Impact of construction stages on Indoor Air Quality

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ABSTRACT

Since the turn of the century, alarming data produced by the Indoor Air Quality Observatory (OQAI) have led to changes in French legislation, including, most notably, the introduction of compulsory labelling for construction products (decree no. 2011-321 of 23 March 2011). The suppliers of internal finishes (soft floors finishes, paints) now aim to reduce the pollutant emissions from their products, and designers such as architects and engineering consultancies promote a high level of indoor air quality through the careful selection of finishes materials and the efficient design of ventilation systems.

Despite these developments, many uncertainties remain with regards to the impact of the construction steps on the indoor air quality levels achieved in the in-use final constructed building: material and ductwork storage conditions (exposure to moisture, dust), composition of the laying and bonding products (primary, gaskets, sealants, etc.).

At the same time, recent energy performance regulations have obliged planners to make buildings more airtight. Although this has certainly helped to reduce energy consumption and improve users' comfort, it poses a challenge insofar as the management of humidity during the construction phase is concerned. Indeed, during construction, buildings are not mechanically ventilated at all. As a result, the water vapour produced as various materials dry (especially concrete) cannot be expelled. It is no coincidence that industry experts and professional bodies (Construction Quality Agency) are reporting the growth of mould on various materials (insulation, drywall, paint etc.) with greater frequency.

The objective of the CHAllenges with Indoor Air Quality during Building Construction (ICHAQAI) scientific project was twofold: firstly, to identify and characterize the different elements that can have a detrimental impact on the indoor air quality during construction; secondly, to propose solutions that will enable professionals to reduce the negative impacts of construction on the indoor air quality of the future constructed building 'in-use'. Measurements were performed on two representative projects, including chemical and microbiological analyses of dust sampled from ventilation ducts, and complete indoor air quality analyses after each construction stage. Finally, remediation solutions were proposed, including ventilation products protection, and provisory ventilation solutions for construction stages.

KEYWORDS

Indoor air, construction, humidity, fungal contamination, airtightness, volatile organic compounds, VOC, semi-volatile organic compounds, SVOC, particles, measurement, recommendations

1 INTRODUCTION

Indoor air quality is now a major public health concern. Although the entire construction industry has become increasingly good at taking energy requirements into account, health issues remain a little-known subject for most building professionals. In France, alarming data produced by the Indoor Air Quality Observatory (OQAI) since the 2000s have led to changes in legislation intended to encourage disclosures to various stakeholders. This includes the introduction of compulsory labelling for volatile pollutant emissions in construction and decoration products (decree of 23 March 2011[(1)]). Such labelling added to the development of environmental labels has raised the construction industry's awareness of the health impacts of chemical contaminants.

Despite these changes, there is still some uncertainty over the impact of construction phases on future indoor air quality: materials storage conditions (exposure to dust and humidity), potential chemical reactions between products, the impact of humidity levels on volatile organic compound emissions from materials, etc. If we look beyond the emissions specific to each construction product, questions are being raised on construction processes: transportation and storage (impact of weather conditions), construction procedures and assembly of various products, construction sequencing and compliance with drying times, etc.

The CHAllenges with Indoor Air Quality during Building Construction (ICHAQUAI) study examined these issues. With support from the French Environment & Energy Management Agency (ADEME), the project brought public health researchers and construction professionals together to meet two goals: first, to increase knowledge by researching contamination factors specific to the construction phase, and secondly, to provide solutions for construction professionals. The project will come to a close at the end of 2018 when a best practices guide for construction industry stakeholders will be produced.

The various findings of the ICHAQAI project raised questions about the lack of ventilation in buildings under construction. Natural ventilation, through open doors and windows, is the only way that humidity and most contaminants are removed once buildings are airtight. Confinement conditions vary, depending on the circumstances at each construction site, and pollutants may accumulate or disorders related to excessively high humidity may arise. The first section of this article covers these issues.

Although limiting contaminant emissions from construction materials is crucial, a regular influx of fresh air is equally important for future building occupants. The transportation, storage, installation and balancing stages for ventilation systems are therefore critical for ensuring high-quality indoor air once buildings are in use. Specific findings on ventilation system installation are outlined in the second section.

2 PROBLEMS ASSOCIATED WITH A LACK OF VENTILATION DURING CONSTRUCTION

During the construction phase, no particular ventilation is provided. Once installed, the final ventilation systems only begin operating at the very end of the construction phase. This is to prevent any wear and tear or possible contamination of the equipment.

Once external woodwork has been installed and the building envelope is completed, all further work is carried out in an airtight space. Air exchange only occurs through leaks in the building envelope or if the windows are opened. Nowadays, leaks are significantly reduced due to improvements in building energy performance (required under thermal regulations). Natural ventilation for buildings in the construction phase varies widely, depending on the circumstances and potential intrusion risks, employee work practices, etc. In many situations, natural ventilation remains limited, which concentrates humidity and pollutants resulting from the various forms of work performed. This creates direct risks for worker health and indirect risks for future occupants.

The ICHAQAI project monitored and measured indoor air quality during the construction phases of two new buildings. With respect to chemical contaminants, concentrations of volatile organic compound emissions (VOCs) varied substantially depending on the type of work carried out. Continuous measurement, carried out using electronic metal-oxide microsensors (Hager Services Fireflies measuring station), revealed that using ventilation systems is effective: for each building, the start of the ventilation system just before delivery significantly reduced total VOC concentrations (see Figure 1). Furthermore, a comparison could be made between both work sites, which had very different aeration conditions and construction sequences. On the second site, windows were regularly opened by workers, and the activities did not overlap: the total VOC concentrations had been 75% fewer compared to the first site which was confined and with tighter deadlines. Special attention to air change conditions on construction sites could therefore have a substantial impact on worker exposure to chemical contaminants. Because some porous materials (textiles, acoustic insulation, wood panels) adsorb and desorb VOCs, improved air change during the construction phase may also result in cleaner air for future occupants.

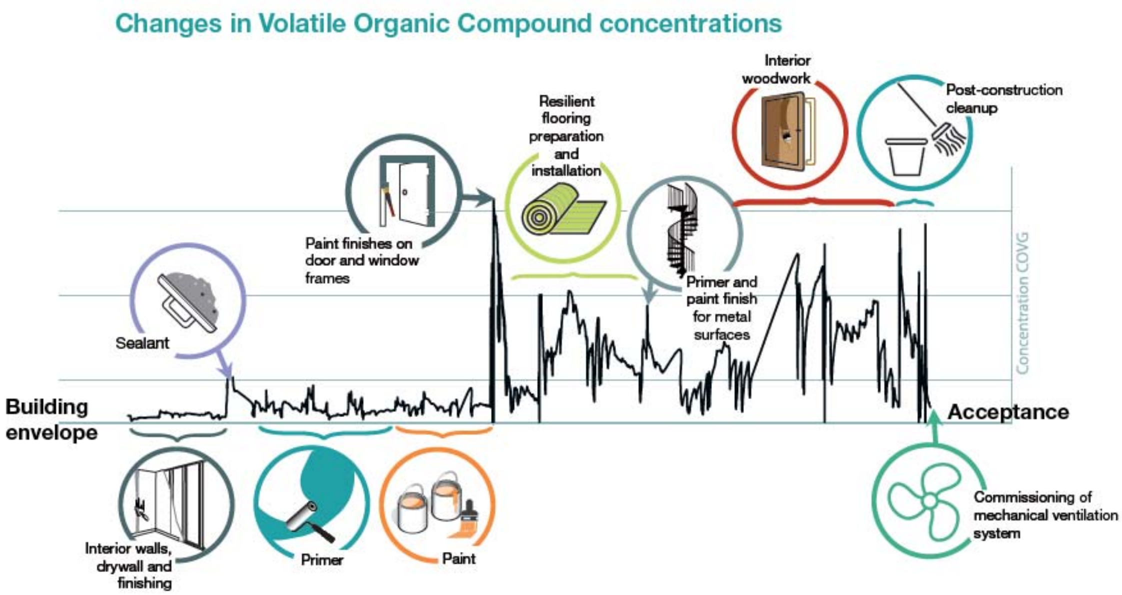

Figure 1 – Changes in Total Volatile Organic Compound (TVOC) Concentrations

Building confinement during construction can also lead to disorders caused by high humidity levels. Many tasks carried out during the construction phase produce water vapour. Once building envelopes are airtight, if there is no ventilation during the construction phase, this water cannot escape, providing ideal growing conditions for the mould that is naturally present in the environment. When fungal contamination is detected in a work site (such as on drywall – see Figure 2), it is rarely dealt with appropriately. Drywall is typically sponged clean with bleach and then painted. Since the material is porous, the mould remains and may reappear when the building is in use. Replacing the affected drywall would be the most effective solution, with obvious economic and operational consequences.

Figure 2 – Mould growth on drywall during the construction phase

The REX Bâtiments Performants[2] study, led by Agence Qualité Construction with support from the PACTE Programme, ADEME and the French government, helped identify mould growth on new construction and renovation sites. This programme, which began in 2010, has been implemented in more than 1,000 buildings in France. The reasons for mould growth varied, depending on the circumstances. Mould sometimes appeared on visible surfaces, and in these cases it was generally treated before the buildings were delivered. Sometimes the growth occurred on non-visible materials (behind wall panels). In both cases, there remains a possibility that mould could grow, resulting in persistent health hazards when the building is in use. Once the building is operational, conditions such as excess humidity and insufficient air exchange could cause any pre-existing mould on porous materials to re-emerge.

The ICHAQAI project measured temperature and humidity on two new-building construction sites, starting from the phase when the building becomes airtight until it is accepted. On both test sites, an analysis of relative humidity variations revealed periods in which indoor humidity was greater than outdoor humidity. In general, humidity levels within buildings were high (always higher than 70%), even when weather conditions caused outdoor humidity to plunge. Periods in which linings and partitions were installed had indoor humidity levels that were particularly conducive to mould growth (see Figure 3). Measurements taken through impaction analysis at this stage of the construction project confirmed these changes.

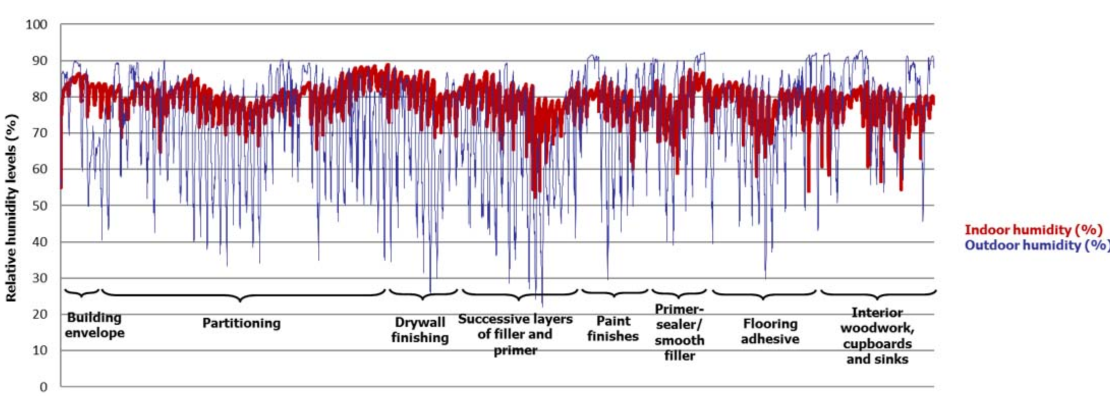

Figure 3 – Changes in relative indoor and outdoor humidity levels

The ICHAQAI project worked to identify sources of humidity in buildings during construction. This research highlighted the variety of possible causes: evaporation of water from the drying of concrete, masonry components, paint and fillers; exposure of materials to rain or humidity; water leakage or delayed installation of stormwater drains; significant water evaporation when installing concrete topping; etc.
Tighter construction deadlines may result in materials and products being given less time to dry, or even in beginning finishing work too early. However, the quality risks related to heightened humidity on work sites are real: warped wood (timber frames, interior woodwork), buckling of surface finishes (especially resilient flooring), cracks in paint finishes, deterioration of thermal performance if insulation is exposed to humidity, mould growth on materials containing cellulose or other bio-utilizable substrates and higher VOC emissions. The impact of relative humidity on VOC (especially formaldehyde) emissions is well documented. Huang and al.[(3)] demonstrated a linear relationship between a material's initial formaldehyde emissions and its relative humidity exposure.
Various solutions have been proposed to stakeholders in the construction industry to reduce risks related to excessively high humidity, including: standards of professional practice (especially on drying times), careful storage of materials sensitive to humidity, monitoring of hygrothermal conditions or even the use of active drying solutions for buildings (mechanical ventilation systems specifically for use in the construction phase, heating or dehumidifying).
Any active solutions nevertheless need to be adjusted to suit the circumstances of each construction project. While heating and dehumidification provide significant economic gains for builders (due to shorter construction schedules), excessive drying could also result in technical failings, such as shrinking or cracking concrete, cement and concrete toppings.

3 VENTILATION SYSTEM INSTALLATION PROCESS

Now that buildings are better insulated and more airtight than in the past, ventilation systems have become critical for reconciling energy efficiency and indoor air quality. They help control and optimize air exchange in order to limit energy loss. At the same time, they ensure sufficient fresh air intake for occupants.
However, in France, installed ventilation systems have repeatedly been found to be non-compliant. According to a study published by the Indoor Air Quality Observatory in June 2009,[(4)] approximately 50% of houses with mechanical ventilation systems do not meet regulatory requirements for total air extraction. According to an ORTEC[(5)] study carried out on 1,500 new homes between 2005 and 2009, 50% of buildings tested do not meet installation requirements meant to ensure ventilation systems work properly. During installation phases, professional standards are not always followed for various aspects, including: load loss limitation, air sealant, insulation on ducts that pass through unheated areas, access to systems and equipment, ease of maintenance, balancing and verification of air exchange rates before delivery, etc.
Although the ICHAQAI project recognizes the absolute necessity of following professional standards when implementing ventilation systems, the measurements were taken to assess the risks of system and equipment contamination during construction. For example, ventilation systems often get dusty during storage and installation, and are also exposed to substantial humidity. This dust can become an ideal breeding ground for mould. When buildings are in use, there is a real risk of dust backflow contaminated by semi-volatile organic compounds (SVOCs) or by similar micro-organisms, especially if the ventilation system is also used for fresh air intake (dual flow system).
In order to evaluate the risk of contaminants being transferred into the premises, dust was gathered from within installed ventilation systems and, once the buildings were in use, from

indoors. The dust settled inside ventilation ducts was collected using swabs and cloth wipes. This dust was analysed for fungal contamination and chemicals to identify any adsorbed SVOCs.
The dust in the indoor air was gathered using a MicroVol device, which measures particulate matter (PM) using pre-weighed filters. After a 72-hour sampling period, the filters were sent to a laboratory to analyse the adsorbed SVOCs.
Analysing dust from ventilation ducts revealed the presence of mould in certain samples. The results of the adsorbed SVOC analysis are presented in the table below.

Table 1 – SVOC analysis and comparison of dust gathered inside ventilation networks and the premises

Dust sampled from inside ventilation networks (settled inside ducts)	**Dust sampled inside the premises (present in the air)**
Presence of anthracene, benzo[b]fluoranthene, fluoranthene, fluorene, phenanthrene and pyrene	Presence of anthracene, benzo[b]fluoranthene, fluoranthene, fluorene, phenanthrene and pyrene

The fluoranthene, fluorene and phenanthrene most probably came from oils and degreasing solvents used in the factories where the ventilation ducts were produced. Except for networks intended for use in hospitals, air ducts are not cleaned when they leave the factory, nor are they capped to protect them during transportation and storage. The presence of these SVOCs make it easier for dust to accumulate on duct surfaces.
Finally, with respect to SVOCs adsorbed into dust in indoor air, significant concentrations of Triclosan were found during the delivery phase of each construction site. Triclosan is an antibacterial and antifungal agent. It is suspected of being an endocrine disruptor and of promoting antibiotic resistance. In a national study carried out on 285 homes[6] in 2016, Triclosan was found in nearly all samples, and identifying where it came from proved problematic. Therefore it would appear that Triclosan is present in construction products and materials, since it has been found in samples taken at the end of construction. However, Triclosan has been banned for use in the treatment of construction products and materials since a decision made by the European Commission on 24 April 2014.[7]

4 CONCLUSIONS

With its research into factors affecting indoor air pollution during the construction phase, the ICHAQAI study was decidedly exploratory in nature. Its findings indicate that there is a need for increased awareness in the construction industry about potential health impacts. Future air quality does not depend entirely on emissions related to each construction product. Instead, it is also closely related to all project parameters, including: construction deadlines, construction sequencing, product combinations, hygrothermal conditions, etc.
Although these measurements show that VOC concentrations quickly fall when spaces are aired out or ventilation systems begin operating, health authorities are becoming increasingly concerned with mould growth. Clear links have been established between respiratory difficulties and the presence of mould in occupied spaces. We cannot rule out the possibility that mould present in the construction phase may re-emerge when buildings are in use, if conditions are conducive to mould growth. This observation raises questions about all construction processes, and every participant in the construction chain is concerned, up to and including principal contractors and decision-makers.
Finally, proper installation of ventilation systems and equipment has emerged as a key issue for health and energy efficiency. Air quality, which does not receive much attention in the field,

should be prioritised as much as clean potable water. That is, serious attention should be paid to compliance with installation rules, airtightness of systems, type of caulking used, protection and cleaning of systems before the acceptance stage.

5 REFERENCES

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