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**Contributed Report 12**

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# Foreword by the AIVC

The primary purpose of ventilation is to guarantee a good indoor climate inside buildings. Although ventilation systems are widely used in all countries, there is relatively limited statistical representative information available on the indoor climate in buildings.

In that context, the French Observatory on Indoor Air Quality (OQAI) is an interesting initiative. It aims at collecting data on population exposure to indoor pollutants in various indoor environments. Accordingly, OQAI undertook a national survey in order to assess the air quality inside the French dwellings. A large amount of information has been collected from 567 dwellings (1612 individuals questioned), representative of dwellings in France. This report gives an overview of the work of the French Observatory on Indoor Air Quality.

# Indoor air quality in French dwellings

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**SUMMARY**
Set up by the French authorities, the Observatory on Indoor Air Quality (OQAI) aims at collecting data on population exposure to indoor pollutants in various indoor environments. Accordingly, OQAI undertook a national survey in order to assess the air quality inside the French dwellings. A large amount of information has been collected from 567 dwellings (1,612 individuals questioned), representative of dwellings in France. This snapshot of indoor pollution focuses on more than 30 variables (chemical, biological and physical). Before beginning to analyze key data, quality control information must be exploited to define the final data set. Inter-laboratory comparison and designed experiments were undertaken to provide the highest confidence level in the final data set. The first results show differences between indoors and outdoors. Most of the target compounds were found in most of the dwellings surveyed. Pollution in homes is not homogeneous: some homes had indoor pollutant concentrations much higher than the median concentrations observed. Approximately one dwelling in 10 had simultaneous high concentrations of several volatile organic compounds (VOC), while inversely 45% of dwellings had low concentrations of all target VOCs. Attached garages had higher VOC levels than the dwellings themselves. House dust mites constitute the most frequent source of allergens.

**KEYWORDS**
Indoor air exposure, VOC, allergens, radon, carbon monoxide

**INTRODUCTION**
Our lack of understanding of the health risks related to air pollutants exposure in buildings is perceived as a major deficiency, even though 80% of our time is spent indoors. In this context the Observatory on Indoor Air Quality (OQAI) has been set up by the French authorities to collect data on population exposure to indoor pollutants in various indoor environments (dwellings, schools, offices, sports and leisure centers, etc.) to be used for public policies development. Accordingly, OQAI undertook a national survey on indoor air quality in dwellings with a four-fold objective: (1) to compile a descriptive inventory of indoor air quality in dwellings (2) to identify high-risk situations by estimating the exposure of populations occupying these premises (3) to draw up an initial list of parameters influencing the presence of this pollution (sources, type of housing, ventilation, human activities, seasons, geographical situation, etc.) (4) to generate advice and guidelines in order to improve indoor air quality in dwellings.

## METHODS

### 1. Sampling from dwellings

The large number of measured pollutants, the poor knowledge of expected concentrations and the large variability of housing conditions and households, have made it necessary to select inquiry locations using a **random method for objectively drawing inquiry units everywhere in mainland France** (Golliot et al. 2003).
A **three degree survey** was conducted, such that **each main residence has the same final probability of being drawn at random**:

- random draw of communes in proportion to the number of main residences in them, communes with more than 100 000 main residences (Paris, Marseille, Lyon, Toulouse, Nice, Nantes, Strasburg, Montpellier, Bordeaux, Rennes, Lille) being selected with certainty;
- random draw of land registry sections (in communes drawn at random in the previous step) in proportion to their number of main residences;
- random draw of a main residence by land registry section (data collection base: General Tax Directorate Rates File for main and secondary residences). For about ten communes, the final step was done in the town hall by investigators from the CREDOC (Research Centre for Study and Observation of Living Conditions), using land registry maps.

One advantage of the method used is that it concentrates dwellings on which inquiries are to be made to geographic sectors (communes and land registry sections), rationalising travel costs and so that a simple random sample of households can be created in a particular land registry section.
As a result of the number of refusals observed, an additional sample of dwellings based on the initial protocol was used in some land registry sections.
Households were thus recruited based on **6268 addresses drawn at random**, **4165 households were contacted**, **811 gave their agreement** to participate representing an **acceptance ratio of 19.5%**, and **567 participated** in the national survey representing a **participation ratio of 13.6%**.
The final sample is composed of **567 dwellings investigated between October 1 2003 and December 21 2005,** distributed in 74 communes.

The geographic distribution of investigated main residences is presented in the following maps, making a distinction between dwellings included in the inquiry between October and April (370 main residences namely 65.3% of the sample) and dwellings included in the inquiry between May and September (197 main residences namely 34.7%).
The inquiries are distributed in time as shown in the following diagram (Figure 3).

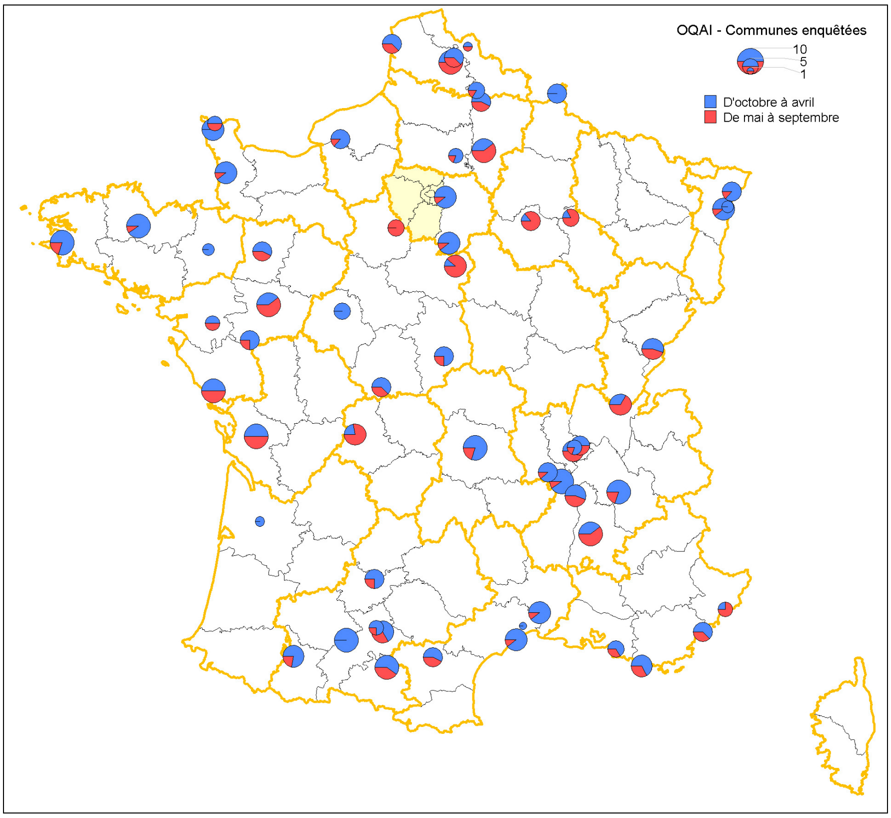


Figure 1:  Geographic distribution of dwellings included in the inquiry in the national survey

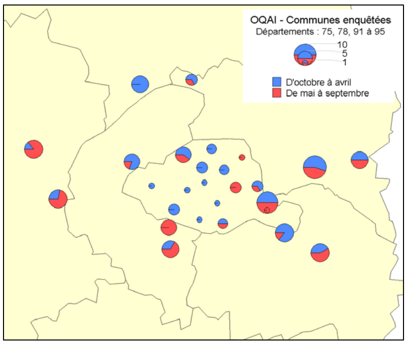


Figure 2:  Geographic distribution of dwellings included in the inquiry – detail for the Paris region

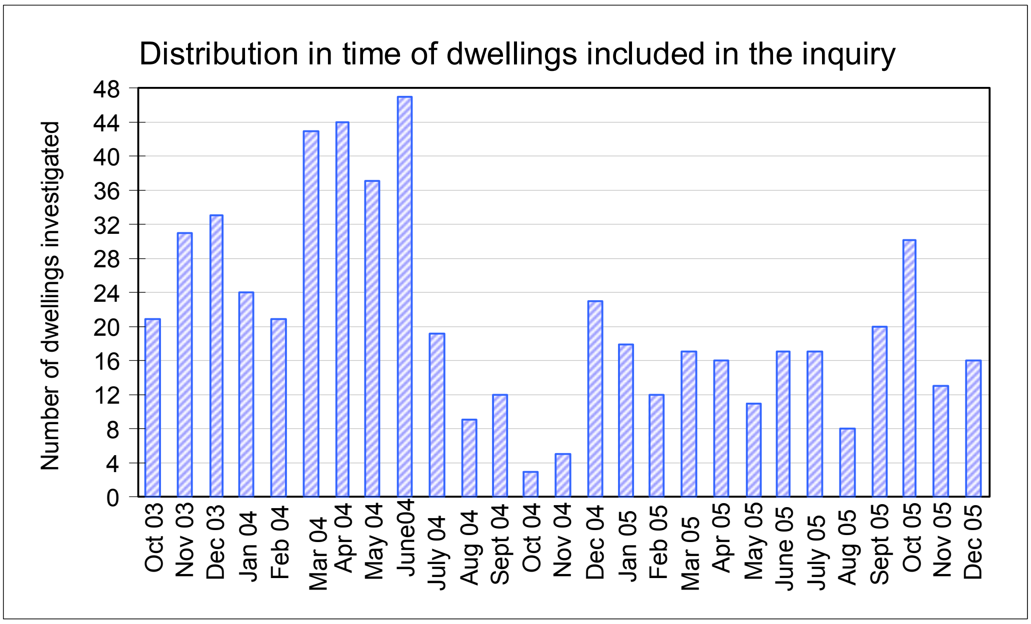


Figure 3: Distribution of dwellings for each month of the inquiry

**Correction to the final sample**

A correction to the final sample was made so that it can be representative of all main residences in mainland France. This consisted of creating distributions of known variables on all main residences by weighting (as a number of main residences).

The correction variables are:

- the dwelling type *(detached house, dwelling in an apartment building, home for elderly persons, farm or agricultural enterprise, dwelling in a building other than a residence);*
- the construction period *(before 1871. 1871-1914. 1915-1948. 1949-1961. 1962-1967. 1968-1974. 1975-1981. 1982-1989. 1990-1995. starting from 1996);*
- the dwelling occupancy status *(owner, tenant, leaser or sharecropper, free housing);*
- the commune sampling region *(Paris region, Paris basin, North-Pas de Calais, East, West, South-West, Centre-East, Mediterranean);*
- the urban unit size range *(rural commune; urban unit with fewer than 5 000 inhabitants, from 5 000 to 9 999 inhabitants, from 10 000 to 19 999 inhabitants, from 20 000 to 49 999 inhabitants, from 50 000 to 199 999 inhabitants, from 200 000 to 1 999 999 inhabitants, Paris urban unit);*
- the winter weather zone;
- the summer comfort zone.

The correction was made using the CALMAR method (Sautory, 1993). This provides a means of starting from the initial weighting of main residences included in the inquiry, and estimating the new weights to achieve target margins while minimising the difference between the final weights and the initial weights. The selected fixing option is the *truncated logit* method that has several advantages:

- final weights are always positive,
- the ratio of the final weight to the initial weight is bounded by lower and upper limits.

The initial weight is the inverse of the genuine probability of being included in the sample, deduced from the initial draw probability and the response rate in the sampling stratum.

The sum of the initial weights is equal to 24 672 135 main residences. The final weight to initial weight ratio is between 0.3 and 2.5.

The sum of the final weights obtained is equal to the sum of the initial weights. The final margins of the sample weighted on the correction variables are perfectly equal to the margins calculated on the total population of the main residences.

## 2. Data collected

Collected data quality is crucial in order to correctly assess population exposure and provide full data interpretation. Quality control was first initiated at the design of sampling protocols and choice of techniques and instrument. It was pursued with formation of technicians, who put designed protocols into practice and ensured correct transfer of monitored data to the database (Bus et al. 2005). Associated laboratories conducted also daily quality control on samples storage, analysis and transfer of final results to the database. Finally, the database manager ensures quality control by tracking subsisting incoherencies and errors throughout the database. To resume, quality control occurs before, during and after each measurement.

The pollutants measured in the context of this survey were chosen on the basis of a classification of indoor air pollutants developed by the OQAI and based on short and long-term toxicity criteria as well as the frequency of their presence in dwellings (Mosqueron et al. 2003). Some thirty chemical, physical and microbiological air pollutants were measured: carbon monoxide (indoor and exhaled concentration), 20 target volatile organic compounds (benzene, ethylbenzene, m/p/o-xylenes, 1,2,4-trimethylbenzene, styrene, n-decane, n-undecane, trichlorethylene, tetrachloroethylene, 1,4-dichlorobenzene, 1-methoxy-2-propanol and acetate, 2-butoxyethanol and acetate, formaldehyde, acrolein, acetaldehyde, hexaldehyde), allergens (from dogs *Can f 1*, from cats *Fel d 1*, from dust mites *Der f 1* and *Der p 1*), radon and gamma radiation, particulate matter ($PM_{10}$ and $PM_{2.5}$). Comfort parameters (relative humidity, temperature, carbon dioxide, exhaust airflow rate) are also measured. Different questionnaires provide characteristic data from investigated sites (building environment, furniture and equipments, rooms' description…), occupant's description, time activities diaries and allergic and respiratory symptoms.

A quality control system was set up for field sampling strategy and laboratory analysis. Technicians followed these protocols throughout the campaign and provided a quality code for every measurement. Quality codes are also provided by the laboratories and by the database administrator whenever errors or incoherencies are detected. There is one valid quality code for numerous non-conformity codes. This valid code means that sampling, transport/transfer and analysis are correct. However, some quality codes mean benign protocol deviation and data can therefore be considered exploitable for future analysis.

### a. Measurements

The measurement protocols of the 30 key indoor pollutants are presented hereafter, along with comfort parameters measurements.

#### - Allergens

Cat and dog allergens (respectively *Fel d 1* and *Can f 1*) were measured in the living room by collecting suspended particulate matter on 37 mm diameter glass microfibre filters (Millipore). The measurement was realized during one hour at 20 litres per minute on three different filters (triplicates). Analyses were conducted at Hôpitaux Universitaires de Strasbourg (HUS) following the immuno-enzymatic ELISA method, a non amplified sandwich method using specific monoclonal antibodies. Limits of detection were 0.18 $ng{\cdot}m^{-3}$ (*Fel d 1*) and 1.02 $ng{\cdot}m^{-3}$ (*Can f 1*). Extended uncertainty for the sampling was determined to be ± 111% (*Fel d 1*) and ± 75% (*Can f 1*). Analytical extended uncertainty was much lower, about ± 26% (*Fel d 1*) and ± 21% (*Can f 1*).

Dust mite allergens (*Der f 1* and *Der p 1*) were measured in the collected dust by a vacuum cleaner from the bedroom mattress belonging to the reference occupant. Vacuum cleaner bags were then sent to Hôpitaux Universitaires de Strasbourg (HUS) for analysis, following the immuno-enzymatic ELISA method [8]. Limits of detection were 15.8 $ng{\cdot}g^{-1}$ (*Der f 1*) and 26.4 $ng{\cdot}g^{-1}$ (*Der p 1*). Analytical extended uncertainty was about ± 29% (*Der f 1*) and ± 25% (*Der p 1*).

- **Carbon dioxide ($CO_2$)**

Carbon dioxide was measured to provide information on confinement and air renewal [9]. Carbon dioxide (along with temperature and relative humidity) was monitored during 7 days (10 min averages) by non dispersive infra-red probe (Q-track, TSI Inc.) in the bedroom. The instrument was verified and calibrated before investigation. Extended uncertainty was calculated to be ± 67 ppm at 1500 ppm target concentration.

Instruments were also yearly calibrated on temperature and relative humidity. These parameters were monitored in the living room as well using Hygrolog sensors (Rotronic).

- **Carbon monoxide (CO)**

Carbon monoxide was monitored during 7 days (5 min averages) by electrochemical sensor (Draeger Pac III) in the living room, outdoors and in each room holding combustion equipment (gas heater, portable heater, etc.). All instruments were verified and calibrated before every investigation. Instrument resolution was 1 ppm although values between -3 and 3 ppm (noise fluctuation) were assumed to be not significantly different from 0. CO profiles presenting negative values lower than -3 were discarded as this indicated a drift in the electrochemical sensor response. Extended uncertainty was found to be ± 4.9 ppm for a target concentration of 50 ppm. The choice of instrument was oriented towards a security system able to warn occupants in case of high concentration of CO that may represent a danger.

Carbon monoxide was also measured in exhaled air of voluntary occupants at least 6 years old. The measurement was performed by means of a FIM CO-Tester Tx. This is an additional measurement added at the request of the Institut de Veille Sanitaire (InVS) to provide population exposure data to environmental tobacco smoke and other sources of carbon monoxide.

- **Exhaust air flow rate**

Exhaust air flow rates were measured in every humid room (kitchen, bathroom, WC) where exhaust openings are present. An array of hot wires (SwemaFlow 233) provides an instantaneous measurement of exhaust air flow rate recorded on a PDA by the technician.

- **Particulate matter ($PM_{2.5}$ and $PM_{10}$)**

Mass concentrations of suspended particulate matter with an aerodynamic diameter below 2.5 µm ($PM_{2.5}$) and below 10 µm ($PM_{10}$) were measured in the living room. The chosen instrument was a model 2100 Mini-Partisol air sampler (Rüpprecht & Patashnick Co., Inc., distributed by Ecomesure), coupled to a ChemPass model 3400 sampling system integrating both $PM_{2.5}$ and $PM_{10}$ PEMS impactor systems operating at 1.8 $L{\cdot}min^{-1}$. Technicians used flowrate calibrator DryCal DC-Lite (Bios International) in the field to check the correct flowrate in both PEMS impactors. The instrument was programmed to sample air during defined occupation hours of the investigation week, i.e. in the evening from 5 pm to 8 am the next day (Monday to Friday) and every time in the week-end. Pre-weighted 37 mm diameter PTFE membranes (2 µm porosity, Gelman Sciences) were used to collect particulate matter and then returned to the Laboratoire d'Hygiène de la Ville de Paris (LHVP), conducting the gravimetric measurement using a 1 µm sensitive electronic balance. Blank filters were left in the field to provide effective detection limit of the method.

- **Radon $^{222}$Rn and gamma radiation**

At the request of the Institut de Radioprotection et de Sûreté Nucléaire (IRSN), Radon and gamma radiation measurements were added to the survey. Passive measurement of Radon volumic activity is performed by accumulating alpha radiation from $^{222}$Rn and his descendants ($^{218}$Po, $^{214}$Po) on a 12 µm cellulose nitrate film (Kodalpha dosimeter) during 2 months. Both bedroom and living room are instrumented. Dosimeters are then sent to Dosirad, the laboratory in charge of the analysis.

External gamma radiation dose rate of cosmic and telluric origin is measured through a gamma radiameter of the Geiger-Müller type (Saphymo 6150 AD6), selecting energies between 60 keV and 1.2 MeV. The measurement stated in $\mu Sv \cdot h^{-1}$ is performed in the living room during 3 to 4 hours.

- **Volatile organic compounds**

Volatile organic compounds (VOC) and aldehydes were collected by radial diffusive sampling [10] onto carbograph 4 adsorbents and 2,4-DNPH coated Florisil respectively. Both bedroom and outdoors are instrumented in each investigated dwelling. After 7 days exposure, adsorbents are sealed and sent to the laboratories in charge of analysis. Two different laboratories (CSTB and Fondazione Salvatore Maugeri (FSM)) perform the identification and quantification of VOC target compounds. Only one undertakes aldehyde cartridges analysis. Adsorbed VOCs were extracted through thermodesorption and analyzed by gas phase chromatography equipped with flame ionization detector and/or mass spectrometry [11]. Aldehyde-hydrazones formed in the cartridge were eluted by acetonitrile solvent and analyzed by liquid chromatography associated with a UV detector [12]. Detection limits were provided by both laboratories and are presented in Table 1.

Table 1. Analytical detection limits of VOCs and aldehydes expressed for a 7 days exposure.

| | Detection limit ($\mu g.m^{-3}$) | |
|---|---|---|
| | CSTB | FSM |
| Benzene | 0.4 | 0.1 |
| 2-Butoxyethanol | 0.4 | 0.2 |
| 2-Butoxyethyl acetate | 0.3 | 0.6 |
| n-Decane | 0.06 | 0.2 |
| 1,4-Dichlorobenzene | 0.03 | 0.2 |
| Ethylbenzene | 0.3 | 0.1 |
| 1-Methoxy-2-propanol | 0.5 | 0.2 |
| 1-Methoxy-2-propyl acetate | 0.7 | 0.2 |
| Styrene | 0.1 | 0.1 |
| Tetrachloroethylene | 0.4 | 0.02 |

| | Detection limit ($\mu g.m^{-3}$) | |
|---|---|---|
| | CSTB | FSM |
| Toluene | 0.4 | 0.1 |
| Trichloroethylene | 0.4 | 0.3 |
| 1,2,4-Trimethylbenzene | 0.02 | 0.1 |
| n-Undecane | 0.5 | 0.4 |
| (m+p)-Xylenes | 0.5 | 0.1 |
| o-Xylene | 0.2 | 0.1 |
| Acetaldehyde | 0.3 | -- |
| Acrolein | 0.1 | -- |
| Formaldehyde | 0.6 | -- |
| Hexaldehyde | 0.1 | -- |

Extended uncertainties were determined for some VOCs at 7 days exposure in indoor environment [13] and range from ± 20% (5 $\mu g \cdot m^{-3}$ benzene or 19 $\mu g \cdot m^{-3}$ toluene) to ± 27% (8 $\mu g \cdot m^{-3}$ m/p-xylene). Another determination of measurement uncertainty of benzene leads to a value of ± 28% for a concentration of 2 $\mu g \cdot m^{-3}$ closer to usual indoor values.

### b. Descriptive data collected by questionnaires

Standardized questionnaires elaborated and tested during a pilot survey conducted on 90 dwellings from March to July 2001 (Kirchner et al. 2002) have been optimized for the national campaign focused on dwellings.

Four categories of questionnaires are used throughout the campaign in addition to the measurement of defined key pollutants. Most of questionnaires present closed questions with single or multiple answers. Quality code can be used in the following cases: no answer, not asked question, refusal to answer.

- **Carbon monoxide questionnaire**: aimed at the detection of poisoning risk from carbon monoxide exposure in dwellings. A risk exists in the following cases:
  - technicians identify defects in the internal combustion installation of the dwelling during the survey,
  - indoor CO level is higher than 60 ppm during the survey week,
  - exhaled CO level is higher than 15 ppm for non-smoker or 35 ppm for smoker,

- **Description questionnaire**: used to detail the characteristics of both dwellings and household inhabitants. This questionnaire consisted of nine parts:
  - a first contact questionnaire in order to collect practical information for the survey organization.
  - a sensory questionnaire to assess initial perceived air quality (completed by the technician).
  - a household questionnaire that describes outdoor environment, building construction characteristics, standard equipment inside dwelling, living and cleaning habits of occupants,…
  - a room description questionnaire that lists for each room, e.g. nature of heating energy, ventilation.
  - system, wall, floor and ceiling coverings, furniture,…
  - a bedding questionnaire providing information on age and size of bed and mattress where dust mite allergens are measured.
  - an individual questionnaire describing all individuals in the household (child caring mode for children less than 10 years, profession and nature of professional exposure, domestic activities, use of cosmetics, tobacco exposure for inhabitants over 10) and gathering results from exhaled CO measurements on voluntary individuals over 6.
  - a retrospective questionnaire to list all particular events that occured during the survey week (use of heating system, cleaning products, air fresheners, cleaning and cooking activities,…)
  - a survey quality questionnaire to know the householder opinion on the quality of investigation the duration of survey,…
  - a household survey form that includes dates of initial and final visit, number of individual questionnaires distributed and the drawed day of daily diary completion.

- **Time-activity diaries:** left to the inhabitants during the week of investigation. Each children and adult must complete two time-activity diaries, one for the survey week (weekly diary) and one for a randomly chosen day of the week (daily diary). Both paper questionnaires are completed to inquire spending time and room location of the inhabitants throughout the dwelling every 10 min. The daily diary details the used room, the activities, the number of occupants at a given time (smoker or not) and the products used.

- **Allergy and respiratory symptoms** for each inhabitant at least 15 years old.

Collect of information by questionnaires is made by technicians who were formed in the same way by CSTB. Six training courses of 4 or 5 days were organized and 50 technicians were formed on the use of survey tools (both questionnaires and measurement protocols of key indoor pollutants). All questionnaires are detailed and technical terms of building or dwelling facilities are described and illustrated.

Three groups of questionnaires are used in the survey (table 2):

- **face to face interview** (FTFI) to collect detailed data when the technician directly communicates with the reference person or each inhabitant,
- **self-administered questionnaire** (SAQ) filled either by the reference occupant or by other individuals,

Table 2. Detailed characteristics of questionnaires

| Questionnaire name | mode of administration | moment of completion | nb of items / questionnaire | nb of items / survey | approximate duration of completion (mm:ss) |
|---|---|---|---|---|---|
| Carbon monoxide | TFQ | after survey | 6 | 6 | 00:30 |
| Description | | | | | |
| first contact | FTFI | before survey | 24 | 24 | 06:00 |
| sensory | TFQ | first visit | 5 | 10 | 01:00 |
| household | FTFI | first visit | 267+10 | 267 + 10 x i | 50:00+06:00 x i |
| room description | TFQ | first visit | 87 | 87 x j | 05:00 x j |
| bedding | TFQ | first visit | 12 | 12 | 01:00 |
| individual | | | | | |
| <10 years | FTFI | first visit | 23 | 23 x k | 08:00 x k |
| 10 years or over | FTFI | first visit | 51 | 51 x (i-k) | 16:00 x (i-k) |
| retrospective | FTFI | second visit | 56 | 56 | 12:00 |
| survey quality | SAQ | after survey | 14 | 14 | 03:00 |
| household survey | TFQ | first visit | 8 | 8 | 01:00 |
| Time-activity diary | SAQ | during survey | - | - | - |
| Health | SAQ | after survey | 50 | 50 x m | 04:00 x m |

i : household inhabitant number
j : dwelling room number
k : household less than 10 years inhabitant number
i-k : household aged 10 or over inhabitant number
m : household aged 15 or over inhabitant number
nb: number

- **Technician filled questionnaire** (TFQ) to acquire objective data of the building or dwelling characteristics by visual inspections.

Each technician used a mobile application, running on personal digital assistant (PDA). This application allows the technicians to collect data through an electronic questionnaire. At the end of each survey, technicians can dump their data into the main database by connecting to the extranet website (Bus et al. 2005). The technician can check that information has been correctly imported into the main database. If electronic questionnaires are modified, surveyors can update the application via the extranet website. Most of questionnaires are electronic and only four stay in paper format (first contact questionnaire, survey quality questionnaire, time-activity diary, health questionnaire). At the moment, only first contact questionnaires have been computerized and sent to database.

Collect of information is mainly made during the survey. At the first visit which lasts approximately 3h30, one of both technicians (tech. 1) completes the survey questionnaires in presence of the reference occupant. The second technician (tech. 2) carries out all room inspection, performs immediate sampling and measurements and sets up continuous measuring instrument.

During 7 days, inhabitants must fill time-activity diaries. After the survey and at the second visit (1h30), retrospective questionnaire is administered and measuring instrument are removed. Time activity diaries are checked, completed and given back to the technicians.

The number of items per survey and the approximate length of time required to complete each questionnaire depend on the number and age of the household occupants and on the number of rooms in the dwelling. For the FTFI questionnaire, the completion duration takes into account the time needed to clarify technical terms, to answer the questions of the inhabitants, etc. Number of items and completion duration for time activity diaries are not indicated since too few items are inquired.

Let us take the example of a household with 2 adults and 2 children of less than 10 years ($i=4$, $k=2$, $i-k=2$, $m=2$) living in a dwelling with a living room, a kitchen, two bedrooms, a bathroom, a independent water closet ( $j=6$ ) and without taking into account time activity diaries.

The total number of items approximately reaches 1200 and is fairly divided between questions asked to occupants (633) and those asked to technicians (568). The majority of questions addressed to the occupants (82 %) is administered by face to face interview.

The time required to complete all questionnaires is estimated to last approximately 3h30. The completion of FTFI questionnaires during the first visit is the longest (approximately 2h20) while 35 minutes are enough for questionnaires filled by technicians.

## 3. Organization of the survey

The survey was coordinated by the OQAI pilot team based at CSTB (Scientific and Technical Building Centre). About 100 multidisciplinary experts from 50 establishments participated to the design of the survey and the data analyzes. About 18 surveyors have collected the data ; 5 laboratories have analyzed the samples. The whole cost of the national survey, including design, field study, data analyses is estimated to be about 12 M€.

## 4. Quality control system (data traceability, quality code and interlaboratory tests)

### a. Quality code

A quality code was associated with every sampling and analysis of a target pollutant. This code allows the validation or reject of collected data to integrate in subsequent statistical analyses. The technician fills all quality codes relevant to sampling, data transfer and questionnaires. The laboratory fills the part relevant to analyses.

The following quality codes were used throughout the survey campaign (Table 3 and 4). They can also be regrouped in different error types:

- protocol error: 1160, 1200, 2110, 2120, 2130, 2140, 2150, 2160, 2170, 2220, 3140, 3500;
- sampling error: 1000, 1330, 3600;
- laboratory error: 3000, 3130, 3210, 3220, 3400, 3710, 3720, 3730, 3740;
- instrument error: 1120, 1131, 1133, 1134, 1135, 3110, 3120;
- transport error: 2210, 4000, 4100;
- other sources of error: 1110, 1136, 1140, 1150, 3300.

Table 3. Quality codes for sampling.

| Quality code | description |
|---|---|
| 60000 | valid sampling |
| 1000 | sampling not valid |
| 1110 | sampling not executable |
| 1120 | sampling instrument defect |
| 1131 | battery problem |
| 1133 | sampling instrument breakdown |
| 1134 | data retrieval problem |
| 1135 | empty data file |
| 1136 | insufficient supply |
| 1140 | sampling not performed |
| 1150 | occupant refusal |
| 1160 | other protocol condition not respected |
| 1200 | instrument calibration not valid |
| 1330 | manipulation error during sampling |
| 2110 | exposure time too low |
| 2120 | exposure time too high |
| 2130 | sampled volume too low |
| 2140 | sampled volume too high |
| 2150 | measurement not required (additional) |
| 2160 | flowrate too low |
| 2170 | flowrate too high |
| 2210 | invalid reception control |
| 2220 | storage temperature not respected |

Table 4. Quality codes for analysis.

| Quality code | description |
|---|---|
| 0 | valid analysis |
| 3000 | analysis not valid |
| 3110 | analytical instrument breakdown |
| 3120 | analytical instrument defect |
| 3130 | calibration error |
| 3140 | other protocol condition not respected |
| 3210 | manipulation error during analysis |
| 3220 | other laboratory problem |
| 3300 | sample not analysed |
| 3400 | sample not exploitable |
| 3500 | storage time too long |
| 3600 | missing information about sampling |
| 3710 | extrapolated data |
| 3720 | insufficient resolution |
| 3730 | extrapolated and insufficient resolution |
| 3740 | co-eluted target compound |
| 4000 | sample not received by the laboratory |
| 4100 | Data not receptionned by coordination team |

Exploitation of quality codes distribution allows the identification of error sources associated with each pollutant measurement. This exploitation was performed on all 567 investigated dwellings, but some analytical results are still not available at the writing of this paper. Nevertheless, this represents an enormous amount of data from single point measurements to data files covering a week measurement every 5 or 10 minutes.

The majority of quality codes associated with protocol deviation and with laboratory errors have been retained, as it was found that some quality codes do not represent sufficient information to decide whether or not a collected data can be exploited. Moreover, the use of quality codes was sometimes misinterpreted by technicians. As such, little confidence can be put in the raw completion of quality codes. Automated logical cross-validation rules are used in order to definitely keep or reject a given data. Nonetheless, the amount of valid data expressed by the quality codes is presented in table 5 for some key pollutants. The values herein must be taken as an upper margin. Current cross-validation rules will slightly lower the values. However, this will particularly affect particulate matter measurement as both $PM_{2.5}$ and $PM_{10}$ are collected with a single mini-Partisol instrument and quality codes are not precise enough to decide the validity of data. Therefore, the following rules have been applied:

- PEMS initial flow rate tolerance: 1.8 ± 0.2 L/min. All values outside this range are rejected.
- Minimum sampling time of 5 days.
- Maximum difference between initial and final flow rate of 0.2 L/min.

The major identified source of error for both sampling and analysis is presented in table 6 for each pollutant. The inability to perform the sampling appears as the major error for aldehydes, carbon monoxide and VOC. This underlines the difficulty encountered by some technicians to realize the outdoor measurement. This is particularly true in block of flats without balconies and easy set up of samples outside the flat is impeded. The 1160 quality code (other protocol condition not respected) is mainly associated with cat and dog allergen measurement. This represents the technician inability to realize the sample in the absence of any pet which positively interacts with the measurement. Instrument fault also account for both carbon dioxide and particulate matter sampling errors, and in VOC analysis. Lack of fresh temperature is the main error source for aldehyde analysis. Damaged filters represent the main inability to perform the weighing. Finally, the analysis of dust mite allergens needs a minimum dust mass that is sometimes not achieved.

Table 5. Estimation (upper margin) of valid rate for the sampling and analyses of pollutants based on quality codes.

| | %valid sampling | %valid analyses |
|---|---|---|
| Aldehydes | 99.4% | 92.6% |
| Carbon dioxide | 93.4% | -- |
| Carbon monoxide (environmental) | 94.0% | -- |
| Cat and dog allergens | 96.0% | 97.3% |
| VOC | 99.8% | 93.7% |
| Dust mite allergens | 96.7% | 77.1% |
| Particulate matter | 84.4% | 97.1% |

Table 6. Major identified source of error (occurrence).

| | Main error code sampling | Main error code analysis |
|---|---|---|
| Aldehydes | 1110 (0.3%) | 2220 (4.9%) |
| Carbon dioxide | 1133 (1.9%) | -- |
| Carbon monoxide (environmental) | 1110 (1.3%) | -- |
| Cat and dog allergens | 1160 (2.2%) | 1160 (0.7%) |
| VOC | 1110 (0.1%) | 3120 (2.4%) |
| Dust mite allergens | 1150 (2.1%) | 3400 (19.8%) |
| Particulate matter | 1120 (3.8%) | 2210 (1.6%) |

### b. Interlaboratory tests

Interlaboratory comparison has been conducted for the analytical determination of target VOC concentration. Fifteen cartridges containing carbograph 4 adsorbents were doped with a mix of 13 target VOCs at a given concentration level by an independent laboratory (Ecole des Mines de Douai). Five cartridges were sent to each laboratory for analysis along with blanks. Three different concentration levels were tested (around 5, 20 and 60 µg·m$^{-3}$). Results are presented in Figure 4.

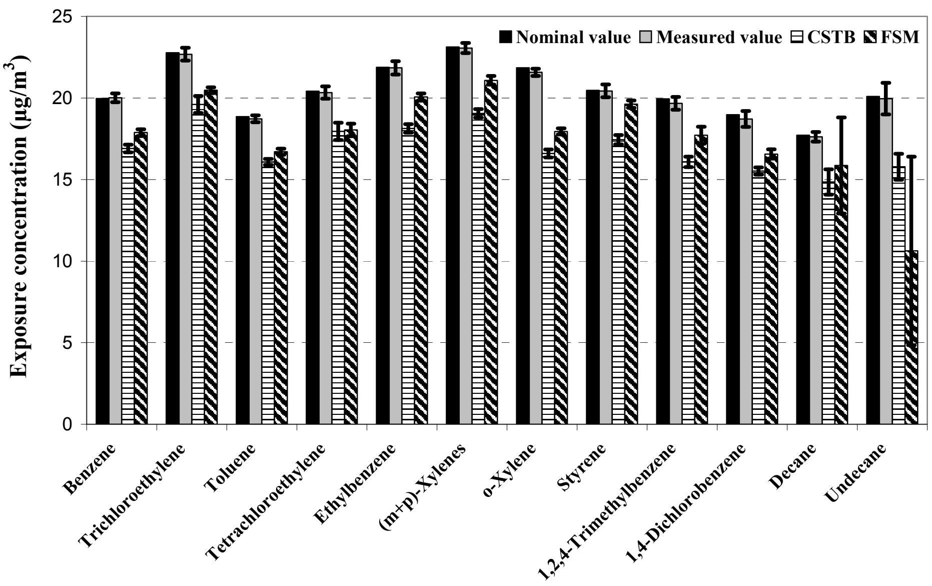


Figure 4. VOC interlaboratory comparison results at intermediate concentration level. Error bars represent standard deviation.

Unexpected delay in the transmission of doped tubes to the laboratory hinders the evaluation of the performance of a given laboratory as regards nominal value. However, laboratory comparison remains possible. Apart from alkanes, analytical differences between laboratories remain low and acceptable even if they are significant for some VOCs. The same conclusion is obtained at low or high concentration level.

The influence of storage conditions (temperature CQ = 2220 and duration CQ = 3500) on concentration of sampled VOCs and aldehydes was assessed (Fig. 5 and Fig. 6 respectively). A longer storage time (2 months instead of less than 1 month) has a significant impact on some VOC concentration: ethylbenzene (-15%), xylenes (-18%), 2-butoxyethanol (+75%), 1,2,4-trimethyl-benzene (-16%), 1,4-dichlorobenzene (-26%), n-decane (-10%), n-undecane (-13%). No significant impact of storage temperature was observed.

Formaldehyde (-24%) and hexaldehyde (-16%) are the most sensitive to a storage temperature conditions and at a lesser extent to an increase in storage duration resulting in a respective loss of 8% and 6%. Data associated with 2220 quality code are then discarded from the final matrix.

Replicates were also used in the investigated dwellings to account for sampling and transport influence. Six samples per sampling point (indoor and outdoor) and per laboratory were installed in 12 different dwellings. Two examples (m+p)-xylenes and 1-methoxy-2-propanol are presented in Fig. 7. Results are acceptable for almost all compounds. Relative differences are more important in the low concentration range (< 2µg·m$^{-3}$), but error in the absolute value remains acceptable. However, a serious deviation is observed for undecane at concentration over 20 µg·m$^{-3}$.

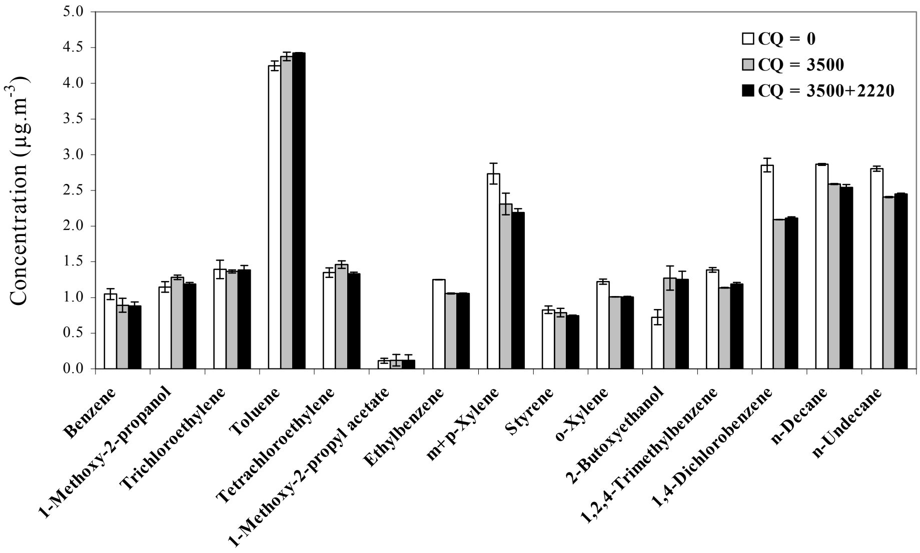


Figure 5. Incidence of storage time (2 months vs < 1 month) and storage temperature (< 4°C vs ambient conditions) on concentration of sampled VOCs.

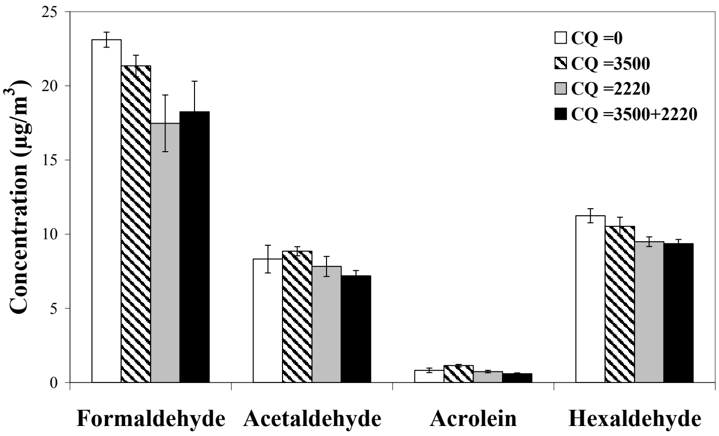


Figure 6. Incidence of storage time (1 month vs < 15 days) and storage temperature (< 4°C vs ambient conditions) on concentration of sampled aldehydes.

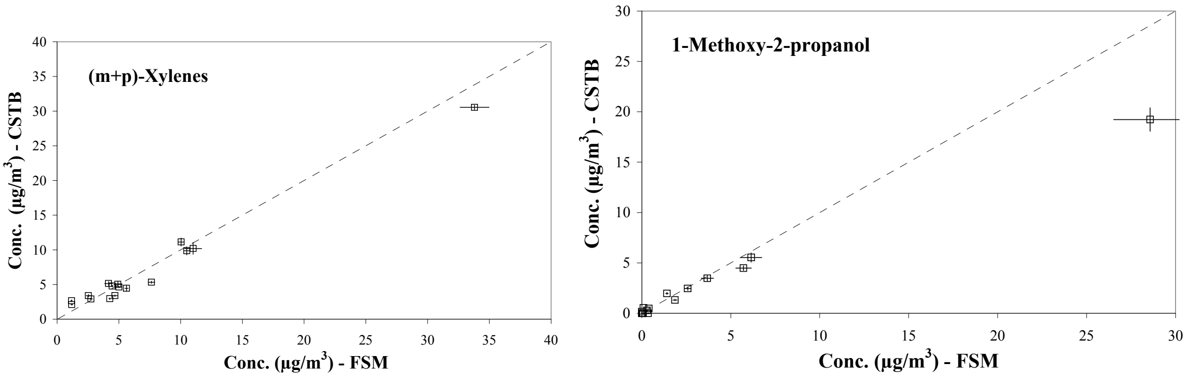


Figure 7. Inter-comparison of VOC field replicates. Error bars represent laboratory standard deviation.

## 5. Statistical analyses of descriptive data

Data were processed on the basis of descriptive statistics in order to present the breakdown of dwellings as a function of the concentrations or levels measured for each pollutant.
Multidimensional statistical analyses were also performed on the data; firstly on the chemical pollutants detected in the 532 dwellings surveyed (10 volatile organic compounds, or all those measured (Table 1) except for 1-methoxy-2 propyl acetate and 2-butoxy ethyl acetate, levels of which were below the limits of detection in more than 90% of dwellings). The aim of these analyses was to determine groups of dwellings where the levels were highest for several pollutants at the same time. The approach was as follows: use of Kohonen self-organizing maps (Kohonen, 2001), which enabled an initial grouping of dwellings with similar or very homogeneous concentrations, taking simultaneous account of the 18 chemical pollutants, with an ascending hierarchical classification based on these initial sub-groups, and then weighting of the results to achieve an estimate at a national scale.

# RESULTS

The characteristics of the distributions of the levels of each pollutant (percentage of data lower than the limit of detection, median, 95 percentile and, for VOC, ratio of indoor concentrations to outdoor concentrations) are shown in Table 7. They are presented in detail in the OQAI report available on www.air-interieur.org.

As a general rule, the pollutants targeted by the national survey were present at quantifiable levels in most French dwellings, reflecting the presence of the numerous sources of indoor pollution from which they arose, and the ventilation conditions. However, the breakdown of pollution was not homogeneous in French housing stock. The distributions of the number of dwellings as a function of pollutant concentrations were usually markedly asymmetric, with some dwellings exhibiting levels much higher than the median observed in the housing stock (for example, see the case of tetratchloroethylene shown in Figure 8).

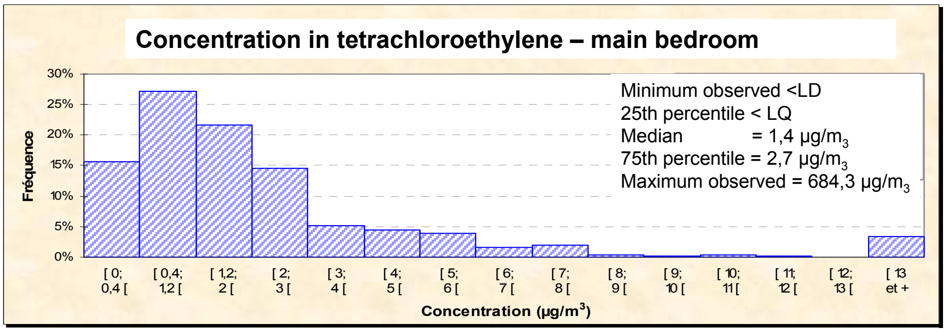


Figure 8. Distribution of dwellings as a function of indoor levels of 1,4-dichlorobenzene (µg/m$^3$) Concentration in 1,4-dichlorobenzene – main bedroom or similar.

### Volatile organic compounds

With the exception of two glycol ethers (EGBEA and 2PG1MEA), all the volatile organic compounds measured were present in 80% to 100% of dwellings, the most widespread compounds being formaldehyde, acetaldehyde, hexaldehyde, toluene and m/p-xylenes.

A search for groups of dwellings with multiple pollution by volatile organic compounds revealed that around 10% of dwellings presented simultaneously with three to eight compounds at very high concentrations (in these dwellings, the median levels of these compounds were 2 to 20-fold higher than those in the overall sample), only one or two compounds were found at high or very high levels in 15% of dwellings (5 to 400-fold higher), 30% of dwellings contained levels of four to seven compounds that were slightly higher than the median of the global sample (about 2-fold) and 45% of dwellings presented with significantly lower than median levels in the global sample for practically all compounds.

Furthermore, indoor air quality in dwellings differed specifically from outdoor air quality, as illustrated in Figure 9, which shows the distribution of median values (in $\mu g/m^3$) for 20 volatile organic compounds, as measured inside and outside dwellings.

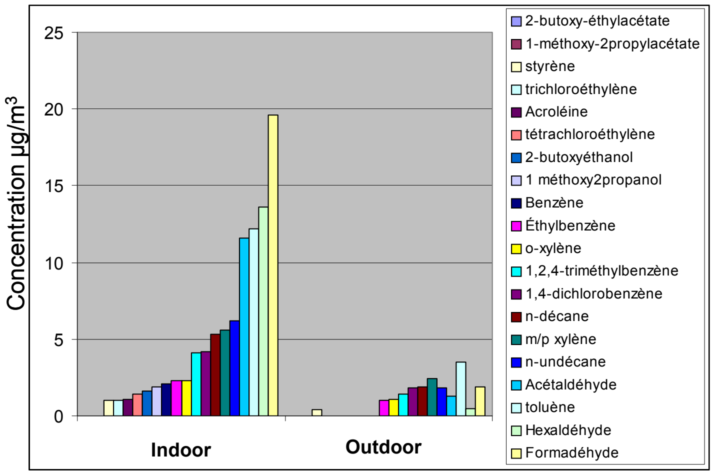


Figure 9. Distribution of median values (in $\mu g/m^3$) of concentrations of the 20 volatile organic compounds measured inside and outside dwellings.

It was seen that median levels were markedly higher indoors than outdoors with respect to the majority of compounds (18 out of 20). For some compounds (trichloroethylene, acrolein, tetrachloroethylene, 2-butoxyethanol, 1-methoxy-2 propanol, benzene), median outdoor levels were even lower than the limit of detection. The percentage of French dwellings with volatile organic compound levels (not including glycol ethers) that were higher indoors than outdoors ranged from 68.4% (trichlorethylene) to 100% (formaldehyde and hexaldehyde).

In attached or integrated garages, median levels of several volatile organic compounds were higher than those measured in all dwellings.

Table 7. Characteristics of the distributions of pollutants inside and outside French dwellings.

**A) Volatile organic compounds (VOC)**

| | Site | % weighted data <limit of detection | Median[a] ($\mu g/m^3$) | P95[b] ($*g/m^3$) | % ratios $C_{int}/C_{ext}{}^{c}$ ≥1 |
|---|---|---|---|---|---|
| **Acetaldehyde** | Indoors | 0.0 | 11.6 [10.8 – 12.3 | 30.0 [26.7 -35.1] | 99.6 |
| | Outdoors | 1.1 | 1.3 [1.2 – 1.3[ | 3.0 [2.6 – 3.1] | |
| **Acrolein** | Indoors | 0.6 | 1.1 [1.0 – 1.2] | 3.4 [2.9 – 3.8] | 98.1 |
| | Outdoors | 18.1 | <LQ [= 0.3] | 0.5 [0.4 – 0.6] | |
| **Formaldehyde** | Indoors | 0.0 | 19.5 [18.4 – 21.0] | 46.6 [40.8 – 55.1] | 100.0 |
| | Outdoors | 0.5 | 1.9 [1.8 – 2.0] | 3.6 [3.4 – 4.2] | |
| **Hexaldehyde** | Indoors | 0.0 | 13.6 [12.6 – 14.7] | 50.1 [37.6 – 55.4] | 100.0 |
| | Outdoors | 18.6 | 0.5 [0.4 – 0.5] | 1.4 [1.1 – 1.7] | |
| **Benzene** | Indoors | 1.4 | 2.1 [1.9 – 2.2] | 7.2 [6.3 – 9.4] | 90.9 |
| | Outdoors | 6.5 | <LQ [= 1.1] | 2.9 [2.5 – 3.4] | |
| | Garage | 0.8 | 4.4 [3.5 – 6.4] | 18.6 [12.6 – 21.6] | |
| **1,4-dichlorobenzene** | Indoors | 1.9 | 4.2 [3.7 – 4.8] | 150 [96.5 – 341.0] | 95.6 |
| | Outdoors | 5.7 | 1.8 [1.6 – 1.9] | 4.3 [3.5 – 5.5] | |
| | Garage | 6.9 | 2.2 [1.8 – 2.5] | 18.1 [8.0 – 40.0] | |
| **Ethylbenzene** | Indoors | 0.3 | 2.3 [2.1 – 2.5] | 15.0 [9.2 – 18.2] | 95.5 |
| | Outdoors | 6.2 | 1.0 [1.0 – 1.1] | 2.6 [2.3 – 3.0] | |
| | Garage | 1.2 | 18.0 [13.9 – 26.4] | 137 [109 – 155] | |
| **n-Decane** | Indoors | 0.7 | 5.3 [4.8 – 6.2] | 53.0 [38.6 – 83.9] | 94.4 |
| | Outdoors | 4.1 | 1.9 [1.9 – 2.1] | 6.4 [5.3 – 9.8] | |
| | Garage | 0.0 | 10.8 [7.3 – 14.0] | 213 [88.3 – 257] | |
| **n-Undecane** | Indoors | 0.6 | 6.2 [5 – 7.1] | 72.4 [45.2 – 93.2] | 94.1 |
| | Outdoors | 12.5 | 1.8 [1.6 – 2.0] | 7.0 [5.5 – 9.5] | |
| | Garage | 1.0 | 8.6 [ 5 – 11] | 106 [65.7 – 115.0] | |
| **Styrene** | Indoors | 1.9 | 1.0 [0.9 – 10] | 2.7 [2.2 – 3.1] | 95.2 |
| | Outdoors | 8.6 | 0.4 [0.3 – 0.4] | 0.7 [0.7 – 0.8] | |
| | Garage | 2.8 | 1.2 [0.9 – 1.6] | 9.3 [4.6 – 11.4] | |
| **Tetrachloro ethylene** | Indoors | 15.7 | 1.4 [1.2 – 1.6] | 7.3 [6.0 – 11.5] | 77.1 |
| | Outdoors | 21.4 | <LQ (=1.2) | 3.9 [2.7 – 4.3] | |
| | Garage | 41.0 | <LQ (= 1.2) | 2.5 [1.5 – 4.9] | |
| **Toluene** | Indoors | 0.0 | 12.2 [11.4 – 13.7] | 82.9 [57.7 – 115] | 96.2 |
| | Outdoors | 0.5 | 3.5 [3.3 – 3.8] | 12.9 [10.8 – 14.8] | |
| | Garage | 0.0 | 110.4[67.6-157] | 677 [426 – 789] | |
| **Trichloroethylene** | Indoors | 17.1 | 1.0 [<LQ-1.1] | 7.3 [5.1 – 16.1] | 68.4 |
| | Outdoors | 23.0 | <LQ (=1.0) | 2.3 [1.8 – 2.8] | |
| | Garage | 38.8 | <LQ (=1.0) | 12.8 [1.7 – 29.3] | |
| **1,2,4-trimethylbenzene** | Indoors | 0.5 | 4.1 [3.7 – 4.4] | 21.2 [15.7 – 25.7] | 95.9 |
| | Outdoors | 1.9 | 1.4 [1.3 – 1.4] | 4.1 [3.6 – 5.3] | |
| | Garage | 0.0 | 18.7 [13.2 – 29.2] | 149 [110 – 164] | |
| **m/p-Xylene** | Indoors | 0.0 | 5.6 [5.1 – 6.0] | 39.7 [27.1 – 56.4] | 92.5 |
| | Outdoors | 3.7 | 2.4 [2.3 – 2.7] | 7.1 [6.1 – 8.3] | |
| | Garage | 1.2 | 58.9 [38.5 – 81.2] | 454 [321 – 530] | |
| **o-Xylene** | Indoors | 0.1 | 2.3 [2.1 – 2.5] | 14.6 [10.5 – 19.5] | 92.1 |
| | Outdoors | 4.6 | 1.1 [1.0 – 1.2] | 2.7 [2.4 – 3.2] | |
| | Garage | 1.2 | 20.8 [14.2 – 27.9] | 166 [121 – 188] | |
| **2-butoxyethanol** | Indoors | 17.0 | 1.6 [<LQ – 1.8] | 10.3 [7.0 – 12.7] | 82.6 |
| | Outdoors | 91.3 | < LD (=0.4) | <LQ (=1.5) | |
| | Garage | 58.2 | <LD (=0.4) | 2.7 [2.0 – 4.5] | |
| **2-butoxy-ethylacetate** | Indoors | 97.7 | <LD (=0.3) | <LD (=0.3) | 2.5 |
| | Outdoors | 97.9 | <LD (=0.3) | <LD (=0.3) | |
| | Garage | 98.3 | <LD (=0.3) | <LD (=0.3) | |
| **1-methoxy-2-propanol** | Indoors | 15.1 | 1.9 [<LQ – 2.3] | 17.5 [13.1 – 20.4] | 84.4 |
| | Outdoors | 94.3 | <LD (=0.5) | <LQ (=1.8) | |
| | Garage | 51.2 | <LD (=0.5) | 9.1 [2.4 – 13.0] | |
| **1-methoxy-2-propylacetate** | Indoors | 77.3 | <LD (=0.7) | 2.3 [<LQ-2.8] | 22.1 |
| | Outdoors | 97.0 | <LD (=0.7) | <LD (=0.7) | |
| | Garage | 90.6 | <LD (=0.7) | <LQ (=2.2) | |

| B) Carbon monoxide | | | |
|---|---|---|---|
| | **Site** | **Median (ppm)** | **P95 (ppm)** |
| **Cumulated mean over 15 minutes** | Main rooms | 2.9 [1.9 – 2.9] | 15.3 [12.4 – 22.0] |
| | Other rooms | 6.0 [4.8 – 7.0] | 37.2 [22.3 – 54.4] |
| | Annexes | 3.8 [1.7 – 5.3] | 53.1 [28.2 – 94.4] |
| **Cumulated mean over 30 minutes** | Main rooms | 2.7 [2.1 – 3.0] | 14.3 [11.4 – 19.1] |
| | Other rooms | 4.9 [3.9 – 5.9] | 27.4 [18.3 – 49.2] |
| | Annexes | 3.3 [1.5 – 4.9] | 36.2 [21.7 – 78.0] |
| **Cumulated mean over 1 hour** | Main rooms | 2.0 [1.6 – 15.2] | 13.1 [9.5 – 15.2] |
| | Other rooms | 3.9 [3.0 – 4.7] | 21.1 [14.4 – 36.3] |
| | Annexes | 3.0 [0.9 – 3.8] | 30.2 [18.0 – 67.4] |
| **Cumulated mean over 8 hours** | Main rooms | 0.5 [0.4 – 0.9] | 6.3 [4.8 – 8.1] |
| | Other rooms | 1.3 [0.9 – 1.9] | 9.5 [5.0 – 19.2] |
| | Annexes | 0.7 [0.1 – 1.3] | 10.5 [5.2 – 13.9] |

| C) Biological compounds | | | | | |
|---|---|---|---|---|---|
| | **Limit of quantification (LQ)** | **Site** | **% weighted data <LQ** | **Median** | **P95** |
| **Fel d 1 cat allergens** | 0.18 $ng/m^3$ | living room | 74.6 | <LQ | 2.7 $ng/m^3$ [1.3 – 5.8] |
| **Can f 1 dog allergens** | 1.02 $ng/m^3$ | living room | 90.7 | <LQ | 1.6 $ng/m^3$ [1.1 – 2.5] |
| **Der f 1 mite allergens** | 0.01 µg/g | mattress | 3.1 | 2.2 µg/g [1.3 – 3.7] | 83.6 µg/g [46.4 – 103.0] |
| **Der p 1 mite allergens** | 0K02 µg/g | mattress | 7.9 | 1.6 µg/g [1.2 – 2.1] | 36.2 µg/g [23.1 – 41.5] |

| D) Physical parameters | | | | |
|---|---|---|---|---|
| | **Unit** | **Site** | **Median** | **P95** |
| **$PM_{10}$** | | Living room | 31.3 [28.2 – 34.4] | 182.0 [119.0 – 214.0] |
| **$PM_{2.5}$** | | Living room | 19.1 [17.2 – 20.7] | 132.0 [88.3 – 174.0] |
| **Radon** | | Bedrooms | 31.0 (with and without correction for seasonal variations) | 220 with correction for seasonal variations (225 without correction |
| | | Other rooms | 33.0 (with and without correction for seasonal variations) | 194 with correction for seasonal variations (214 without correction) |
| **Gamma** | | Living room | 0.062 [0.058 – 0.064] | 0.122 [0.109 – 0.125] |

Main rooms: bedroom, sitting room, living room, study, open-plan kitchen; other rooms: kitchen, bathroom, WC, indoor circulation areas. Annexes: cellar, boiler room, storage areas, veranda, laundry, garage communicating with living areas.
[a] 50% of dwellings with levels lower or higher than this value.
[b] 95% of dwellings with levels lower than this value.
[c] $C_{int}/C_{ext}$ ratio: ratio between indoor and outdoor concentrations

### *Carbon monoxide*

The great majority of carbon monoxide levels were close to zero in the different rooms of dwellings, whatever the duration of measurement (15 minutes, 30 minutes, 1 hour, 8 hours). However, higher values were observed occasionally. Depending on the rooms considered, the maximum values observed ranged from 130 to 233 ppm (over 15 minutes), 90 to 174 ppm (over 30 minutes), 53 to 120 ppm (over 1 hour) and 31 to 36 ppm (over 8 hours), with service areas (kitchens, bathrooms, WCs) presenting the highest maxima over 15 minutes, 30 minutes and 1 hour. Comparison of WHO guidelines and the carbon monoxide levels found shows that 0.7% to 9.4% of French dwellings exceeded guideline values for 15 minutes (87 ppm), 30 minutes (52 ppm), 1 hour (26 ppm) and 8 hours (9 ppm) (Table 8). Excessive levels mainly affected service areas (kitchens, bathrooms, WCs, etc.) and annexes (cellars, lofts, garages, etc.).

Table 8. Percentage of dwellings with CO concentrations higher than WHO guidelines.

| **Exposure time** | **Guideline value (WHO)** | **Main room** *(bedroom, living room, office, open kitchen, etc.)* | **Other rooms** *(kitchen, bathroom, toilet, corridor)* | **Annexes** *(cellar, garage, loft, ,...)* |
|---|---|---|---|---|
| 15 minutes | 87 ppm | 0% - 0,8% | 0,2% - 6,8% | 1,5% - 10,5% |
| 30 minutes | 52 ppm | 0,1% - 1,2% | 0,4% - 6,5% | 1,9% - 11,1% |
| 1 hour | 26 ppm | 0,6% - 3.2% | 1,6% - 8,2% | 2,8% - 12,9% |
| 8 hours | 9 ppm | 2% - 5,6% | 3,4% - 12,9% | 3,3% - 11,5% |

**Biological pollutants**

***Dog and cat allergens***

Dog and cat allergens were not very common in the indoor air of dwellings (quantification in 9% and 25% of dwellings, respectively, even though 54% of households declared they owned or kept domestic animals). The respective median values were lower than the limit of quantification. Five per cent of dwellings exhibited levels higher than 2.7 ng/m$^3$ for cat allergens (*Fel d1*) and higher than 1.6 ng/m$^3$ for dog allergens (*Can f 1*).

***Mite allergens***

Mite allergens were observed in mattress dust in more than 90% of dwellings, with levels exceeding 83.6 µg/g for *Der f 1* and 36.2 µg/g for *Der p 1* in 5% of dwellings (median values of 1.6 µg/g and 2.2 µg/g respectively for *Der p 1* and *Der f 1*).

**Physical pollutants**

Fifty per cent of dwellings contained *particle* levels higher than 19.1 µg/m$^3$ for particles with a diameter smaller than 2.5 µm ($PM_{2.5}$) and 31.3 µg/m$^3$ for particles with a diameter smaller than 10 µm ($PM_{10}$). Five per cent of dwellings had concentrations higher than 133 µg/m$^3$ ($PM_{2.5}$) and 182 µg/m$^3$ ($PM_{10}$).

Median concentrations of *radon* were 31 Bq/m$^3$ in bedrooms and 33 Bq/m$^3$ in other rooms. Maximum values (1215 Bq/m$^3$ in a bedroom and 2161 Bq/m$^3$ in another room) were measured in the same dwelling. These levels were slightly lower than those measured by the Directorate General for Health (DGS) and the Institute for Radioprotection and Nuclear Safety (IRSN) in France between 1982 and 2000 at nearly 13,000 measurement points (median value: 50 Bq/m$^3$) (IRSN, 2000). This difference was certainly linked to the sampling methods employed in dwellings during the two campaigns. Based on voluntary participation, and with a number of measurements available in different regions that did not correspond to the density of residential housing, the DGS-IRSN campaign focused particularly on non-collective residential buildings and configurations and periods which were in principle "risky" (individual residential buildings, ground floor, measurements performed in winter).

Gamma radiation was found to be present at levels lower than 0.062 µSv/h in 50% of French dwellings, and only exceeded 0.1 µSv/h in 5% of dwellings.

## CONCLUSIONS

This first national campaign carried out by the OQAI in French dwellings enabled an inventory of air quality that targeted some thirty chemical, physical and microbiological pollutants. These findings will be supplemented by data on the levels of fungal contamination and the presence of damp in dwellings (to be published).

An enormous amount of data was collected and, associated to it, quality control data. Before beginning to analyze key data, quality control information must be exploited to define the final data set. Inter-laboratory comparison and designed experiments were undertaken to provide the highest confidence level in the final data set. The use of quality codes self-completed by technicians represents a good estimate of data validity but remains insufficient to be used as a decision tool. This role is assumed by logical cross-validation rules that are still being applied to the database. The sampling and analysis valid rate is satisfactory. Thus, a correct representativeness of the sample is preserved. And representativeness is essential in order to provide data interpretation and conclusions at a population level.

Indoor pollution is different from outdoor pollution, particularly in terms of the presence of some substances that are not observed outdoors, or by markedly higher concentrations indoors. The pollutants targeted were present at quantifiable levels in most French dwellings. However, the distribution of organic chemical pollution was not homogeneous throughout the housing stock. Only a minority of dwellings (around 10%) exhibited very high levels of several pollutants at the same time; by contrast, 45% of dwellings presented very low levels of all the pollutants measured. Furthermore, the distributions of the number of dwellings as a function of pollutant levels were usually highly asymmetric, with some dwellings presenting values that were markedly higher than the median levels observed throughout the housing stock.

This study constitutes the first reference available on the quality of indoor air in French housing stock and cannot be compared with any previous situations because of its originality. Nevertheless, it generated levels similar to those already demonstrated during occasional studies in France and in the context of major international surveys. These findings are currently being analyzed by the health authorities in order to better evaluate the health risk to populations. These values are crucial to situating the measurements established in the context of claims or emergencies where the quality of indoor air is called into question.

This overview of pollution at the level of the French housing stock now constitutes a reference to establish a context for policies concerning the prevention and reduction of health risks. In this respect, the data are currently being used for studies by the AFSSET (French Agency for the Health Safety of the Environment and Working Conditions) in order to draw up guidelines for the quality of indoor air. This state of pollution has also led the authorities to recommend the display of information relative to chemical substances emitted by all types of products (household cleaning agents, construction materials, furniture, etc.).

The detailed information collected in parallel on the construction characteristics of dwellings and their environment, as well as on households, their activities and the time spent in dwellings, are currently being processed. The long-term aim is to draw up a typical profile of the most polluted dwellings and to search for the factors incriminated so that measures can be taken to protect the population. Pollution tracers and indicators are also being developed in order to provide different actors in the construction industry with the tools they need to manage and communicate on indoor air pollution.

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