio-economic costs due to IAQ (2014), IAQ in schools (2013), Photocatalytic air purification (2012), the potential of botanical air filtration (2010), Ventilation at home (2008), etc..

Since 2003, OQAI has hosted conference seminars, which serves as a regular forum for dialogue with building air quality sector professionals. The OQAI has followed up each of these conference seminars with papers and reviews keynoting the discussions.

8 CONCLUSIONS

Over the course of a decade of research, the OQAI has acquired a unique body of knowledge and insights into the living spaces and venues where the French spend most of their time: the wealth of information can be harnessed to describe living spaces at building-type scale and hence across the entire occupant population, while integrating the full range of real-world occupancy settings and scenarios. This reference data is used by health risk assessors to inform on exposure levels in populations where representative data is often notably lacking, and by community facility managers to forge public policy such as the mandatory monitoring of indoor air quality in public buildings and labelling of construction products, floorings, wall coverings, paints and varnishes regarding their volatile pollutant emissions.

However the task is far from complete, as there is still only a fragmentary understanding of indoor air quality and its driving factors in a significant proportion of our living spaces. Effective countermeasures to guard against at-risk situations will hinge on gaining a deeper understanding of these spaces.

Every day sees new construction materials and new building products and fittings hit the marketplace, yet experience teaches us that new products sometimes cause unforeseen problems for indoor air quality. The building industry is continually adapting and readapting, especially now that greenhouse gas mitigation policy has the building sector in its sights. The construction sector is set to make a major contribution on rational energy use, bringing with it radical shifts that should be tightly monitored to stay a step ahead of any potential impacts on indoor air quality, occupant comfort and health.

The holistic approach strategy that OQAI adopted from the outset to survey living spaces has given shape to a one-of-its-kind research programme producing unique insights into building technical performances, building equipment and their immediate environment, and unique research output on the occupants, their patterns of behaviour and their perceptions of the spaces they live in. Indeed, OQAI-led research has demonstrated how occupants play a major role in shaping indoor air pollution levels, largely through their behaviour patterns that will either worsen (smoking, using cleaning agents and DIY products, odour neutralizers, etc.) or improve (regularly airing rooms) their indoor environment. If we are to learn to build healthy, comfortable buildings, it is vital to gain a more fine-grained understanding of occupant usage patterns, needs and perceptions of the living space they evolve and interact with.

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