Ranking indoor pollutants according to their potential health effect, for action priorities and costs optimization in the French permanent survey on indoor air quality

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ABSTRACT

The first survey of the 'French permanent survey on Indoor Air Quality' will start in 2003 on a random sample of 710 dwellings. To optimize the study cost, a ranking method was developed for prioritizing 70 pollutants including chemical and biological agents. Excepted for pesticides, the approach only addresses inhalation exposures.

The method is a risked-based ranking analysis using indoors concentrations measured in France, dose response for acute and chronic exposure, and indoor detection frequency. A 'Ranking index' was calculated in summing an 'Acute index', a 'Chronic index' and a 'Frequency index'. Hence, we have categorized pollutants in 'very high priority', 'high priority', 'priority' and 'no priority'.

Seventeen pollutants were classified 'very high priority' (formaldehyde, benzene, acetaldehyde, dichlorvos, particles, radon) or 'high priority' (mite, dog and cat allergen, NO_2, toluene, trichloroethylene, dieldrin, lead, tetrachloroethylene, aldrin, CO). Most of the chemicals compounds are 'priority' (45%) or 'no priority' (33%).

INDEX TERMS

Indoor air; Risk analysis; Inhalation exposure; Acute effect; Chronic effect

INTRODUCTION

Created by the French government in 1999, the 'French permanent survey on Indoor Air Quality' (or 'Observatoire de la Qualité de l'Air Intérieur', OQAI) will start in 2003 with a nation-wide campaign on a random sample of 710 dwellings. To optimize the study cost and make the choice of the target parameters to be measured in the campaign according to health priorities, a ranking method has been developed for prioritizing 70 indoors pollutants. Based on lists of substances established by experts of the French OQAI, 31 VOC and aldehydes, 34 pesticides, radon, nitrogen dioxide, carbon monoxide, particles, lead, man-made vitreous fibres, asbestos, cat, dog and mite allergens, endotoxin and electromagnetic field (Extremely Low Frequency) were included in this study.

Except for pesticides, searched both in air and dust floor houses, the approach only addresses inhalation exposures as far as only air media will be investigated in the OQAI. The method consists in developing a ranking score for both acute and chronic health effects.

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METHODS

The method is a risked-based ranking analysis. We developed a ranking score based on indoors pollutant concentrations found in the French dwellings and dose–response relationship for each pollutant for acute and chronic exposure. We also took into account the pollutant frequency detection in indoor air of French dwellings. A 'Ranking index' (RI) was calculated for each pollutant by summing an 'Acute index' (AI), a 'Chronic index' (CI) and a 'Frequency index' (FI).

Indoor concentration and detection frequency were estimated using data collected during the OQAI pilot survey, conducted between March and July 2001 in 90 French dwellings (Kirchner and Pasquier, 2002). The indoor air concentrations used for acute and chronic exposure calculation were, respectively, 'indoor 95th percentile' and 'indoor median concentration'. Unfortunately, OQAI pilot study data were not available for all the agents included in the ranking analyse. For data gaps, we used data collected in other French studies (Mosqueron *et al.*, 2002) or, in case of French data not available, data collected in the European or international surveys.

We draw up an inventory of the dose response for acute and chronic inhalation exposure from the US-EPA, ATSDR and WHO databases. Values for acute and chronic non-cancer response represent air concentration below which there was not found any adverse non-cancer effect, neither in animal studies nor in human studies; in order to simplify and to make uniform the terminology, we will call them here Reference Concentration (RfC). For cancer effects, Unit Risk (UR) represents a quantitative estimate of lifetime excess risk per µg/cu m air breathed. When several dose responses were found for a pollutant, for the same duration and route of exposure, we selected the most protective for human health (e.g. for non-cancer effects, the smallest value, for carcinogenic effects, the higher value).

The AI was calculated by dividing indoor concentrations (95th percentile) by the acute RfC. According to this value, an AI score between 0 and 5 was attributed to each chemical (see Table 1).

Table 1 Ranking scores accorded to the different indexes (AI, CI, FI) included in the Ranked Index (RI)

Ranking score	Acute index (AI)	Chronic index (CI)		Frequency index (FI)
		Carcinogenicity index (KI)	Potential chronic effect (PCE)	
5	AI > 1	Known human	PCE > 1	0.8 < FI < 1
4	0,5 < AI < 1	Probable human	0.5 < PCE < 1	0.6 < FI < 0.8
3	0,1 < AI < 0,5	Possible human	0.1 < PCE < 0.5	0.4 < FI < 0.6
2	0,01 < AI <	Not classified	0.01 < PCE < 0.1	0.2 < FI < 0.4
1	NE[a]	Not available	NE	FI < 0.2 or NE[b]
0	AI < 0.01	No human carcinogen	PCE < 0.01	FI = 0

[a]Not estimated (no dose response or no indoor concentration). [b]Not estimated (no data).

The CI is the sum of the two scores described below:

- The first one, 'Carcinogenicity Index' (KI) was based on the US-EPA and IARC classifications of carcinogenicity to humans of agents, mixtures and exposures; a score between 0 and 5, reflected the evaluation result on the weight-of-evidence that the substance is a human carcinogen, was attributed to each pollutant (see Table 1).
- The second one, called 'Potential Chronic Effect' (PCE), was calculated as the AI calculation by dividing the indoor concentration (50th percentile) by the chronic dose response. For chronic non-cancer effects, the score was obtained by dividing the median chronic exposure by the chronic RfC. For cancer effects, the PCE score was estimated by dividing the median indoor concentration by the exposure concentration giving a 10^{-6} lifetime cancer risk. For agents with both cancer and non-cancer dose

responses available, the two values were compared and the greatest one was selected. In this way, a PCE score between 0 and 5 was attributed for each agent (see Table 1).

The FI corresponds to the indoor detection frequency of each pollutant (percentage of results above the Limit of Quantification). An FI value between 0 and 5 was accorded to each pollutant (see Table 1).

According to the score in each index, the RI varies between 0 and 20 for each selected substance. Scores are stratified in four categories: 'very high priority' (RI: 15–20), 'high priority' (RI: 10–14), 'priority' (RI: 5–9) and 'no priority' (RI < 5).

RESULTS

Six chemicals reach the 'very high priority' category: formaldehyde, benzene, acetaldehyde, dichlorvos, particles and radon. Eleven pollutants enter the 'high priority' category: dog allergen, NO_2, mite allergen, toluene, trichloroethylene, dieldrin, lead, tetrachloroethylene, aldrin, cat allergen and CO. Most of the chemicals analysed are classified in 'priority' (45%) or 'no priority' category (around 33% with a large proportion of pesticides and glycol ethers). Detailed results from the chemicals at the top of the ranking (first 20) are presented in Table 2.

Table 2 Ranking of the 20 first pollutants analysed in the OQAI ranking method

	Acute index	Chronic index	Frequency index	Ranking index	Category
Formaldehyde	5	9	5	19[a]	'Very high priority'
Benzene	2	10	5	17	
Acetaldehyde	2	9	5	16	
Dichlorvos	3	9	4	16	
Particles (PM_{10})	5	6	5	16	
Radon	1	10	5	16	
Dog allergen	5	6	2	13	'High priority'
Nitrogen dioxide	3	5	5	13	
Mite allergen	5	4	3	12	
Toluene	3	4	5	12[b]	
Trichloroethylene	0	9	3	12	
Dieldrin	1	9	1	11	
Lead	1	9	1	11	
Tetrachloroethylen	2	4	5	11[c]	
Aldrin	1	8	1	10	
Cat allergen	3	6	1	10[d]	
Carbon monoxide	3	2	5	10[e]	
Heptachlor epoxide	1	7	1	9	'Priority'
Lindane	1	4	4	9	
Xylenes	0	4	5	9[f]	

[a]RI = 18 if AI estimated with 90th percentile. [b]RI = 13 if AI estimated with 100th percentile. [c]RI = 12 if AI estimated with 98th or 100th percentile. [d]RI = 12 if AI estimated with 98th or 100th percentile. [e]RI = 12 if AI estimated with 100th percentile. [f]RI = 11 if AI estimated with 100th percentile ; modify the categorization.

DISCUSSION

Our results are consistent with preliminary screening level ranking of chemicals found in indoor air presented in a draft report by Johnston for the United States (Johnston, 2002). Among the indoor chemicals defined as 'priority' in the US-EPA analyses (e.g. the 20 substances at the top of the indoor grading), 11 are classed in the top of our ranking

(formaldehyde, benzene, acetaldehyde, dichlorvos, toluene, trichloroethylene, tetrachloroethylene, dieldrin, aldrin, xylenes and lindane). Allergens (dog, cat, mites), carbon monoxide, nitrogen oxides and radon were not included in the US ranking programme. On the other hand, some agents not selected by the OQAI experts appear in the top of the US ranking (chloroform, dichloromethane, arsenic, carbon tetrachloride, naphtalene, chloromethane, manganese, hexane, etc.). Environmental Tobacco Smoke (ETS), an important indoor risk factor (Bukowski, 2002), was not ranked as an individual pollutant but a large number of components of this mixture (e.g. formaldehyde, acetaldehyde, benzene, etc. ranked in 'highly priority' OQAI group) have been ranked as individual chemicals.

In accordance with the OQAI missions, we attributed a more important score to the potential chronic health impact (0–10) than to the acute impact (0–5). This strategy supports the health impact of long term exposure to low concentration exposure (situation in dwellings) without ignoring acute accidental exposure (CO for example) or high situations (emission of VOC or particulate after odd jobs, housework, etc.). Acute exposure was not failed because it is the most frequently source of complaints of discomfort or annoyance by inhabitants.

Indoor concentrations were estimated by the data collected during the OQAI pilot survey. Its aim was to test monitoring feasibility in a 90 dwellings located on three French metropolitan areas. Dwellings were not selected using a random sampling; hence, the indoor air concentration data representativeness is unknown. Thus, preliminary results shown in this paper will have to be revised when data collected during the first survey of the 'OQAI' will be available; results collected during this large campaign (2003–2004) will be more representative because they will be collected in a nation-wide random sample of 710 dwellings (Golliot, 2003). Nevertheless, use of indoor concentrations collected on a non-random French sample was tested by comparison with data from the international literature. It shows a good accordance with the medium concentrations measured in dwellings. Despite the lack of representativeness of the OQAI pilot survey data, this accordance supports the use of this preliminary French data. However, confidence in the indoor pesticide exposure estimation is low. Pesticide measurements were not included in the OQAI pilot survey; they were measured only in nine dwellings selected for practical convenience in a feasibility study conducted for the OQAI (Blanchard, 2001). In addition, homogeneity between OQAI pilot survey measurement and literature data permits, for some chemicals not measured in the OQAI pre-survey, to use published data to allow inclusion of all the chemicals initially selected by the OQAI experts. This approach contains an uncertainty that we cannot quantify.

The micro-organisms (bacterium, fungi, virus, protozoa, etc.) were not included in our ranking study because there is a lack of knowledge on dose response for respiratory exposure. Potential health adverse effect of respiratory exposure to micro-organisms and their derived compound (e.g. mycotoxin, ergosterol, COV) cannot be ignored (Nedellec, 2002), the method allowing their inclusion remain to be found.

Our methodology contains limits and uncertainties. We tried to reduce and quantify some of them by testing some assumptions. For example, percentile 95 of the concentration distribution was chosen to estimate the acute indoor exposure. We test the influence of this choice by ranking all the pollutants with the 90, 98 and 100 percentiles. This sensibility analysis shows that this indicator has a little influence: eight substances have their AI score modified by this choice (toluene, tetrachloroethylene, cat allergen, CO, xylenes, formaldehyde, styrene and 1,4-dichlorobenzene). Finally, influence on the RI is very limited: except for the xylenes (classified as 'high priority' using the maximal indoor concentration versus 'priority' using the 95th percentile), categorization is not modified for those chemicals (see Table 2). Percentile 95 seems to be a good value to assess acute indoor exposure.

'Frequency Index' is not directly a sanitary stake indicator. However, we decided to keep it in our RI because of its interest for the decision-maker. Testing its influence on the final

ranking by building an 'RI' with and without this 'FI' shows that the relative final ranking is not substantially modified. When we look at the top of the ranking through both approaches, only three chemicals appear on the new ranking without 'FI': alpha HCH, asbestos and heptachlor replaced CO, lindane and xylenes (see Table 3).

Table 3 : Top of the Ranking with and without Frequency Index in the Ranking Index

Substance	Ranking index[a] without frequency index	Substance	Ranking index[b] with frequency index
Formaldehyde	18.7	Formaldehyde	19
Benzene	16.0	Benzene	17
Dichlorvos	16.0	Acetaldehyde	16
Acetaldehyde	14.7	Dichlorvos	16
Dog allergen	14.7	Particles (PM_{10})	16
Particles (PM_{10})	14.7	Radon	16
Radon	14.7	Dog allergen	13
Dieldrin	13.3	Nitrogen dioxide	13
Lead	13.3	Mite allergen	12
Aldrin	12.0	Toluene	12
Mite allergen	12.0	Trichloroethylene	12
Cat allergen	12.0	Dieldrin	11
Nitrogen dioxide	12.0	Lead	11
Trichloroethylene	12.0	Tetrachloroethylene	11
Heptachlor epoxide	10.7	Aldrin	10
Alpha-HCH	9.3	Cat allergen	10
Asbestos	9.3	Carbon monoxide	10
Heptachlor	9.3	Heptachlor epoxide	9
Toluene	9.3	Lindane	9
Tetrachloroethylene	8.0	Xylenes	9

[a]Scored on 15 brought back to 20 for comparison. [b]Scored on 20.

CONCLUSION AND IMPLICATIONS

Among more than 70 indoor pollutants included in the 'French permanent survey on Indoor Air Quality' (OQAI) risk-based analysis, 17 are classified as 'very high priority' or 'high priority' according to their acute and chronic potential health effect and the indoor concentrations usually found in France. This categorization aims at defining action priorities for the OQAI, along future surveys and at optimizing their costs: thus, aldehydes, COV, several pesticides, particles, allergens (mite, cat, dog) and carbon monoxide must be measured in priority in the nation-wide OQAI survey.

Because indoor concentration and dose response are not available for all the chemicals included in this study, ranking is largely influenced by toxicological (dose response) or indoor pollution data knowledge. Thus, data for chemicals ranked at the top are generally more complete than for pollutants in the end. However, for the pollutants without data, we identified the priority filled to a homogenous ranking (need to have an accurate estimation of indoor pollution or to have toxicological development). Biological contaminants were not included in our strategy because there are not currently recognized dose responses for respiratory exposure for them.

OQAI decision-makers will have to decide to integrate direct ETS measurement during the next campaigns or to consider that indicators are sufficient to estimate ETS in French dwellings. They also will have to decide to integrate or not other priority pollutants defined by the US-EPA (e.g. arsenic, chloroform, carbon tetrachloride) in the further OQAI survey.

Moreover, the frequency of pathology associated with each pollutant was not taking into account in our method. This parameter, important for the public health policy, should be

integrated in a further study that will be developed on an analogous strategy than the one presented in this preliminary paper.

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