Index for surveys of indoor pollution in Brussels dwellings

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SUMMARY

Since September 2000 and on medical request, the Regional Unit for Indoor Pollution Intervention (French acronym: CRIPI) conducts indoor pollution analyses in Brussels dwellings. Currently, more than 2200 interventions were performed. These interventions are based on a multifactorial approach including amongst others a questionnaire on Health and Environment to be completed by the patient, chemical and microbiological analyses. In order to facilitate result interpretation, CRIPI developed and uses several indices. Concerning the chemical pollutants, a global index based on six categories of Volatile Organic Compounds (COVs) is applied. Concerning the microbial pollutants, several indices are also available: 1) fungal spores in air, 2) settled dust on furniture, 3) dust present in/on mattress, carpets or armchairs. Both chemical and microbiological indices allow to identify anomalies in the patients environment, which can help in the communication of effective sanitation procedures to the patient. Concerning the physician, this environmental assessment can also help to refine his diagnosis.

PRACTICAL IMPLICATIONS

In the framework of CRIPI, indices for several chemical and microbiological pollutants were calculated. These indices facilitate result interpretation and the identification of some environmental anomalies present in the patients dwelling. This information helps to propose specific remediation measures and also helps the physician to refine his medical diagnosis.

KEYWORDS

Green ambulance, chemical pollutants, biological pollutants, index of threshold alert

1 INTRODUCTION

Indoor air quality has become of growing concern. We spend more than 80% of our time in indoor environments: at home, at work, in transport,… Despite the existence of strict regulations on indoor pollution in the occupational environment, regulations on the indoor air quality in dwellings is still lacking. According to the example of Germany and the Grand Duchy of Luxembourg, green ambulances were created in the Brussels Capital Region and in the Walloon Region in order to provide a support to physicians. Each of these services adds an environmental complement to the medical diagnosis in case of health complaints related to the indoor environment of the patients habitat. Concerning Brussels, 'the Regional Unit for Indoor Pollution Intervention' or 'CRIPI' was launched in 2000 (Chasseur *et al*, 2015a).
This "environmental approach" is complex as many potential pollutants generally appear in low concentrations in the indoor environment. Moreover, some of them can infiltrate into the habitat, but many others are also generated indoors like, *e.g.*: construction materials, floor

coverings, paintings, furnishing, human activities and pets. In order to correctly provide an environmental diagnosis, many factors should therefore be taken into account. For chemical pollutants, this is for example the case for lead poisoning (ATSDR, 2007) or the carcinogenic effect of some organic substances such as benzene (Needleman, 2004) or formaldehyde (*www.cancer.org*, 2014). Moreover, insecticides, cleaning products, deodorants, perfumes, … are also sources of indoor pollution whose health effect is still unknown, especially concerning its impact on long-term at very low concentrations. Concerning the biological contaminants present in dwellings with humidity problems, the omnipresence of moulds and their impact on health should not be underestimated (Zureik, 2002; Fisk & al, 2007; Reboux, 2010; Mendel, 2011; Ticher & al, 2011; Park, 2011; Weinmayr & al, 2013). Various other organisms, which can be sources of allergens, are also present in house dust. These can be amongst others: mites (Chen, 2010), cats, dogs (Chen, 2010, Kelly, 2012; Lodge, 2012) and cockroaches.

This implies that, during an environmental survey, it is very difficult to state which of the numerous contaminants that are often simultaneously present in the environment could have a negative impact on health. Furthermore, people are not all equally sensitive to the presence of pollutants. Children show a greater fragility on the respiratory and immune level compared to adults (Belanger, 2003; Han & al, 2009; Claussen, 2012; Pakeu & al, 2012; Hsu & al, 2012; Weinmayr & al, 2013). In case of allergy, if the specific allergenic potential of microorganisms must be taken into account, the predispositions of the patient (atopy) constitute an additional factor which may sometimes be more important than the nature and intensity of exposure. For all the above mentioned reasons, and in particular the last one, it is clear that it is nearly impossible to establish threshold values not be exceeded for reasons of health.

In order to facilitate result interpretation, CRIPI has developed several chemical and microbiological indices, based on the calculation of percentiles, for the main pollutants present in the investigated dwellings. It permits to identify the environmental anomalies which constitute as many tracks to be investigated by the physician, for example from specific immunological tests. The medical doctor can also assess the impact of the environmental remediation measures proposed by CRIPI on his patients health.

This paper provides an overview of the different indices used by CRIPI.

2 MATERIALS/METHODS

2.1. The survey

The Regional Unit for Indoor Pollution Intervention (French acronym CRIPI) provides an assistance to the medical diagnosis of the physician, when he/she suspects that a health problem may be related to the patients habitat. For this purpose, chemical and biological samples are systematically collected. Each investigation also includes the completion of a questionnaire by the patient. The questionnaire comprises several sections related to health problems, cleaning products, maintenance and ventilation of the rooms. During the inquiries, CRIPI provides first general advises on healthy housing to the patient.

2.2. Chemical sampling and analyses

Chemical air samples were taken using a passive radial diffusion device (Radiello's) filled with TENAX for adsorption of *volatile organic compounds* (VOCs) such as benzene, toluene, xylene, terpenes,... during one hour. Subsequently, the compounds retained on the cartridges were thermally desorbed. The VOC analysis was carried out by gas chromatography coupled with mass spectrometry (GC-MS).

Formaldehyde was directly measured via a real-time portable analyser INTERSCAN based on electrochemical principles. The detection limit of this analyser can be lower than 10 ppb.
During each inquiry, other chemical pollutants were also measured, like pesticides in air, lead in paint or water, carbon monoxide in case of a risk of gas emission, airborne particulate matter. However, due to the lack of relevant indices, only VOCs and formaldehyde results will be discussed.

2.3. Microbiological sampling and analyses

Humidity and visible mouldy surfaces: during each inquiry, humidity was assessed and visible mouldy surfaces were sampled. Scratch samples (tape) were taken and analysed by direct microscopy (coloured with Lactophenol blue). This method is also useful to observe the presence of mites on mouldy surfaces.
Air sampling: in parallel, air samplings were performed in each room and outdoors using a RCS+ (Biotest®, 80 liters). Strips filled with HS Agar media were used and incubated at 25°C during 5 days to isolate and identify mesophilic hygrophilic moulds. Strips with TSA were used to isolate environmental mesophilic bacteria and were incubated at 25°.
Dust deposits on furniture: RODAC plates filled with MEAChloramphenicol were applied on different horizontal surfaces such as furniture. This simple method allowed to assess deposited mesophilic (25°C/5 days) hygrophilic mould spores from wet contaminated building material. The thermophilic moulds spores concentration (45°C, 2 days), was a good indicator to appreciate the dust accumulation because of their long survival in dry conditions.
Dust sampling: Carpet, old armchairs and especially mattresses may be an important reservoir for micro-organisms for survival and replication. A vacuum-cleaner (1200W) equipped with a special filter adaptor and a Filter "3M filtrete" (MC/US/diam 57mm/PB) was used. Dust was aspirated on a surface of 1 m^2 during 2 minutes. In the laboratory, a first filter was suspended in a physiological solution with tween and agitated during 20 minutes. The primary solution was successively diluted 10 times and plated on Malt Extract Agar Chloramphenicol for hygrophilic moulds and on M40Y+10%NaCl, for xerophilic moulds. The dust of the second filter was tested with the Acarex test (Allergopharma).
Moulds identification: Identification of fungal strains was conducted microscopically according to taxonomic monographs.

2.4. Indices calculation

Based on the chemical and microbiological data obtained during the surveys, several pollutant indices were established. They are based on the calculation of percentile values.

3 RESULTS

All indices presently used by CRIPI are shown in Tables 1 and 2. Some of them are already published. This is the case for the chemical pollutants (Bladt et al, 2010) and the airborne moulds (Chasseur et al, 2015b).
Concerning the chemical pollutants, Table 1 shows the different percentile values calculated from the chemical CRIPI database (about more than 2000 surveys). These values are updated each year.
An overall Index of Chemical Indoor Air Pollution was established for the main VOCs present in the Brussels dwellings (limonene, α-pinene, benzene, toluene), formaldehyde and also for the total VOCs. The index categories are based on the percentile values P20, P50, P70, P90 and P95. These percentile values represent an average concentration of all rooms in the habitat were VOCs were sampled and detected, like the living, kitchen, bathroom and

bedroom. A chemical index per room was also calculated and is used in case of pollution or a specific problem in only one room.

For the VOCs concentrations, the value of percentile 50, corresponding to 50% of surveys, reached 80 µg/m³, which is lower than the comfort range of 200 µg/m³ applied in the United States (Molhave, 1986). The same was observed for the other VOCs when compared to the existing guidelines.

The "bad" category, defined from percentile 70 to percentile 90, shows acceptable concentrations for TVOCs, toluene, formaldehyde and limonene. However, the benzene concentrations are higher than the air quality guidelines in France (CSHPF, 1998).

Table 1: indices used for interpreting results of VOCs analyses and formaldehyde measurements.

CHEMICALS	**Excellent**	**Good**	**Normal**	**Bad**	**Very bad**	**Execrable**
Percentile	**0-P20**	**P20-P50**	**P50-P70**	**P70-P90**	**P90-P95**	**>P95**
TVOCs *(percentiles, µg/m3)*	**0-48**	**48-80**	**80-108**	**108-178**	**178-242**	**>242**
benzene	0-1.9	1.9-2.5	2.5-3.8	3.8-6.0	6.0-21.0	>21,0
toluene	0-9	9-11	11-15	15-22	22-60	>60
formaldehyde	0-14	14-18	18-25	25-34	34-67	>67
limonene	0-6	6-8	8-13	13-19	19-54	>54

Concerning the microbiological pollutants, our index is the first one developed for airborne moulds (Chasseur *et al*, 2015b). This index is based on concentration percentiles obtained for some specific airborne moulds (Table 2). In Brussels, the best represented airborne moulds in the visited dwellings were *Penicilium spp.*, *Aspergillus versicolor* and *Cladosporium sphaerospermum*. These 3 taxa are the basis of the index. However, if other specific toxic moulds were present, these were also taken into account. For each mould species, different alert values were calculated: 75-200 cfu/m^3 for *Aspergillus versicolor*, 38-88 cfu/m^3 for *Cladosporium sphaerospermum*, 338-828 cfu/m^3 for *Penicillium spp*. Only 13 and 25 cfu/m^3 were respectively noted for *Chaetomium spp* and *Stachybotrys chartarum*.

In this paper, an index of airborne bacteria was added for the microbiological assessment (Table 2). It concerns total bacteria growing at 25°C. These bacteria are considered to essentially originate from an environmental origin (ACGIH, 1999). We noticed that the bacterial load in the habitat is significantly higher compared to offices located in buildings equipped with a centralised air conditioning system (Chasseur *et al*, 2003), with a median value of 726 cfu/m^3 (125 cfu/m^3 in offices), and an alert level starting at 1898 cfu/m^3 (<500 cfu/m^3 in offices).

Settled dust analyses are complementary to airborne analyses. For CRIPI, the RODAC plates applied on the furniture allowed the calculation of two new indices (Table 2). One concerns moulds but is only focused on *Aspergillus fumigatus*, with an alert level around 31-36 cfu/25cm^2. The second one concerns total environmental bacteria with an alert level around 31-36 cfu/25cm^2.

Table 2: Indices used in order to support the interpretation of microbiological results.

MICRO-ORGANISMS						
Airborne moulds (*CFU/m^3*)	**Percentiles**					
	0-75 Good	**75-85 Average**	**85-90 Bad**	**90-95 Alert**	**95-99 Unacceptable**	**>99**
Aspergillus versicolor	0-25	25-38	38-75	75-200	200-2550	>2550
Cladosporium sphaerospermum	0	0-25	25-38	38-88	88-765	>765
Penicillium spp.	0-113	113-225	225-338	338-828	828-2550	>2550
Chaetomium spp.	0	0	0	0	0-13	>13
Stachybotrys chartarum	0	0	0	0	0-25	>25
Cladosporium herbarum, C. cladosporioides, Alternaria spp.	Not to be taken into account (outside origin)					
Aspergillus fumigatus	0-7	7	7-14	14-20	20-47	>47
Steriel mycelia	0-50	50-75	75-100	100-138	138-288	>288
Yeasts	0-13	13-25	25-38	38-63	63-250	>250
Other species	0	0	0	13	13-75	>75
	Percentiles					
	0-50 Good	**50-75 Average**	**75-90 Bad**	**90-95 Alert**	**95-99 Unacceptable**	**>99**
Airborne bacteria (*CFU/m3*)						
Total environmental Bacteria (22-25°C)	0-725	726-1206	1207-1897	1898-2417	2418-3671	>3671
Settled dust on furniture *(CFU/25cm^2)*						
Aspergillus fumigatus	0-1	2-4	5-9	10-15	>15	
Total environmental Bacteria (22-25°C)	0-5	6-15	16-30	31-36	>36	
Mattresses, carpets, armchairs *(CFU/mg)*						
Total filamentous moulds (alert level for a mixture of several species)	100					
Mites (Acarex test)	0	weak	average	high		
Mouldy surfaces assessment *(m^2)*						
Visible mouldy surfaces by room *(m^2)*	0		>0.3 - <3.0		>3.0	
Mites with visible molds (*on tape*)	absence			presence		

Mattresses, armchairs, carpets are excellent reservoirs where dust can settle and thus where many microorganisms can accumulate and multiply. Moulds, yeasts and mites are among the best represented and constitute a factor known to be of health concern. They cannot be neglected during a health and environmental survey. Concerning moulds, 100 cfu/mg (Beguin, 1995) constitute an alert level for a mixture of species.

Finally, to complete the survey, it is also important to take into account mite allergens in dust mattresses and to check the presence of mites in visible mouldy surfaces.

4 DISCUSSION

In order to provide recommendations to improve the chemical indoor air quality one is confronted with the need to use standards or guideline values. At the moment, such guideline values exist in countries like France (ANSES, 2015), Germany (German Committee on Indoor Guide Values (UBA), 2012), Canada (Santé Canada, 2015). Also, the World Health Organization (WHO, 2010) recommends concentration limits for a series of pollutants.

Unfortunately, it is not always easy to apply or use these recommendations due to their incompleteness (the exposure time is sometimes not mentioned) or the fact that they are not comparable (differences in the way of living, in building materials, or in the climate, …). Certain components like limonene and pinene even have no corresponding guideline value (Schleibinger *et al.*, 2002). In order to address the lack of applicable guideline values and to enhance the comparability between specific situations, CRIPI uses the overall Index of Chemical Indoor Air Pollution. It informs the doctor and its patient on the chemical pollution of the visited dwelling in comparison with the Brussels habitat. However, this index has certain limitations. This index is solely based on analytical results from measurements realized in dwellings, with suspected health problems, it does not take into account the 'health factor'.

For the non-pathogenic microorganisms present in the dwellings, there is no standard available. It was therefore necessary to develop a tool that can support the interpretation of the results. Our index was based on the percentile values. It varies from "good" to "unacceptable" through 5 categories. On the scale of percentiles, a first increase occurs between the P75 and the P85 according to the germs and examined matrices. At this level we consider the situation "abnormal" and "bad". A second rapid increase of germs concentration occurs in P90. At this level, the situation must be regarded as an alert level. In P95, the levels should be considered as unacceptable. However, the total mould contamination is often an insufficient criterion. This is why in some indices the presence of specific mould taxa is rather used. Our results concerning airborne moulds show how relevant it is to consider in priority 3 taxa, *Aspergillus versicolor, Cladosporium sphaerospermum,* and *Penicillium spp*. In addition, two strong cellulolytic taxa, *Stachybotrys chartarum,* and *Chaetomium spp,*. are less frequent in Brussels dwellings but their indoor impact is important. But this method has limitations. Microbiological air sampling with a RCS+ is only performed during a short period (2 to 4 minutes). Considering the instability of air and therefore the contaminant load, it was prudent to add further investigations during the survey. Settled dust on the furniture is the result of the days preceding the survey. It is also a reflection of the quality of maintenance in housing. For CRIPI, the RODAC plates applied on the furniture allowed the calculation of two new indices. One concerns moulds but is only focused on *Aspergillus fumigatus*, a thermophilic species with an outside origin. At 45°C, competition between species is limited on the RODAC plate. The accumulation of this species whose spores survival is high, is an easy method to objectively assess dust accumulation levels. For further complementary investigations, mesophilic moulds (25°C) can be taken into account, but an index is difficult to calculate due to frequent colonies confluences.

Concerning mattress dust, the alert level for total moulds of 100 cfu/mg should be considered. In mattresses, it is also important to take into account in priority some specific taxa. For instance xerophilic species such as *Aspergillus glaucus* gr. or *A. restrictus* gr. are considered as frequent contaminants (Chasseur and al, 2015a). Under this alert level, the presence of these species may anticipate an high development in the near future.

5 CONCLUSIONS

These indices are useful to support interpretation of chemical and microbiological results but it remains however necessary to take into account other parameters and the specific context for the final diagnosis. It is also important to recall that these percentiles values do not directly correspond to a health hazard. However, high values of chemical and microbial contamination point to a unhealthy environment and needs to be further explored by the physician. In this period of profound changes in our lifestyles and in particular in our homes, it is useful to have references on indoor pollution, both qualitative and quantitative. Energy saving, new concepts and new materials are innovations that could have an impact on our health in the near future.

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