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Supérieur de la Santé

INDOOR AIR QUALITY IN BELGIUM

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Conseil Supérieur de la Santé

ADVISORY REPORT OF THE SUPERIOR HEALTH COUNCIL No. 8794

Indoor air quality in Belgium

In this scientific policy advisory report the Superior Health Council of Belgium reviews national data on indoor air quality in residences and public buildings and its potential impact on the health of building occupants.

The Superior Health Council recognizes the need for national, harmonized data on indoor air quality and formulates general as well as specific recommendations for research, for policy and the implementation hereof.

This version was validated by the Board on
6 September 2017[1]

SYNTHÈSE

L'air intérieur contient une multitude de contaminants, généralement d'une plus grande variété que ceux rencontrés à l'extérieur, et à des concentrations plus élevées pour certains polluants. Dans notre région, la population passe en moyenne 85 % de la journée à l'intérieur. La qualité de l'air intérieur (QAI) pouvant affecter l'exposition totale (étude UE ENVI, 2009) des occupants d'un bâtiment, il s'agit là d'un déterminant environnemental clé de la santé d'un individu.

L'impact potentiel d'une mauvaise QAI sur la santé et son contexte sont reconnus depuis plusieurs décennies (Nederlandse Gezondheidsraad, publication n° 1984/01), la fumée de tabac ambiante (FTA) étant pointée du doigt comme l'un des principaux responsables de la pollution intérieure et l'enveloppe du bâtiment et sa ventilation comme déterminants potentiels de la QAI. Les tendances mondiales actuelles et les évolutions en matière de durabilité, conduisant à une utilisation accrue de nouveaux matériaux de construction plus durables ou recyclés ainsi qu'à des bâtiments mieux isolés, plus étanches, et de plus en plus écologiques, dotés d'une ventilation mécanique contrôlée, sont en effet susceptibles d'avoir une incidence considérable sur la qualité de l'environnement intérieur dans un avenir proche (Crump et al., 2010). Cette évolution tend également à responsabiliser les occupants des bâtiments dans le maintien d'un air intérieur sain, en termes d'utilisation et d'entretien des systèmes de ventilation, mais aussi en termes de comportements et d'utilisation de produits en intérieur. Des initiatives correctives, préventives et éducatives ciblées, qui respectent le contexte social de ce domaine, sont dès lors nécessaires afin de garantir un air intérieur sain aux citoyens belges.

L'air ambiant serait responsable des 2/3 de la charge de morbidité totale découlant des expositions à l'air intérieur en Europe (Jantunen et al., 2011).

[1] The Council reserves the right to make minor typographical amendments to this document at any time. On the other hand, amendments that alter its content are automatically included in an erratum. In this case, a new version of the advisory report is issued.

Le 1/3 restant de la charge de morbidité liée aux expositions à l'air intérieur est causé par les installations de chauffage et de combustion (cuisson et chauffage à l'aide de combustibles solides), les systèmes d'approvisionnement en eau, et les fuites d'eau. La condensation et le sol sous-jacent sont deux autres sources importantes de radon dans la charge de morbidité liée à la QAI.

Cet examen critique de la QAI des foyers belges et des bâtiments publics s'appuie sur des études scientifiques et des documents parallèles publiés entre 2005 et 2015. Les connaissances actuelles à l'échelon national portant sur les agents chimiques, la pollution intérieure microbiologique, mais aussi le radon, ont été recensées et examinées, et ont permis d'identifier les lacunes nationales et la nécessité de mener de nouvelles recherches. Cette analyse est divisée en trois parties : Polluants chimiques prioritaires de l'air intérieur (PARTIE A), Polluants intérieurs microbiologiques (PARTIE B) et Présence de radon dans l'air intérieur (PARTIE C). Les sous-parties de chaque section analysent avec critique la situation nationale actuelle (en termes de concentrations et d'expositions), identifient les sources intérieures, les effets sur la santé et l'évaluation des risques, la législation en vigueur, et quantifient les bienfaits sur la santé résultant de politiques, ou de mesures préventives ou réparatrices, puis proposent des conclusions, recommandations et appellent à la réalisation de nouvelles recherches. Les environnements intérieurs décrits dans cette analyse sont les logements et les bâtiments publics, par exemple les écoles, les garderies, les bureaux, à l'exclusion des moyens de transport et des expositions professionnelles intérieures. Les contaminants envisagés sont les agents chimiques présents dans l'air intérieur, les polluants microbiologiques et le radon, à l'exclusion des paramètres physiques de l'environnement intérieur (par exemple, la température, l'humidité, les champs électromagnétiques). Les sources chimiques intérieures traitées ici sont les émissions de produit (des matériaux de construction, du mobilier, des produits ménagers et de consommation), à l'exclusion des mesures relatives à l'activité humaine (par ex., tabagisme passif, impact des installations HVAC et des appareils de purification de l'air). Ce point n'est pas repris dans cette analyse en raison de preuves scientifiques exhaustives portant sur l'impact important de la FTA sur la santé et l'exposition intérieure, ainsi qu'en raison de l'existence de mesures préventives législatives, de campagnes de sensibilisation et de recommandations, passées et actuelles, européennes, fédérales et régionales, concernant la fumée de tabac à l'intérieur. Les auteurs soulignent néanmoins l'importance de l'impact du tabagisme intérieur sur la QAI et la santé humaine.

Depuis 2005, une large gamme de produits chimiques a été examinée sur au moins 788 sites intérieurs en Belgique, essentiellement des résidences, écoles et garderies où aucune plainte relative à la santé n'avait été enregistrée. Grâce à ce travail, nous disposons d'un grand nombre d'informations sur la présence en intérieur de produits chimiques, caractérisés par des méthodes d'analyse et d'échantillonnage bien établies et par des impacts toxicologiques connus (tels que les BTEX (benzène, toluène, éthylbenzène, and xylènes), formaldéhyde, acétaldéhyde, trichloroéthylène, tétrachloroéthylène, pinène, limonène et aussi les particules fines (PM), CO, CO_2 et radon). En revanche, des méthodes d'analyse et d'échantillonnage moins bien établies ne nous permettent pas d'en savoir autant sur la présence intérieure d'agents chimiques. Une évaluation traditionnelle de l'impact sur la santé du NO_2, des PM, des composés organiques volatils (COV), des composés organiques volatils totaux (COVT) et du formaldéhyde dans cette analyse indique que 95 % des sites en intérieur étudiés en Belgique peuvent être classés dans la catégorie « danger limité pour la santé causé par la QAI », mais aussi que 5 % des sites étudiés présentent des risques élevés. Le dépassement des valeurs de référence sanitaires et les niveaux de concentration élevés en COVT apparaissent le plus souvent dans des bâtiments où des plaintes relatives à la santé ont été enregistrées. Le benzène et le benzo(a)pyrène sont identifiés comme ayant le plus d'impact sur l'incidence du cancer sur les sites en intérieur étudiés. Il convient de noter que cette conclusion se base sur une évaluation classique substance par substance de quelques composés et sur une sélection de valeurs de référence sanitaires disponibles. Un contrôle des sources dédié est nécessaire pour réduire les risques pour la santé d'une exposition intérieure. Cependant, la disponibilité limitée des données d'émission empêche d'évaluer l'impact des émissions matérielles sur la QAI et les risques associés pour la santé.

La présence d'animaux, de plantes et d'êtres humains à l'intérieur du bâtiment est une source importante d'allergènes. L'air extérieur est également une source importante de spores fongiques naturels en suspension qui peuvent s'introduire dans les bâtiments et former des dépôts de poussière. Des bactéries provenant de l'extérieur et des pollutions spécifiques autour des habitations, produites par l'activité humaine, peuvent s'introduire à l'intérieur et former des dépôts de poussière. Si l'on tient compte de la remise en suspension des poussières, le phénomène d'accumulation des poussières peut être une source importance d'effets nocifs tout au long de l'année. Dans nos régions, la formation de moisissures visibles dues à un excès d'humidité est fréquente et souvent considérée comme la principale contamination microbiologique de l'habitat. L'humidité semble également être un facteur important de l'infestation de cafards et acariens. En Belgique, il existe des structures publiques locales qui effectuent des interventions sur site. Les résultats de ces interventions aident les médecins dans leur diagnostic. Des actions coordonnées contribuent à une meilleure compréhension des pathologies grâce à une étiologie environnementale. Pour la pollution intérieure biologique, il n'est pas possible de définir des normes sanitaires sur le nombre admissible de microorganismes dans l'environnement intérieur, mais certaines valeurs seuils sont calculées à partir de bases de données existantes et sont utilisées par les différents laboratoires. Ces valeurs sont liées à la méthodologie spécifique d'analyse et d'échantillonnage utilisée par chaque laboratoire et permettent de détecter des anomalies microbiologiques dans l'environnement.

Compte tenu du rôle important du radon dans l'exposition de la population belge et le lien clairement établi avec un risque accru de cancer du poumon, l'objectif sur le long terme de la Belgique est de réduire l'exposition moyenne de la population au radon. Dans la partie sud du pays, cet objectif peut être atteint en mettant en œuvre des initiatives de prévention du radon dans les nouvelles constructions et en appliquant des mesures et procédés d'atténuation dans les constructions existantes. Afin d'éviter une nouvelle augmentation de l'exposition au radon, la radioactivité des matériaux de construction doit faire l'objet d'une surveillance, et le radon doit être pris en compte dans la conception de bâtiments basse consommation (avec des taux de ventilation adaptés, en évitant le contact direct entre le sol et l'air, etc.). Pour la partie nord de la Belgique, cela se traduira par le statu quo de la situation actuelle en matière d'exposition. Il convient de noter qu'une réduction de la fumée de tabac entraînerait une diminution du risque présenté par le radon en raison de la relation presque synergique entre le radon et la fumée de tabac. Le radon doit faire partie d'une approche intégrée générale en matière de QAI. Pour ce qui est des mesures de prévention, la garantie d'un environnement intérieur sain dépend largement de l'efficacité et de la pertinence du système de ventilation. L'exposition aux polluants de l'air intérieur (*c.-à-d.* le radon) augmente lorsque la ventilation des bâtiments basse consommation est mal réglée ou ne fonctionne pas correctement.

Pour atteindre une bonne QAI dans les bâtiments, une **approche globale et intégrée en matière de QAI** (comprenant les occupants et leur comportement) devrait être appliquée et consister en une série de mesures de contrôle des sources des polluants chimiques et microbiologiques, de prévention contre le radon ainsi que d'une ventilation intérieure efficace et adaptée. L'expérience a montré que l'exposition aux polluants intérieurs (chimiques, microbiologiques et radon) tend à augmenter lorsque la ventilation du bâtiment est mal réglée ou ne fonctionne pas correctement. Il est, par conséquent, recommandé d'intégrer la QAI dans les exigences et les procédures en matière d'efficacité énergétique de la directive européenne sur la performance énergétique des bâtiments (PEB) ; il est, de plus, nécessaire d'avoir une intégration plus poussée de la QAI dans les systèmes d'évaluation des bâtiments écologiques (BREEAM, Leadership in Energy & Environmental Design (LEED), etc.). Des données récentes ont souligné l'importance d'une QAI saine dans les bâtiments écologiques, après avoir réalisé des rénovations énergétiques, lors de l'utilisation de produits (durables) de construction, ou en modifiant l'isolation ou la ventilation mécanique du bâtiment.

Les mélanges complexes de substances chimiques dans l'air intérieur découlent de différences quantitatives et qualitatives notables entre les émissions provenant de sources de pollution intérieure et leurs effets potentiels sur la santé. Une analyse plus approfondie concernant la formation d'une réaction secondaire et les effets cumulatifs qui découlent d'expositions combinées à diverses substances (par ex., un regroupement de substances provoquant des effets semblables/identiques) est nécessaire pour mieux comprendre la question de la santé et du confort des occupants en intérieur. Une attention toute particulière devrait être accordée aux substances présentant un mécanisme d'action différent mais complémentaire entraînant certains effets sur la santé, telles que les agents mutagènes déclencheurs du cancer, les agents exerçant des effets de formation des tumeurs et des substances entraînant des perturbations du système endocrinien. Dans le cas des polluants chimiques, l'utilisation de **produits à faibles émissions** devrait être renforcée. De plus, une mise au point régulière de la **liste des composés prioritaires** des nouveaux produits chimiques, identifiés lors des mesures d'émission, est recommandée. Par exemple, la liste prioritaire en Belgique ne comprend pas certains composés tels que les retardateurs de flamme ou les phtalates (composés organiques semi-volatils (COSV), soupçonnés d'être des perturbateurs endocriniens) et pour certaines substances de la liste des composés prioritaires (par ex., l'ammoniac), il est urgent de mettre au point/optimiser une méthode d'essai de référence. Il est nécessaire de tenir compte de **la composition chimique de l'air intérieur** dans la caractérisation chimique de l'air intérieur et le contrôle des émissions. Davantage de recherches sont donc nécessaires sur la manière dont un matériau/produit est évalué actuellement dans le cadre de l'étiquetage/la certification par rapport à son comportement dans un environnement intérieur réel où des émissions secondaires viennent s'ajouter aux émissions primaires. **De nouveaux dispositifs d'échantillonnage, méthodes et techniques d'analyse** adaptés au prélèvement en intérieur de nouveaux polluants doivent être mis au point et/ou optimisés.

Il faut procéder à une **harmonisation des stratégies d'échantillonnage, des méthodes d'analyse et des stratégies de traitement des données**. Pour les polluants chimiques et microbiologiques, il a été conclu qu'un cadre consensuel devait être fixé, lequel envisagerait la très grande variété de stratégies d'échantillonnage, de méthodes d'analyse, d'instruments, et d'outils d'évaluation des données en termes de risques pour la santé, d'exactitude et de représentativité. La législation sur les contaminants microbiologiques doit être revue et clarifiée, sur la base d'un consensus méthodologique. Il est nécessaire de mettre sur pied un groupe de travail dédié à la QAI au niveau national, qui conduirait à l'identification des aspects devant être encadrés. L'harmonisation des stratégies pour les outils de répartition des sources, dans le cadre des évaluations QAI dans les milieux intérieurs ayant fait l'objet de plaintes relatives à la santé (répartition des sources) ou non, permettra une anticipation plus ciblée des sources et de la santé des occupants. Les données nationales sur la QAI sont comparables et applicables à plus grande échelle lorsqu'elles se basent sur des stratégies et des méthodes d'analyse et d'échantillonnage (de référence) harmonisées. Cette harmonisation améliorera la validité et l'utilisation d'une base de données de référence sur la QAI et les sources intérieures.

Compte tenu des expositions relativement élevées au radon de la population belge, et le lien bien établi avec l'incidence du cancer du poumon, **une réduction de l'exposition** est l'objectif sur le long terme pour le radon. Dans la partie sud du pays, cet objectif peut être atteint en mettant en œuvre des initiatives de prévention du radon dans les nouvelles constructions et en appliquant des mesures et procédés d'atténuation dans les constructions existantes. Afin d'éviter une nouvelle augmentation de l'exposition au radon, la radioactivité des matériaux de construction doit faire l'objet d'une surveillance, et le radon doit être pris en compte dans la conception de bâtiments basse consommation (avec des taux de ventilation adaptés, en évitant le contact direct entre le sol et l'air, etc.). Pour la partie nord de la Belgique, cela se traduira par le statu quo des niveaux actuels d'exposition.

Il est recommandé d'établir une **base de données de référence à grande échelle sur la QAI en Belgique**, représentative des milieux et des sources intérieures en Belgique, et adaptée à l'exploration des données. Cette base de données devrait donc comprendre divers milieux intérieurs ; des (futurs) composés prioritaires (produits chimiques, radon et contaminants microbiologiques) ainsi que des données d'émission de tout type de produit utilisé dans un environnement intérieur. La base de données permettra une évaluation des tendances d'exposition au fil du temps, et fournira des données pour évaluer les **mesures (politiques) de prévention et de réduction de l'exposition** dans l'air intérieur et pour une étude préliminaire des **coûts socio-économiques** de la qualité de l'air intérieur, afin d'obtenir un calcul plus précis des années de vie ajustées sur l'incapacité (AVCI). Pour le radon, cela permettrait une mise à jour régulière de la cartographie des risques liés au radon et la conception d'un instrument permettant de mesurer et évaluer l'impact et l'efficacité du programme sur le radon sur le long terme. Pour les autres produits chimiques, davantage de données sur les niveaux de base des polluants intérieurs devenus récemment prioritaires (par ex., à partir des données d'émission du produit), ou les nouveaux polluants, conduiront à une évaluation plus précise des risques pour la santé et à la définition d'actions de prévention adaptées. À des fins de prévention, l'établissement d'un **suivi à long terme de la QAI dans un parc de logements représentatif** contribuera à quantifier l'impact des tendances de construction et du comportement des occupants sur la QAI et permettra de rassembler les outils appropriés en matière de gestion des données.

Une **validation et une communication approfondies par rapport aux mesures de réparation** sont nécessaires tant pour les contaminants chimiques que microbiologiques. Dans le cas des mesures de réparation contre les contaminants microbiologiques, des spécifications devraient être rédigées en tenant compte des risques associés des divers types de réparation. Pour la prévention contre le radon, il est recommandé d'établir un code de construction à tous les niveaux législatifs. Une approche progressive est recommandée en matière de protection des occupants, selon le niveau de risque de la zone de construction, avec une protection accrue dans les zones à risque. Un système qui fournit une aide financière pour les mesures d'atténuation des effets du radon pourrait avoir un effet positif. De même, pour l'exposition intérieure aux agents chimiques, il faut une communication claire au sujet de l'efficacité des diverses mesures de réparation.

Une harmonisation s'impose dans l'**évaluation des concentrations recherchées** pour les polluants intérieurs chimiques et microbiologiques préoccupants. Pour les concentrations de moisissures dans l'air ou les spores de moisissure, des valeurs seuils font défaut. Au moment d'évaluer les expositions intérieures aux produits chimiques, il faut en outre envisager une gamme plus large de composés émis, qui aille au-delà des émissions des produits de construction et qui dépasse le champ de compétences de l'Organisation mondiale de la santé (OMS). Par ailleurs, une liste complète et harmonisée des valeurs de référence sanitaires, notamment les nouveaux polluants, permettra une évaluation plus précise de l'impact de la QAI sur la santé. Actuellement, ce travail consiste en un « patchwork » de valeurs de référence (VR) avec divers facteurs d'évaluation.

Cette analyse souligne qu'une approche holistique est nécessaire pour créer une QAI saine qui intègre les polluants chimiques, le radon et les contaminants microbiologiques et qu'elle est soutenue par l'utilisation d'un système de ventilation adapté et efficace. Les lignes directrices nationales et régionales portant sur tous les aspects relatifs à une QAI saine devraient être harmonisées et alignées les unes sur les autres.

Keywords and MeSH *descriptor terms*[2]

MeSH terms*	Keywords	Sleutelwoorden	Mots clés	Schlüsselwörter
Cost of illness	Burden of Disease	Kostprijs van ziekte	Coût de la maladie	Krankheitskosten
-	Disability Adjusted Lifeyears			
Air	Air pollution, indoor	Luchtvervuiling, binnen	Pollution de l'air, intérieur	Luftverschmutzung,innenraum
Environmental pollutants	Microbial pollutants	Microbiële polluenten	Polluants microbiens	Mikrobielle Schadstoffe
	Priority compounds	Prioritaire polluenten	Polluants prioritaires	Schadstoffe met hoher priorität
Radon	Radon	Radon	Radon	Radon
Risk assessment	Risk assessment	Risicobeoordeling	Evaluation des risques	Risikobewertung
Volatile organic compounds	Microbial volatile organic compounds	Microbiële vluchtige organische stoffen	Composants organiques volatils microbiens	Mikrobielle flüchtige organische verbindungen
	Volatile organic compounds	Vluchtige organische stoffen	Composants organiques volatils	Flüchtige organische Verbindungen
	Very volatile organic compounds	Zeer vluchtige organische stoffen	Composants organiques très volatils	Sehr flüchtige organische verbindungen
	Semi-volatile organic compounds	Semi-vluchtige organische stoffen	Composants organiques semi-volatils	Semi-flüchtige organische verbindungen

MeSH (Medical Subject Headings) is the NLM (National Library of Medicine) controlled vocabulary thesaurus used for indexing articles for PubMed http://www.ncbi.nlm.nih.gov/mesh.

[2] The Council wishes to clarify that the MeSH terms and keywords are used for referencing purposes as well as to provide an easy definition of the scope of the advisory report. For more information, see the section entitled "methodology".

CONTENTS

ABBREVIATIONS AND SYMBOLS

ACGIH	American Conference of Governmental Industrial Hygienists
AFSSETT/ANSES	*Agence française de sécurité sanitaire de l'environnement et du travail*
AgBB	*Ausschuss zur gesundeheitlichen Bewertung von Bauprodukten*
AIDS	Acquired Immuno Deficiency Syndrome
AIRMEX	European Indoor Air Monitoring and Exposure assessment
ALARA	As Low As is Reasonably Achievable
APW	*Association des Provinces Wallonnes*
ATSDR	Agency for Toxic Substances and Disease Registry Atlanta US
BIBA	*Binnenlucht in Basisscholen* – Indoor air in Primary schools
BoD	Burden of Disease
Bq	Becquerel
Bqh/m³	Becquerel hour per cubic meter
BSS	Basic Safety Standards
BTEX	Benzene, Toluene, Ethylbenzene and Xylenes
CDC	Centers for Disease Control and Prevention US
CEHAP	Children's Environment and Health Action Plan
CEN	European Committee for Standardization
CFU	Colony Forming Unit
CI	Confidence interval
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COPD	Chronic Obstructive Pulmonary Disease
CPR	Construction Products Regulation
CRIPI	Regional Unit for Indoor pollution in the Brussels Region / *Cellule Régionale d'Intervention en Pollution Intérieure* / *Regionale Cel voor Interventie bij Binnenluchtvervuiling*
DALY	Disability Adjusted Lifeyears
DNA	DeoxyriboNucleic Acid
DNPH	2,4-Dinitrophenylhydrazine
EBoD	Environmental Burden of Disease
EC/OC	Elemental Carbon/Organic Carbon
EHAP	European Environment and Health Action Plan
EOTA	European Organisation for Technical Assessment
EPA	US Environment Protection Agency
EPBD	Energy Performance of Buildings Directive
ETS	Environmental Tobacco Smoke
FANC	Federal Agency for Nuclear Control
FARES	*Fonds des Affections RESpiratoires ASBL*
FLIES	Flemish Indoor Exposure Study
GC-MS	Gas Chromatography – Mass Spectrometry
GerES	German Environmental Survey
HPLC	High Performance Liquid Chromatography
HVAC	Heating, Ventilation and Air-Conditioning
IAQ	Indoor Air Quality
IARC	International Agency for Research on Cancer
ICRP	International Commission on Radiological Protection
IBGE-BIM	*Bruxelles Environnement - Leefmilieu Brussel*

ICP-OES	Inductively Coupled Plasma Optical Emission Spectrometry
IgE	Immunoglobulin E
ISO	International Organization for Standardization
ITS	Internal Transcribed Spacer
IUR	Inhalation Unit Risk
JRC	Joint Research Centre
LC	Lung cancer
LCI	Life Cycle Inventory
LCI	Lowest Concentration of Interest
LEED	Leadership in Energy & Environmental Design
LNE	*Departement Leefmilieu Natuur en Energie, Vlaamse Overheid*
LPI	*Laboratoire d'études et de prévention des Pollutions Intérieures*
MCR	Maximum Cumulative Ratio
MMK	*Medische MilieuKundige*
MTBE	Methyl tert-butyl ether
mSv	milliSievert
MVOCs	Microbial Volatile Organic Compounds
NEHAP	National Environmental Action Plan
NS	Non Smoker
nSv	nanoSievert
ODTS	Organic Dust Toxic Syndrome
OEHHA	Office of Environmental Health Hazard Assessment
ONE	*Office de la Naissance et de l'Enfance*
OQAI	*Observatoire de La Qualité de L'Air Intérieur*
OR	Odds Ratio
PAH	Polyaromatic Hydrocarbons
PCR	Polymerase Chain Reaction
PM	Particulate Matter
RCS	Reuter Centrifugal Sampler
RIVM	*Rijksinstituut voor Volksgezondheid en Milieu*
RV	Reference Value
S	Smoker
SAMI	*Services d'Analyse des Milieux Intérieurs de Wallonie*
SBS	Sick Building Syndrome
SCHER	Scientific Committee on Health and Environmental Risks
SHC	Superior Health Council
RPA	Radon Prone Areas
SVOCs	Semi Volatile Organic Compounds
TMB	Trimethylbenzene
TVOCs	Total Volatile Organic Compounds
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
US EPA	United States Environmental Protection Agency
VAZG	*Vlaams Agentschap voor Zorg en Gezondheid, Vlaamse Overheid*
VEA	*Vlaams Energieagentschap*
VOCs	Volatile Organic Compounds
VVOCs	Very Volatile Organic Compounds
WHO	World Health Organisation
WIV-ISP	*Wetenschappelijk Instituut Volksgezondheid – Institut Scientifique de Santé Publique*

XRF	X-ray fluorescence
YLD	Years Lost due to Disability
YLL	Years of Life Lost

I. INTRODUCTION AND ISSUES

Indoor air contains a wide variety of contaminants, typically in a wider range than encountered outdoors and some pollutants are present at higher concentration levels indoors. Due to the time activity pattern of the population, in which people spent typically on average 85 % indoors, the overall exposure to environmental pollution is to a large extend determined by the indoor environment (EU ENVIE study, 2009). Therefore, indoor air is an important environmental determinant of an individual's health.

The potential health impact of a poor IAQ and its context have been acknowledged since several decennia (Nederlandse Gezondheidsraad, 1984), highlighting environmental tobacco smoke (ETS) as a major indoor air pollutant and assigning the building envelope and its ventilation as potential determinants of IAQ. Current global trends and evolutions in sustainability, leading to an increased use of new, more sustainable or recycled building materials and resulting in the construction of increasingly energy efficient, airtight and insulated buildings with controlled mechanical ventilation, will indeed have a considerable impact on the quality of the indoor environment in the near future (Crump et al., 2010). More sustainable buildings also trend to lead to an increasing responsibility of building occupants in creating a healthy indoor air, in terms of use and maintenance of ventilation systems.

The contribution of non-ideal IAQ to the loss of healthy life expectancy, expressed as the burden of disease (BoD) in disability adjusted life years (DALY) was calculated in the EU Envie study for 7 health burdens: asthma, cardiovascular diseases, chronic obstructive pulmonary disease (COPD), lung cancer, sick building syndrome, respiratory infectious diseases and acute carbon monoxide (CO) intoxication. The annual BoD contribution in Belgium varied from 1 to 12 thousand per disease. At the EU level this involves overall 2 million DALY's per year within a population of 480 million. A follow up study (IAIAQ, Jantunen et al., 2011) confirmed that the European burden of disease caused or mediated by indoor air is 3 % of the total BoD. It should be noted that this percentage is calculated based on available risk numbers which may underestimate the impact, because for several substances present in the indoor air, no risk numbers are available and therefore ignored in the calculations.

The health benefits of IAQ policies were quantified for a selection of 12 policies. The figures for Belgium varied from 0.7 to 17 thousand DALY's per year per policy. The most significant indoor contaminants in terms of BoD were: fine particulate matter (PM), dampness, bio aerosols, radon, CO, volatile organic compounds (VOC's).

In this context, there is a need for the formulation of guidance and recommendations for the reduction of the health impact caused by the indoor environment, focusing on contaminants that significantly contribute to the BoD. This review of the Superior Health Council (SHC) critically evaluates the current knowledge on the IAQ (chemical pollutants, microbial contaminants and radon exposures) in Belgian households and public buildings, aiming at the identification of research gaps, recommendations and needs on a national level.

II. METHODOLOGY OF THE ADVICE

After analysing the request, the Board and the Chair of the working group identified the necessary fields of expertise. An ad hoc working group was then set up which included experts in the fields of chemical pollutants, radon, microbial pollutants. The experts of this working group provided a general and an ad hoc declaration of interests and the Committee on Deontology assessed the potential risk of conflicts of interest.

This advisory report is based on a review of existing scientific literature and grey literature published from 2005 until 2015, supported by the expertise of the national experts.

The review is divided into 3 main sections: Chemical indoor air priority pollutants (PART A), Indoor microbial pollutants (PART B) and Radon in indoor air (PART C). Subsections of each section critically evaluate the current national state-of-the-art (in terms of indoor concentrations and exposures), identified indoor sources, selected health effects and risk assessments, available legislation, and quantified health benefits resulting from policies, prevention or remediation, followed by the formulation of conclusions, recommendations and research needs.

The indoor environments considered in this review are homes and public buildings e.g. schools, day care centres, offices, excluding interiors of transport vehicles and professional (occupational) exposures indoors. The contaminants considered are chemical agents present in indoor air, microbial pollutants and radon, excluding physical parameters of indoor environments (e.g. temperature, humidity, electromagnetic fields). The indoor chemical sources addressed are product emissions (of building materials, furnishing, household and consumer products). Human activity controlled measures, such as passive smoking, impact of HVAC installations and air cleaning devices, are excluded from this review. Note that passive smoking is not included in this review because of the extensive availability of literature on the impact of indoor smoking on IAQ and occupants' health.

Once the advisory report was endorsed by the working group and by the standing working group «Chemical agents», it was ultimately validated by the Board.

III. ELABORATION AND ARGUMENTATION

1. Chemical indoor air priority pollutants in Belgium

1.1 Introduction

Indoor air contains a wide variety of pollutants, typically in a broader range than encountered outdoors and for large numbers of pollutants at higher concentration levels than outdoors. The overall exposure to air pollution is to a large extend determined by the indoor environment due to the time activity patterns of the population (ENVIE study, 2009) which shows that people typically spend on average 85 % of their time indoors. As a consequence, indoor air is an important environmental determinant of the individual health of a person. Indoor Air Quality (IAQ) is typically determined by the ambient air, the building envelope (air tightness, building ventilation and ventilation system) and indoor sources (such as heating, building materials, consumer products, etc.). The indoor concentration of a pollutant depends not only on its indoor emission rate, but also on the rate at which it is transported from outdoors to indoors, and the rates at which it is scavenged by indoor surfaces, consumed by indoor chemistry and removed by ventilation or filtration (Weshler, 2009). Therefore, global trends in sustainability, resulting in more energy efficient, more airtight, and better insulated dwellings with a controlled mechanical ventilation system, may have an important additional effect on the indoor environment in the future (Crump et al., 2010). In this context, there is a need for the formulation of guidelines and recommendations for the reduction of the health impact attributed to the indoor environment.

The contribution of non-ideal IAQ to the loss of healthy life expectancy, the so-called burden of disease (BoD), expressed in disability adjusted life years (DALY), has been calculated in the EU ENVIE study (2009) for 7 burdens: asthma, cardiovascular diseases, COPD (Chronic Obstructive Pulmonary Disease), lung cancer, SBS (sick building syndrome), respiratory infectious diseases and acute CO intoxication. At EU level overall it involves 2 million DALY's per year within a population of 480 million. Jantunen et al. (2011) reported in the follow up study (IAIAQ, 2010) that ambient air is responsible for two thirds of the total burden of disease (BoD) from indoor air exposures in Europe. The other one third of the BoD related to indoor air exposures is caused by heating and combustion equipment (cooking and heating with solid fuels), water systems, and water leaks. Condensation and underlying soil as a source of radon are other important sources for the IAQ associated BoD. The most important indoor contaminants in terms of BoD were: fine PM, dampness, bio aerosols, radon, CO and to a lesser extend VOCs.

Across Europe, the largest total BoD caused by IAQ from indoor sources is situated in Eastern European countries (up to 8400 DALY/year × million inhabitants), while Northern European Countries have the lowest total BoD caused by IAQ from indoor sources (690 - 980 DALY/year × million inhabitants). Belgium is situated in the second best performing quartile within Europe (980 - 1230 DALY/year × million inhabitants) (Jantunen et al., 2011).

Although the BoD in Eastern European and Balkan countries was reported to be considerably higher (4th Quartile, 1760 – 8400 DALY/year × million inhabitants) than in Belgium, an improvement of the IAQ in Belgian indoor environments would further decrease the total BoD for the Belgian population.

Targeted policy recommendations, abatement measures and guidelines to improve the environment in various indoor settings on a national level can only be formulated after a thorough analysis of the knowledge on the actual Belgian indoor situation.

Neighbouring countries like France and Germany, have taken initiatives to centralize and review IAQ related research on a national scale. Billionnet et al. (2011) reported indoor levels of 20 VOC compounds in 490 dwellings in France in relation to the outcomes of standardized questionnaires on the prevalence of asthma and rhinitis of 1012 inhabitants. The German GerES (German Environmental Survey) consists of representative nationwide population studies that have been repeatedly carried out since the mid-1980s. It focuses on exposure, biomonitoring and assessments via questionnaires in domestic environments. Throughout the years, the outcomes of this large German study have been reported in more than 14 scientific papers (http://www.umweltbundesamt.de). Other initiatives have been carried out in selected European countries, like the EXPOLIS study, on personal exposures and micro-environment levels of air pollutants of urban adults in six European cities during 1 year (1998) (e.g. Kousa et al., 2002; Saarela et al., 2003; Lai et al., 2007) and the AIRMEX study (European Indoor Air Monitoring and Exposure assessment) on indoor, outdoor and personal exposure to VOC from 2003-2008 in public buildings, schools, kindergartens and private homes of eleven cities over Europe (Geiss et al., 2011).

Open literature contains a large volume of scientific, public and official literature on chemical contaminants in indoor environments. A search on the Scopus literature database using the keywords 'indoor air quality', led to a total of 2547 European publications between 2005 and 2013 in the EU (search executed on 16/05/2013). According to this search, United Kingdom, Germany and France are the major contributors to this total amount of European publications. Belgium is ranked at position 13 of the 18 cited European countries and thereby only accounts for 3.8 % of the EU publications on IAQ. Note that countries with less than 20 references are not listed.

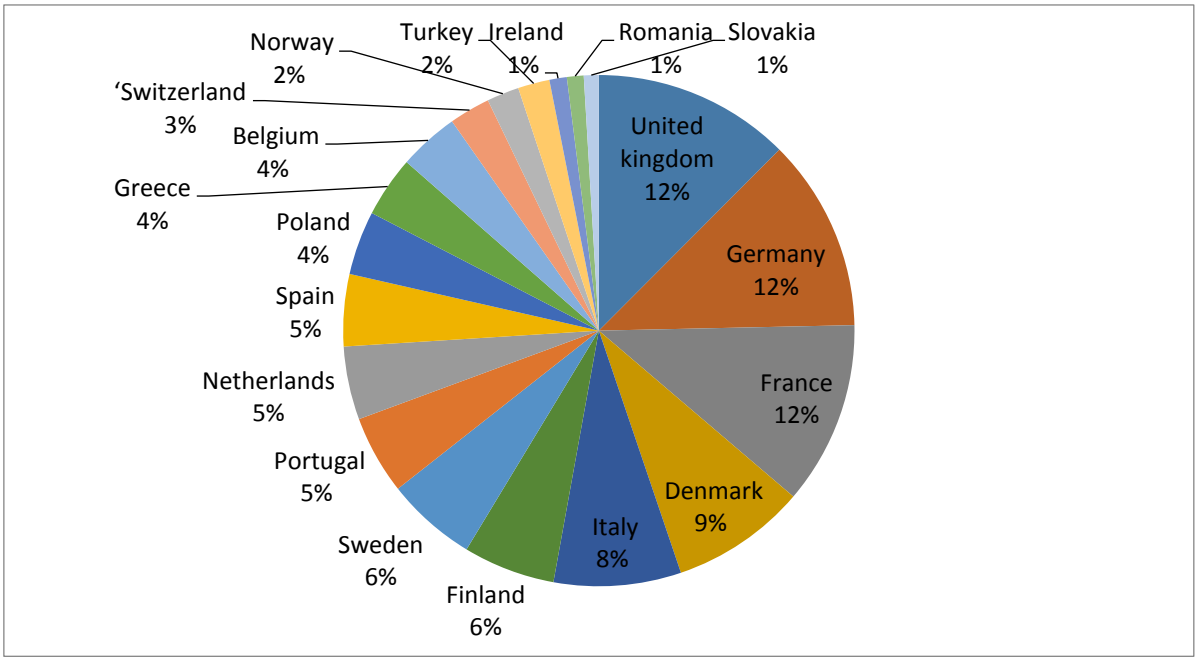

Figure 1. Relative contributions to the total amount of publications on IAQ in Europe from 2005 to 2013 ('Scopus' search 16/05/2013)

Even though in the last decade several Belgian IAQ assessment studies and projects have been carried out on national, regional as well as on provincial level, only few projects have been published scientifically (Bladt et al., 2010; Stranger et al., 2009; Stranger et al., 2008; Stranger et al., 2007). Up to now, no initiative has been undertaken to integrate and critically analyse the various study outcomes of assessments in Belgian schools, day-care centres, dwellings, offices, and other indoor settings in a comprehensive review on IAQ in Belgium.

This review inventories and reviews the various IAQ assessment studies that have been carried out in Belgium since 2005, and reports on a health risk assessment based on the assessed IAQ levels. The wide variety of studied indoor settings and air pollutants will contribute to a more accurate assessment of the health impact of IAQ in Belgium. A comparison of the existing knowledge on IAQ to the current state-of-the-art on product emissions will allow a mapping of future needs on IAQ. Research gaps and needs will be identified and will contribute to the formulation of conclusions and recommendations for the reduction of the health impact caused by the indoor environment.

1.2 Overview of Belgian indoor air monitoring initiatives

1.2.1 IAQ assessment studies in Belgium

Data included in this review are restricted to studies performed between 2005 and 2015. The indoor settings here discussed, are residences and public buildings. However, in order to review IAQ data that are representative for the majority of the population in terms of contribution to the total exposure, public buildings in which people tend to spend less than 5 % of their time (Glorieux et al., 2002; Torfs et al., 2008), are excluded from this analysis.

This review is focused on priority compounds, which are selected based on their prevalence in WHO guidelines for Indoor Air Quality (WHO, 2010), the Flemish IAQ guideline and intervention values at regional level (*Vlaams Binnenmilieu Besluit*, Flemish Decree of the 11th of June 2004), the INDEX project (JRC, 2005), and the Belgian NEHAP (National Environmental Action Plan) priority compounds (Belgian implementation of the European Environment and Health Action Plan). An overview of the targeted chemical priority compounds in this study, supplemented by the health effect that they may cause, is listed in Table 1. Note that for the chemicals below the dashed line in the table, no guideline value was assigned by the WHO, by the Flemish IAQ guidelines or the EU Index project, however they were prioritized in the NEHAP workshop.

Table 1. Overview of the priority compounds considered in this review

Compound	WHO	Flemish IAQ guidelines	EU Index project	NEHAP workshop	IARC classification [$]	Critical health effects*
Benzene	x	x	X(G1)**	X	Group 1	Leukaemia, genotoxicity, haemotoxicological effects
Carbon Monoxide	x	x	X(G1)		-	Neurobehavioral effects, ischaemic hearth disease /death
Formaldehyde	x	x	X(G1)	X	Group 1	Sensory irritation, Respiratory symptoms
Naphthalene	x		X(G1)		Group 2B	Respiratory tract lesions
Nitrogen dioxide	x	x	X(G1)		-	Respiratory symptoms
Benzo(a)pyrene	x					Lung cancer, respiratory effects
Radon	x				Group 1	Lung cancer
Trichloroethylene	x	x		X	Group 2A	Carcinogenicity (liver, kidney, bile duct and non-Hodgkin's lymphoma)
Tetrachloroethylene	x	x			Group 2A	Effects on kidney
Acetaldehyde		x	X(G2)	X	Group 2B	Respiratory symptoms
Total aldehydes**		X				-
Asbestos		X			Group 1	Cancer
Carbon Dioxide		X			-	-
Ozone		X			-	Respiratory symptoms
Toluene		X	X(G2)	X	Group 3	Neurological effects
VOC (total)**		X				-
$PM_{2.5}$ (airborne particles)		X			-	Cardiovascular and Respiratory effects
PM_{10} (airborne particles)		X			-	Cardiovascular and Respiratory effects
Xylenes			X(G2)		Group 3	Sensory irritation, neurological effects
Styrene			X(G2)		Group 2B	Neurological effects
Alfa-pinene			X(G3)	x		Sensory irritation
Limonene			X(G3)	x	Group 3	Sensory irritation, neurological effects
Ammonia			X(G3)		-	Respiratory effects
1,2,4 trimethylbenzene				x	-	Neurological effects, decreased clotting time
Triclosan				x	-	Endocrine effects
Methylene-di-isocyanate				x	-	Hyperplasia of the olfactory epithelium
Glycol ethers				x		
Permethrin				x	Group 3	Neurological effects
Vinylchloride				x	Group 1	Cancer, effects on liver
Brominated Flame Retardants				x	-	Neurobehavioral effects

**health effects reported in the INDEX study (JRC, 2005), WHO IAQ guidelines (2010)*

*** G1: high priority compounds; G2: second priority compounds and G3: Chemicals requiring further research with regard to human exposure or dose response*

[$] IARC classification: Group 1: Carcinogenic to humans; Group 2A: Probably carcinogenic to humans; Group 2B: Possibly carcinogenic to humans; Group 3: Not classifiable as to its carcinogenicity to humans (http://monographs.iarc.fr/ENG/Classification/index.php)

The listed initiatives in establishing guideline values and priority compounds have resulted in several national and European initiatives related to the indoor environment, source characterisation, exposure and risk assessments, health impact evaluations and scattered national or regional legislative initiatives. In the time frame of the EHAP (European Environment and Health Action Plan)-NEHAP, several IAQ monitoring campaigns and studies (e.g. FLIES (Flemish Indoor Exposure Study), BIBA (*Binnenlucht in Basisscholen* – Indoor air in Primary schools), Clean Air Low Energy, screening of dwellings, green ambulances), policy inventarisation studies, source characterisation projects (e.g. Hemicpd) and related risk assessments have been initiated in Belgium, resulting in proposals for measures to tackle sources and reduce the health impact. Sources that mainly have been addressed in Belgium up to now are indoor consumer and building products e.g. air fresheners, floor coverings, construction materials rather than mechanical ventilation systems, air cleaning devices or activity control (except Environmental Tobacco Smoke (ETS)). Legislation with a strong impact on the indoor environment was implemented through EPBD regulations and through regional IAQ guidelines and intervention values.

The experience and expertise that has been built up through this wide variety of studies and projects in Belgium, led to considerable contributions and leading roles in multiple ongoing EU projects (e.g. Officair, EPHECT, Sinphonie, Intarese, etc.) as well as data supply for SCHER (Scientific Committee on Health and Environmental Risks) and IndoorMonit.

In the field of Belgian indoor air quality monitoring, two different types of IAQ assessments can be distinguished: **(1) IAQ studies in health complaint-free indoor settings**, organized in buildings where no health complaints are reported by the occupants, in order to determine representative pollutant levels in characteristic indoor micro-environments (to set 'baseline' indoor air quality values) and to evaluate the potential health risk hereof, and **(2) IAQ studies in buildings where occupants report indoor-related health complaints**, organized to identify a cause or a source of indoor contamination and health complaints. The two different types of IAQ assessments are discussed in the following paragraphs.

1.2.2 Air Quality assessments in health complaint-free indoor settings

1.2.2.1 Description of the Belgian studies

This first type of IAQ assessments consists of targeted larger scale studies. In Belgium, this research is organised on a regional level or consists of national contributions to larger-scale EU research projects. The main objectives are to identify common indoor sources in the study population and to establish baseline values of chemical indoor air pollutants in specific indoor environments. This type of studies is also organized to evaluate IAQ in relation to regional (Flemish Indoor Environment Decree, 11th of June 2004) or other relevant IAQ guidelines (e.g. WHO IAQ guidelines) as well as to assess the exposure and health risk related to a specific indoor setting. The study design (recruitment and selection of indoor sites, pollutants, sampling methods, sampling duration and strategies) is subject to the specific focus of the project, and thus may vary between the different studies.

The **FLIES** study was organized in 2006-2007 to explore indoor and related outdoor levels of 14 air contaminants and the associated health risk in different environmental settings. Dwellings, learning environments (schools, day-care centres), transport (public and private transport) and recreational rooms (gym room, swimming pool and library) were included; sampling was performed on 190 sampling points at 73 locations. Passive air samplers were exposed during one week to assess air concentrations of aldehydes (Umex 100 passive sampler, SKC), VOCs (radiello passive sampler, Supelco) and NO_2 (IVL passive sampler, Sweden). Indoor CO_2, temperature and relative humidity were monitored as well.

The **BIBA** project was organised during the heating season of 2008-2009 in 90 classrooms of 30 primary schools; 14 air contaminants were measured during 5 consecutive school days in 150 indoor and outdoor sampling points. The objective was to assess indoor concentration levels in a set of classrooms, homogeneously covering Flanders, and representative for the actual school building patrimony in Flanders. The impact of ambient air, classroom furniture and (non-) ventilation on the IAQ, and the relation with the respiratory health of pupils was studied. Passive air samplers were exposed simultaneously indoors and outdoors during five consecutive school days to assess air concentrations of aldehydes (Umex 100 passive sampler, SKC) and VOCs (radiello passive sampler, Supelco). Particulate matter levels were studied optically (Grimm 1.108 monitor) as well as gravimetrically (Harvard type MS&T area samplers, Air Diagnostics) during teaching hours (i.e. from 8:00 a.m. until 04:00 p.m.). Indoor CO_2, temperature and relative humidity were monitored continuously during the sampling period of each school.

In the **Surveillance of Complaint-Free Dwellings**, a set of 20 chemical contaminants was assessed in 450 residences, geographically covering the regional area of Flanders and including a selection of residences that is representative for the actual building stock and urban as well as rural areas. Fieldwork was organized from 2008-2012 and covered all seasons. The objective of this study was to assess IAQ values in representative complaint-free houses, to identify sources and causes of increased indoor levels and to evaluate the indoor environment of complaint-free houses to the Flemish Indoor Environment Decree. Passive samplers were exposed indoors during 7 days to assess air concentrations of aldehydes (Umex 100, SKC), VOCs (radiello) and NO_2 (IVL, Sweden). Indoor CO_2, temperature and relative humidity were monitored as well.

Clean Air Low Energy was targeted to dwellings and schools in mechanically ventilated low-energy and passive buildings. Simultaneous indoor and outdoor sampling was performed in 25 houses and 26 classrooms using passive samplers for aldehydes (Umex SKC) and VOCs (radiello) measurements. PM was studied gravimetrically ($PM_{2.5}$, Harvard type MS&T area samplers; in classrooms from 8:00 a.m. until 04:00 p.m.; in houses during 3 successive days of 24h) as well as optically (Grimm 1.108). Besides CO_2, temperature and relative humidity monitoring, the building air tightness and the ventilation rate were characterised as well. Additionally air samples and settled dust was analysed for bacterial and fungal content.

In the activities of the **Green Ambulance CRIPI** (French acronym of the Regional Unit for Indoor pollution in the Brussels Region), a new project was developed in 2006. A third of the total number of CRIPI enquiries concern the age group of 0-6 years and nurseries; so places where young children spend a lot of their time. Therefore an extension of the routine work of CRIPI has been developed to carry out enquiries on the quality of the indoor environment in nurseries. Approached on a voluntary basis, 28 nurseries have been analysed. A questionnaire was completed by the staff of the nursery before the measurements were performed in the different rooms (playrooms, bathrooms, bedrooms and kitchen). The following pollutants are quantified: VOC (benzene, toluene, xylenes, chlorinated solvents, terpenes, etc.), formaldehyde, and pesticides. Temperature, relative humidity, particles matter (PM1-2.5-10), CO_2 and nitrogen oxides were also measured.

The **NEHAP Nurseries project** aimed at identifying problems in the indoor environment of nurseries in order to reduce a potential negative impact on children's health, to enhance awareness and prevention in nurseries in relation to indoor environment, to support participating nurseries in adapting and improving the quality of indoor environment and to suggest efficient solutions to the identified problems. Jointly financed by the Belgian ministers in charge of environment or health as part of the implementation process of the CEHAP (Children's Environment and Health Action Plan) (www.nehap.be), the project developed an auto-assessment tool enabling to evaluate the indoor environment of nurseries. It was based on factors that could be observed by the staff. The aim of this phase was to assess about 600 nurseries on a national scale. Training sessions have been organised locally, explanatory guidelines were developed and a help desk service was made available during the whole process.

An additional analytical phase enabling evaluation of factors that could not be observed by the staff was organised. This investigation was carried out in a limited number (25) of nurseries. The temperature and relative humidity have been measured by means of a CTN device and CO and CO_2, respectively by means of an electrochemical device and a PID device (all TESTO 400). VOCs have been analysed by gas chromatography – mass spectrometry (GC-MS) according to the NBN EN ISO 16017-1 standard after 4 hours of sampling (300 ml/min) with a Gilair 5 programmable personal sampling pump (Gillian) having a capacity of 20 ml to 6 l/min. on carbotrap cartridges. Formaldehyde and acetaldehyde have been analysed by high performance liquid chromatography (HPLC) (ISO 16000-3) after 48 hours of passive sampling on a DNPH (2,4-Dinitrophenylhydrazine) cartridge. Lead in paintings has been tested with a portable X-ray fluorescence (XRF) spectrometer (NITON XLP/300) and confirmed by atomic absorption if presence was detected, according to the standard NF FD T90-119. Lead in water has been analysed by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) (ISO 11885 standard) with a Perkin-Elmer. PM2.5 and PM10 have been sampled through a gravimetric method (Impactor Harvard) and the inorganic composition of the samples determined with an EDXRF Epsilon-5 system. An alpha counter (RADIM 3A) allowed to identify the level of radon. Mould in air has been sampled by means of a RCS + Biotest and on surfaces by means of the RCS (Reuter Centrifugal Sampler) method and RODAC boxes. Legionella, for which the lab is ISO 17025 certified, has been identified through a PCR (Polymerase Chain Reaction) research method and culture undertaken when PCR was positive (standard NF T90-431). Dust mites have been tested with an Acarex test. The analytical phase has allowed confirming some elements highlighted through the questionnaire or highlighted new ones. In order to increase the long term impact of the project, all participating nurseries received targeted recommendations, results have been presented during training sessions and a tool kit has been proposed for future workshops.

The **PAH study** (Polyaromatic Hydrocarbons study) was organized in order to assess the indoor exposure and demonstrate the applicability of human biomarkers for PAHs in Flanders. More specific the study aimed at: (i) an estimation of the sources of indoor PAHs, (ii) the use of biomarkers for estimation of PAH exposure and effects, (iii) putting forward interesting indicators/compounds for policy follow-up of indoor air quality. Indoor measurements of PAH in suspension and in settled dust were performed in 25 residences in the provinces of Antwerp and Limburg, in Flanders during winter and summer of 2010. 16 PAH compounds were identified in both fractions: naphthalene, acenaphtylene, acenaphthene, fluorene, fenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, dibenzo(a,h)antracene, benzo(g,h,i)perylene.

The **SAMI-LUX** (*Services d'Analyse des Milieux Intérieurs de Wallonie - Luxembourg*) **study in primary schools** was organised in 72 schools in the province of Luxembourg in order to assess the school indoor environment, to formulate recommendations and to sensitize the school population. VOCs and TVOC were monitored actively during 60 minutes (carbotrap), and formaldehyde was sampled actively during 240 minutes. Temperature, relative humidity and CO_2 were determined by 6 point measurements during the first half of a school day.

Table 2 gives an overview of all IAQ surveys campaigns that have been performed in Belgium in health complaint-free buildings since 2005. In the table it can be noticed that the majority of these locations concerns residences. Knowledge on IAQ in public buildings is focussed to studies in schools and nurseries. Only a minor fraction of the air samples has been collected in recreational rooms or transport means. In total 573 health complaint-free residences, 117 schools and 98 nurseries have been characterised by surveys on IAQ in Belgium. Furthermore, it can be noticed that IAQ surveys are commonly focused to the characterization of multiple components. In fact every reported study reports at least 12 indoor chemical parameters. It should be noted that Table 2 only reports studies with open access to data.

Table 2. IAQ surveys in health complaint-free indoor environments in Belgium since 2005

Study	Objective	N° of chemical contaminants	Locations	N° of sites	Coordinator
LNE FLIES (2006-2007)	Explore IAQ levels; measure IAQ guidelines	14 – indoors and outdoors	Dwellings, learning environments, transport and recreational rooms	190 sampling points of 73 locations	Environment, Nature and Energy Dept., Flemish Government
LNE – VAZG BIBA (2008-2009)	Explore IAQ levels at school; identify sources; measure IAQ guidelines	14 – indoors and outdoors	Primary school classrooms	150 sampling points, 90 classrooms , 30 schools	Environment, Nature and Energy Dept. and Dept. of Public Health Flemish Government
VAZG Flanders Surveillance of Complaint-Free Residences (2008-2012)	Explore IAQ levels in dwellings; identify sources; measure IAQ guidelines	20 - indoors	Dwellings	450 residences	Dept. of Public Health Flemish Government
LNE – VEA Clean Air, Low Energy (2011-2012)	Explore IAQ levels in dwellings; identify sources; measure IAQ guidelines	23 – indoors and outdoors	Energy efficient dwellings and school classrooms	104 sampling points, 27 classrooms and 25 dwellings	Environment, Nature and Energy Dept. and Energy Agency, Flemish Government
CRIPI nurseries	Explore IAQ levels in day-care centres, identify sources	37 - indoors and outdoors	Playrooms, bathrooms, bedrooms, kitchen	28 nurseries	Brussels Environment (BIM)
NEHAP nurseries project (2007-2009)	Develop an auto-assessment tool, confirm and explore IAQ levels , propose appropriate recommendations and develop a training toolbox	Auto-questionnaire + 15 parameters indoors, part outdoors	Day care centres	494 nurseries through auto-questionnaire + 25 nurseries tested, 3 rooms/nursery	*Hainaut Vigilance Sanitaire – Hygiène Publique en Hainaut*
Nurseries in Hainaut Province (2004-2005)	Explore IAQ levels and propose appropriate recommendations	12 parameters	Day care centres	45 nurseries	*Hainaut Vigilance Sanitaire – Hygiène Publique en Hainaut*
LNE - PAH study (2010)	Assessment of indoor exposure and use of human biomarkers for PAHs in Flanders	16 parameters, in gas phase, particulate matter and settled dust, indoors and outdoors	Dwellings	25 residences	Environment, Nature and Energy Dept. Flemish Government
SAMI-LUX (2010)	Explore IAQ levels in primary schools	18 parameters, indoors	Primary school classrooms	72 schools	SAMI-LUX

1.2.2.2 IAQ monitoring results in complaint-free settings

The set of chemicals assessed in a survey on IAQ is function of the specific research objective of that study, e.g. studies aiming at an impact assessment of outdoor environmental conditions on the indoor environment such as traffic, typically include NO_2, BTEX, and PMx; whilst studies focussing on the assessment of the impact of ventilation, building materials, furniture, or decoration on the IAQ target on indoor aldehydes and VOCs. **Erreur ! Source du renvoi introuvable.** provides an overview of the different sets of chemicals that have been quantified in the respective Belgian studies on IAQ since 2005.

According to this overview (**Erreur ! Source du renvoi introuvable.**) 9 of the 30 priority compounds (as listed in Table 1) have not been quantified in any of the Belgian IAQ surveys. These include CO, ozone, ammonia, triclosan, methylene-di-isocyanate, glycol ethers, permethrin, vinylchloride, and brominated flame retardants. CO however, was reported to be part of the measuring plan of several studies, but it was only monitored in case of suspicion. Ozone was not included in the measuring plan of the studies reported in this review, but it has been monitored in residential and school indoor environments before the year 2005 (Stranger et al. 2009; Stranger et al. 2008). Because of the instability of this compound in indoor environments, indoor levels are generally low. It can be concluded that for the compounds *ammonia, triclosan, methylene-di-isocyanate, glycol ethers, permethrin, vinylchloride and brominated flame retardants*, there is a need for baseline reference values for indoor air on a national level. Note that several of these are emerging pollutants of which indoor levels, the toxicological impact and related exposures are currently still being explored and evaluated (e.g. the INFLAME study, in which exposures, exposure pathways, and toxicological aspects of flame retardants are studied - http://www.birmingham.ac.uk/research/activity/inflame/index.aspx).

Only 11 of the 30 priority compounds listed in Table 1 have been quantified in a major part of the 788 Belgian health complaint-free indoor settings (residences, schools and nurseries). Based on the quantity and the random selection procedures of the sampling sites, we can assume a representative subsample of the Belgian building stock. In fact, only *benzene, toluene, formaldehyde, acetaldehyde, tetrachloroethylene* (all but two) *and TVOC* have been quantified in all listed Belgian studies, except for one. An overview of the indoor air concentration levels that were found for these compounds is shown in Table 3. Concentrations varied considerably for certain compounds, such as benzene, toluene, acetaldehyde and TVOS of which the median values in the different datasets ranged from 0.7 to 5.0 µg/m³, from 1.7 to 20 µg/m³, from 5 to 22 µg/m³ and from 63 to 490 µg/m³ respectively. For other compounds quantified in the major part of the datasets, such as formaldehyde, smaller variations were noticed between the different datasets, with median values ranging from 11 to 23 µg/m².

NO_2, $PM_{2.5}$, PM_{10}, styrene, alpha-pinene and limonene were only characterised in half of the available Belgian studies. For these parameters a considerable variability was noticed, which was most pronounced, for PM fractions and limonene. For PMx (particulate matter in suspension) the lowest concentrations were observed in residences, the highest levels were found in schools and nurseries, both characterised by more resuspension of settled dust as a consequence of the movements of people/children, with a higher impact on the larger PM fractions.

Additionally, a significant set of chemical parameters, other than the listed priority compounds, has been quantified in health-complaint-free indoor environments. They include alkanes, methyl tert-butyl ether (MTBE), pesticides, and PAH compounds different from naphthalene and benzo(a)pyrene.

Table 3. Indoor concentration levels of benzene, toluene, formaldehyde, acetaldehyde, tetrachloroethylene and TVOC (in µg/m³).

		benzene	toluene	formaldehyde	acetaldehyde	tetrachloroethylene	VOC (total)**
FLIES residences	min	0.7	1.3	1.4	1.1	0.1	138
	median	2.1	8.1	23.7	21.8	0.3	491
	mean	2.95 ± 3.1	14.0 ± 18.5	31.6 ± 23.6	23.7 ± 17.8	1.45 ± 6.0	580 ± 337
	max	23.7	122	124	65	52	2790
VAZG residences	min	0.1	0.9	0.2	0.7	0.1	0.1
	median	1.0	5.1	22.7	6.2	0,1	337
	mean	1.65 ± 2.56	31 ± 366	26.1 ± 16.4	8.5 ± 16.0	1.24 ± 10.0	437 ± 550
	max	29	7704	180	264	195	7520
Clean Air Low Energy residences	min	0.1	0.9	5.0	6.3	0.1	184
	median	0.8	1.7	16.3	7.7	0.1	271
	mean	0.98 ± 0.57	3.1 ± 2.68	16.9 ± 6.8	8.5 ± 1.74	0.10 ± 0.000	318 ± 193
	max	2	11	29	13	0.1	1170
FLIES day-care centres	min	1.22	2.93	10.8	3.1	0.2	255
	median	1.98	4.2	16.5	18.5	0.2	395
	mean	1.92 ± 0.60	4.7 ± 1.87	19.4 ± 9.5	21.2 ± 19.6	0.28 ± 0.20	429 ± 179
	max	2.85	7.9	34	43	0.68	766
BIBA schools	min	0.4	0.9	6.3	2.2	0.1	11
	median	1.1	3.2	23.0	5.1	0.2	64
	mean	1.41 ± 0.88	4.5 ± 4.8	25.6 ± 12.9	5.4 ± 1.84	0.37 ± 0.44	74 ± 60
	max	4.0	40.5	70.6	11.7	2.2	500
Clean Air Low Energy schools	min	0.7	1.2	12.1	4.1	0.1	146
	median	1.1	5.2	22.9	6.5	0.1	439
	mean	1.64 ± 1.14	10.9 ± 17.8	25.9 ± 11.0	8.7 ± 5.2	0.14 ± 0.12	455 ± 229
	max	5.8	89.0	62.3	23.7	1	1036
CRIPI nurseries	min	1.0	3.0	5.6		0	21
	median	2.0	7.7	17.9		2	75
	mean	2.1	10.7	20.6		4	79
	max	4.3	46.6	78.0		19	186
Belgian nurseries	min	0.5	0.5	6.2	2.9		93.9
	median	2.0	19.7	15.1	6.7		467
	mean	2.9	35.5	21.2	8.7		736
	max	8.5	344	103	24.3		2700
SAMI-LUX schools	min	0.6	0.0				8,0
	median	5.0	8.2				228
	mean	7.5	40.9				1170
	max	43	2681				42100

An important consideration concerning the applied sampling methods should be made when comparing and evaluating the outcomes of the IAQ assessments. In fact the different study objectives of the surveys that were translated into measuring plans and sampling methods differ between the different studies. As a consequence both active and passive measurement techniques have been applied to assess the same chemical.

For VOC quantification as an example, passive sampling devices were utilised during 1 hour, 5 days and 7 days, but also active sampling on Tenax was applied during shorter periods of time in one study. However, assuming an effective quality assurance and quality control in each laboratory involved in the different field studies, the accuracy of all outcomes should be acceptable and data can be mutually compared. Specifically when reporting TVOC concentrations, different analytical definitions of this compound group may have been applied (ECA report n°19, 1997), which could (will) impact on the reported concentration ranges. Also for PMx quantifications, both gravimetrical and optical techniques have been applied. Considering the influence of meteorological circumstances on the outcomes of optical PMx measurements, caution should be taken when comparing the PMx outcomes of different studies. Concerning field sampling and installation procedures, guidelines for indoor sampling as described in ISO 16000-1 were respected in the Belgian studies.

Table 4 Overview of chemical characterisations in health complaint-free indoor settings

Compound	SCHOOLS/DAYCARE CENTRES **COMPLANT-FREE**						HOUSES **COMPLAINT-FREE**				
	BiBa	Clean Air Low Energy	Nurseries Hainaut	NEHAP Nurseries	CRIPI Nurseries	FLIES - child care	SURVEILLANCE	Clean Air Low Energy	FLIES dwelling	PAKS	500 dwellings
Prioritised compounds											
Benzene	X	X	X	X	X		X	X			
Carbon Monoxide											
Formaldehyde	X	X	X	X	X	X	X	X			X
naphthalene										X	
Nitrogen dioxide					X	X	X		X		
Benzo(a)pyrene										X	
Radon			X	X							
Trichloroethylene		X					X	X			
Tetrachloroethylene	X	X					X	X			
Acetaldehyde	X	X		X		X	X	X			
Total (other) aldehydes**	X	X				X	X	X			
Asbestos			X	X							
CO_2 (24h) [ppm]	X	X	(X)	(X)	X		X	X			
Ozone											
Toluene	X	X	X	X	X		X	X			
VOC (total)**	X	X	X	X		X	X	X	X		
PM $_{2.5}$ (airborn particles)	X	X		X	X	X		X			
PM $_{10}$ (airborn particles)				X	X	X					
m- + p-Xylene [µg/m³]	X	X	X	X	X		X	X			
o-Xylene [µg/m³]	X	X	X	X	X		X	X			
Styrene		X	X	X			X	X			
Alpha-pinene		X			X		X	X			
Limonene		X			X		X	X			
Ammonia --- 1,2,4 trimethylbenzene	X	X					X	X	X		
Triclosan											
Methylene-di-isocyanate											
Table 4 continued											
Glycol ethers											
Permethrin											
Vinylchloride											
Brominated Flame Retardants											

Compound	SCHOOLS/DAYCARE CENTRES **COMPLANT-FREE**						HOUSES **COMPLAINT-FREE**				
	BiBa	Clean Air Low Energy	Nurseries Hainaut	NEHAP Nurseries	CRIPI Nurseries	FLIES - child care	SURVEILLANCE	Clean Air Low Energy	FLIES dwelling	PAKS	500 dwellings
---------- **other compounds**											
Hexane		X					X	X			
Heptane		X					X	X			
Cyclohexane		X					X	X			
Methyl cyclohexane											
MTBE	X	X					X	X			
Ethylbenzene	X	X	X	X			X	X			
1,4-Dichlorobenzene		X			X		X	X			
n-Butylacetate		X					X	X			
3-Carene		X					X	X			
Hg											
Pesticides					X						
acenaftyleen (ng/m³)										X	
acenafteen (ng/m³)										X	
fluoreen (ng/m³)										X	
fenanthreen (ng/m³)										X	
antraceen (ng/m³)										X	
fluorantheen (ng/m³)										X	
pyreen (ng/m³)										X	
benzo(a)antraceen (ng/m³)										X	
chryseen (ng/m³)										X	
benzo(b)fluorantheen (ng/m³)										X	
benzo(k)fluorantheen (ng/m³)										X	
benzo(a)pyreen (ng/m³)										X	
indeno(1,2,3,c,d)pyreen (ng/m³)										X	
benzo(g,h,i)peryleen (ng/m³)										X	
dibenzo(a,h)antraceen (ng/m³)										X	

1.2.3 Air quality assessments in health complaint indoor settings

1.2.3.1 Description of the Belgian studies

The second type of IAQ studies in Belgium focuses on settings where occupants report health complaints that are potentially related to the indoor environment. The studies are organized to identify a cause or a source of indoor contamination, and may therefore be of smaller scale, and more diagnostically than the first study type, since each case is considered and reported separately. Aiming at the reduction of health complaints related to the indoor environment in residences and in public buildings, the regional Belgian governments have developed the local IAQ services for citizens. The local IAQ services offer a screening of the indoor environment, adapted to the occupant's health complaint(s) and to the diagnostics of treating doctors. The aims of their actions are the identification of these problems and the formulation of remedial actions. The monitoring objective is to organise measurements in response to health and comfort complaints of occupants; in specific cases they can also be organised with the objective to evaluate the success of remedial actions.

For reasons of authorisation, the Belgian local IAQ services are organized on a regional level. This implies that Belgium has the '*Ambulance Verte CRIPI-RCIB'* (Brussels), the 'IAQ Service' (Flanders) and the 'SAMI' service (the Walloon region, e.g. the 'SAMI-Lux' in the Province of Luxembourg). These 3 Belgian systems follow a similar strategy and share the same aims and objectives. They typically follow a stepwise, systematic approach, which is described in an IAQ service protocol. This protocol consists of a questionnaire-based screening of the environment, an indoor environment inspection, the consultation of previous cases in a database on IAQ complaints, the organisation of air quality measurements and the comparison of the outcomes with similar cases, with IAQ guidelines and with typical pollutant levels reported in complaint-free houses. The results and, if applicable, a proposal for remedial actions are directly reported to the occupant. If necessary this process is followed by a verification of the effectiveness of the remedial actions.

It should be emphasized that not for all complaints all stages of the protocol are undertaken. In some cases, the cause of the health problem can already be identified in one of the first stages of the protocol. This is then based on experience and IAQ measurements in previous, similar cases. In such a case no further actions are needed to formulate remedial actions for the occupant to create a healthier indoor environment.

In the Brussels-Capital Region the unit termed "CRIPI" developed the format of "**Green Ambulances**". It provides a service to medical doctors in an "indoor environmental diagnosis" to support medical diagnoses and to relate indoor environment and its impact on health. Until now CRIPI has performed more than 1800 enquiries. The investigation at each home included three parts: the completion of a questionnaire by the occupant, if possible the patient; and chemical and biological sampling of the dwellings. At the chemical level, air samples are taken using a passive radial diffusion device (radiello, Supelco) filled with Tenax for adsorption of volatile organic compounds such as benzene, toluene, xylene, chlorinated compounds, terpenes etc. The complete sampling procedure takes on average one hour. The compounds retained on the cartridges are subsequently thermally desorbed. Formaldehyde is directly measured by using a portable analyser INTERSCAN with electrochemical cell. A systematic diagnosis of the chemical and biological parameters is realized from the main living rooms and from outside. Each result is stored in a database together with information from the questionnaire. This allows to evaluate the quality of indoor air in the Brussels Region but also to develop a strategy for preventive actions in indoor pollution.

In the **VAZG** (*Vlaams Agentschap voor Zorg en Gezondheid*) **IAQ service** in Flanders, the indoor environment was assessed using passive samplers for aldehydes (Umex 100, SCK) and VOC (radiello, Supelco) measurements. Depending on the nature of the potential indoor source, complementary active sampling on Tenax was performed. If included, PM was studied gravimetrically ($PM_{2.5}$, Harvard type MS&T area samplers), where after it was subject to further characterisation steps (XRF, electron microscopy, Elemental Carbon/Organic Carbon (EC/OC) analysis, etc.). CO_2, temperature and relative humidity are monitored throughout each respective sampling campaign.

The **SAMI** (Service for Indoor Environmental Analysis) in the Walloon region closely collaborates with doctors in order to identify a possible relation between patients' health problems and the occurrence of indoor air pollutants in buildings. A wide variety of chemicals can be characterised in the indoor environment depending on walk-through observations and symptoms of the inhabitants. Results of the IAQ assessment and recommendations to improve the indoor environmental quality are reported to the doctors, who inform their patients.

Table 5. IAQ surveys in health complaint indoor environments in Belgium since 2005

Study	Objective	N° of chemical contaminants	Locations	N° of sites	Coordinator
CRIPI	IAQ source/cause identification	14 – Indoors and outdoors	Residences in the Brussels Region	1800 dwellings	Brussels Environment (BIM)
VAZG IAQ service	IAQ source/cause identification	Variable, depending on the case	Residences and public buildings in the Flanders Region	54 without measurements / 27 with measurements	Dept. of Public Health Flemish Government
SAMI	IAQ source/cause identification	Variable, depending on the case	Residences and public buildings in the Walloon Region		

1.2.3.2 IAQ monitoring results in health complaint indoor settings

1.2.3.2.1 Indoor related health effects and their origins

Health complaints (defined as health symptoms diagnosed by a medical doctor), reported by the occupant to be potentially related to the indoor air quality of a residence or a public building, are inventoried by the respective regional organising services for public health. Although a wide variety of health complaints is reported, the nature of the complaints allows a categorisation into 9 commonly reported health symptoms: (1) airway related symptoms, (2) fatigue, (3) allergies, (4) irritation of mucus membranes, (5) eye irritation, (6) headache, (7) dizziness, (8) skin irritations, (9) others.

The prevalence of these health symptoms is illustrated in Figure 2, which is based on 194 reported health complaints in 2012 at the Flemish IAQ Services. The figures highlight airway related symptoms as being the most prevalent symptom related to the indoor environment, followed by allergies and headaches. Eye irritations and dizziness are least frequently reported.

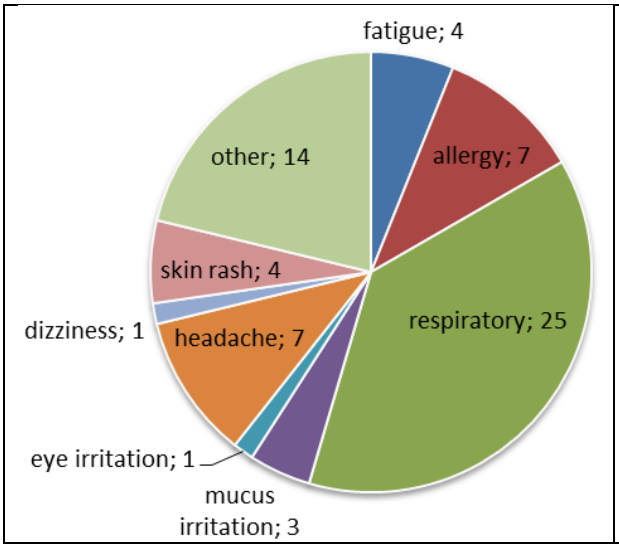

Figure 2. Health symptoms related to 194 reported complaints in 2012 (Flanders)

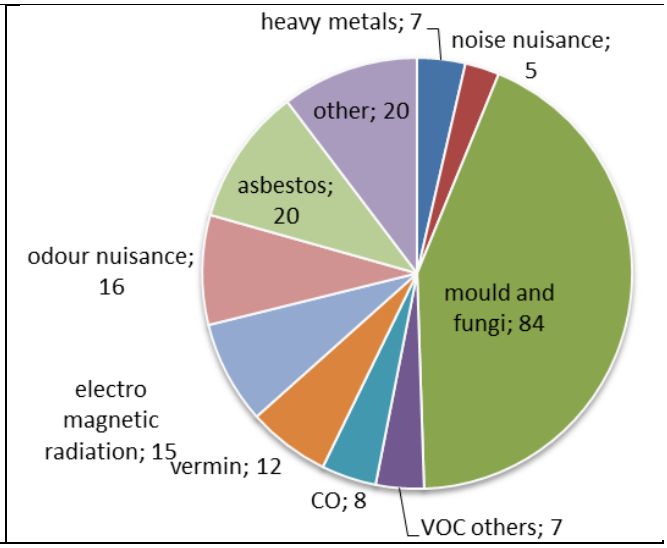

Figure 3. Prevalence of parameters causing IAQ health complaints based on 36 walk-throughs in 2012 (Flanders)

From: Vragen en klachtenrapport, Agentschap Zorg en Gezondheid, 2012

The 194 reported Flemish health complaints in 2012 were each treated individually, by informing and sensitizing inhabitants for remedial and preventive actions. A selection of 36 cases hereof could not be solved by providing information and was thus subjected to a walk-through inspection. Figure 3 illustrates that reported health complaints may have variable (and multiple) causes, but moulds and fungi are by far most abundant, which is noticed (confirmed) by each IAQ Service in Belgium. However, a similar quantity of reported health complaints is related to chemicals, such as asbestos, odour nuisance, CO, VOCs, heavy metals and other chemicals. A considerable part of the indoor related health complaints was also attributed to pests and electromagnetic radiation .

1.2.3.2.2 IAQ in residences and public buildings with indoor related health complaints

The considerable case-by-case variation in the nature of the health complaints, as well as the applied measuring plans, leads to a small overlap of the quantified chemicals between the different IAQ services, as indicated in Table 6.

It should also be noticed that the marked compounds in the table represent chemicals that can be quantified in these small-scale individualised measuring campaigns; however they are not always part of a standard set of air pollutants that is monitored indoors when a health complaint is reported.

According to the table, most of the health complaint IAQ assessments are related to residential indoor environments, rather than public indoor environments. This observation should be considered with caution, since health complaints in schools may have been reported in the general health complaint report of an IAQ service.

Table 6. Overview of chemical characterisations in health complaint indoor settings

Compound	SCHOOLS/DAYCARE CENTRES **COMPLAINT**			HOUSES **COMPLAINT**		
	CO in schools	other	other	CRIPI	HEALTH COMPLAINT SURVEY	SAMI
Prioritised compounds						
Benzene				X	X	
Carbon Monoxide	X					X
Formaldehyde				X	X	X
naphthalene						
Nitrogen dioxide						
Benzo(a)pyrene						
Radon						
Trichloroethylene				X	X	
Tetrachloroethylene					X	
Acetaldehyde					X	
Total (other) aldehydes**					X	
Asbestos						
CO_2 (24h) [ppm]					X	
Ozone						
Toluene				X	X	
VOC (total)**				X	X	
$PM_{2.5}$ (airborne particles)				X		
PM_{10} (airborne particles)				X		
m- + p-Xylene [µg/m³]				X	X	
o-Xylene [µg/m³]				X	X	
Styrene				X	X	
Alpha-pinene				X	X	
Limonene				X	X	
Ammonia						

1,2,4 trimethylbenzene						
Triclosan						
Methylene-di-isocyanate						
Glycol ethers						
Permethrin						
Vinylchloride						
Brominated Flame Retardants						
----------						
other compounds				X		
Hexane					X	
Heptane					X	
Cyclohexane					X	
Methyl cyclohexane				X		
MTBE					X	
Ethylbenzene				X	X	
1,4-Dichlorobenzene					X	
n-Butylacetate					X	
3-Carene					X	
Hg					X	
Pesticides				X		X
acenaftyleen (ng/m³)						
acenafteen (ng/m³)						
fluoreen (ng/m³)						
fenanthreen (ng/m³)						

Compound	SCHOOLS/DAYCARE CENTRES **COMPLAINT**			HOUSES **COMPLAINT**		
	CO in schools	other	other	CRIPI	HEALTH COMPLAINT SURVEY	SAMI
Table 6 continued						
antraceen (ng/m³)						
fluorantheen (ng/m³)						
pyreen (ng/m³)						
benzo(a)antraceen (ng/m³)						
chryseen (ng/m³)						
benzo(b)fluorantheen (ng/m³)						
benzo(k)fluorantheen (ng/m³)						
benzo(a)pyreen (ng/m³)						
indeno(1,2,3,c,d)pyreen (ng/m³)						
benzo(g,h,i)peryleen (ng/m³)						
dibenzo(a,h)antraceen (ng/m³)						

1.2.4 Discussion and conclusions on IAQ studies in Belgium

Since 2005, a wide variety of chemicals was assessed in at least 788 Belgian indoor settings; mostly in residences, schools and nurseries. Although this large dataset contains representative indoor levels for a considerable portion of the priority compounds listed in Table 1, for certain priority emerging compounds no information on typical indoor levels, representative for Belgium, is available.

Benzene, TVOC and formaldehyde have been quantified in 97 % of the 788 Belgian indoor settings. A comparison of the reported concentration levels in the Belgian IAQ studies is visualized by means of box and whiskers plots, shown in Figure 4, Figure 5 and Figure 6. Health complaint-free residential indoor environments are reported at the left side of the plot, health complaint-free schools and nurseries at the right side; measurement outcomes originating from health complaint locations are visualized in the centre of the X-axis (grey coloured). Red dashed lines indicate guideline and intervention values of the Flemish Indoor Environment Decree (*Vlaams Binnenmilieu Besluit*, Flemish Decree of the 11th of June 2004). The Guideline values are measurable quantities that represent the quality level of an indoor environment; intervention values are defined as a measurable quantity that represents a maximum allowable risk level that should not be exceeded and in case of surpassing, preventive actions should be taken. In the plots it can be noticed that in general exceedances of guideline and intervention values are more abundant in settings with reported indoor-related health complaints, which underlines the value of this legislative context when evaluating IAQ related health complaints.

As illustrated in figure 4, with exception of SAMI-LUX schools, low levels of benzene are quantified in health complaint-free schools and nurseries (at the right side of the plot) in comparison to the higher maximum concentrations in complaint-free residences (at the left side of the plot). The outlying character of the benzene (P75) results of SAMI-LUX schools (confirmed outlier by the Q-test for outliers), underlines the need for harmonized methods and strategies, when comparing data on a national level; the data are therefore not further in detail discussed in this analysis. The different pattern of houses and schools without health complaints can be attributed to the larger ranges of potential sources in residences compared to schools and nurseries. Furthermore, increased median benzene concentrations, upper quartiles and maximum values are registered in complaint houses as compared to the complaint-free locations.

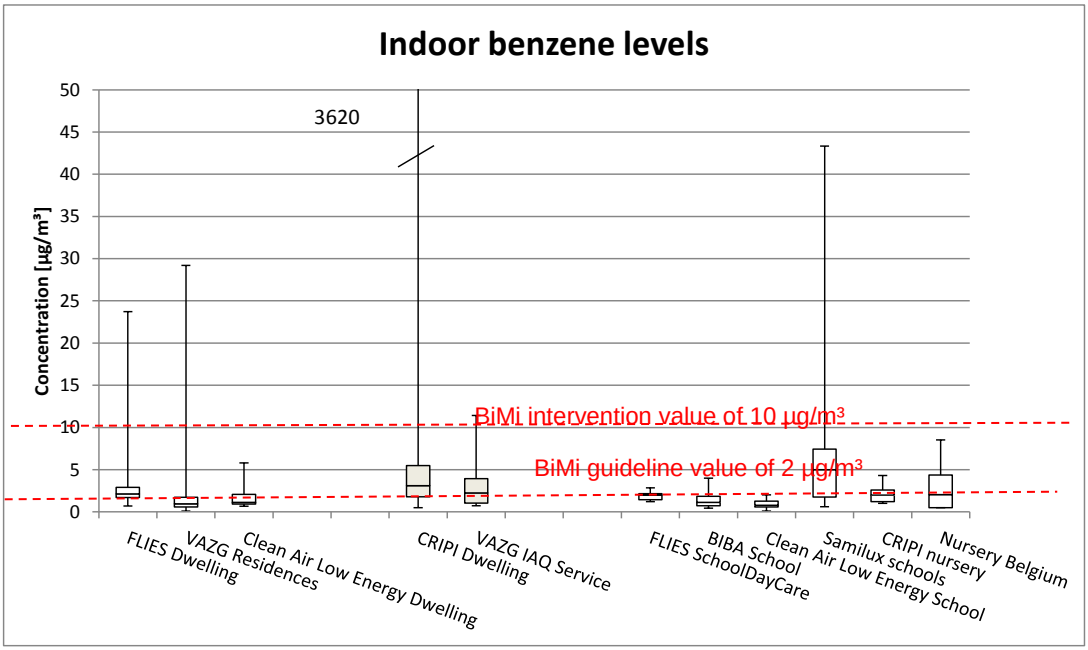

Figure 4. Box and whiskers plot of indoor benzene levels in residences and schools/nurseries with and without health complaints. The box frames represent the upper and lower quartile, the line represents the median, and whiskers denote range.

A similar pattern can be noticed on the box and whiskers plot of TVOC, illustrated in Figure 5. SAMI-LUX schools again report substantially higher TVOC results. In complaint-free residences, indoor TVOC concentrations reached levels up to 7050 µg/m³; however, indoor levels in some cases largely exceeding 10.000 µg/m³, were registered in indoor settings with reported health complaints.

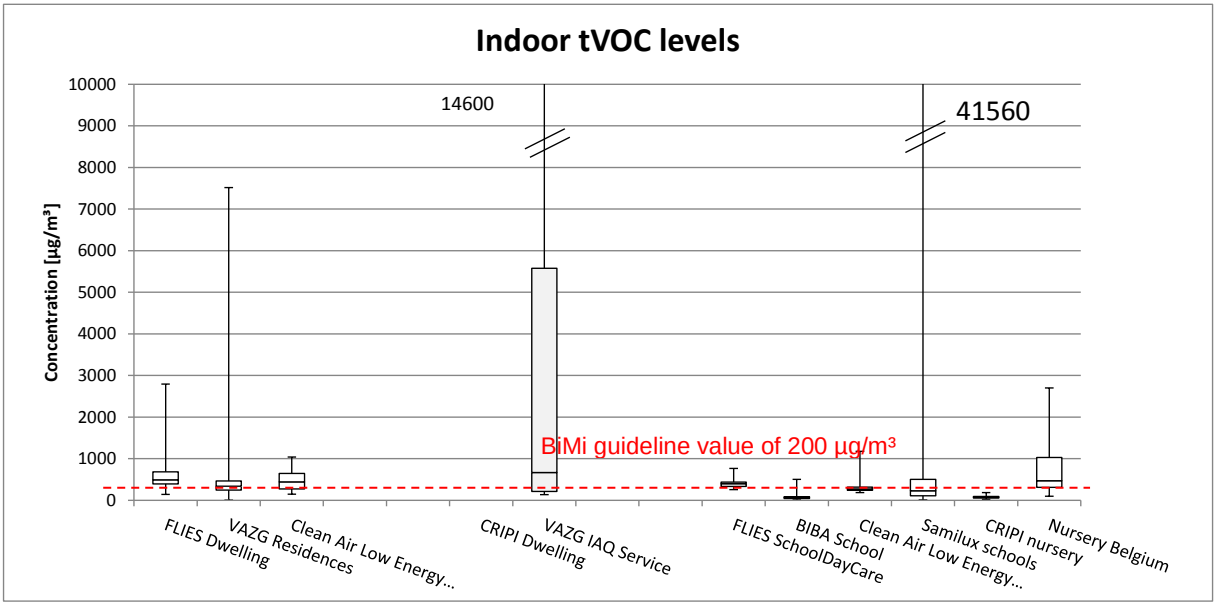

Figure 5. Box and whiskers plot of indoor TVOC levels in residences and schools/nurseries with and without health complaints. The box frames represent the upper and lower quartile, the line represents the median, and whiskers denote range.

The box and whiskers plot that represents the formaldehyde occurrence in indoor settings is illustrated in Figure 6. In health complaint-free settings, the increased amount of potential formaldehyde sources in residences is reflected in the wider concentration range for houses than for schools or nurseries. Except for the highest registered concentration value in complaint settings, there is no significant difference with complaint-free indoor settings.

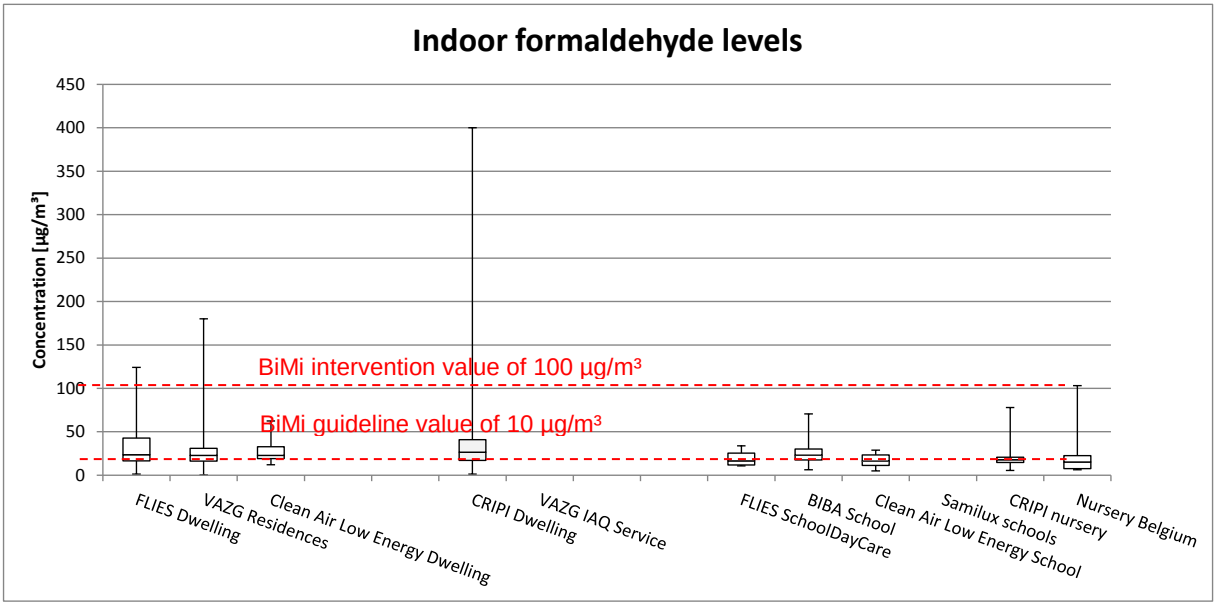

Figure 6. Box and whiskers plot of indoor formaldehyde levels in residences and schools/nurseries with and without health complaints.

Although indoor CO_2 was not quantified in every survey, and averaging times vary between the different datasets, the impact of controlled mechanical ventilation systems on the indoor CO_2 level is clearly visualised in figure 7, by the smaller ranges and median values in Clean Air Low energy dwellings and schools. The wider spread on the indoor CO_2 levels of classroom environments, is reflected in the wider box frames of the box and whiskers plots.

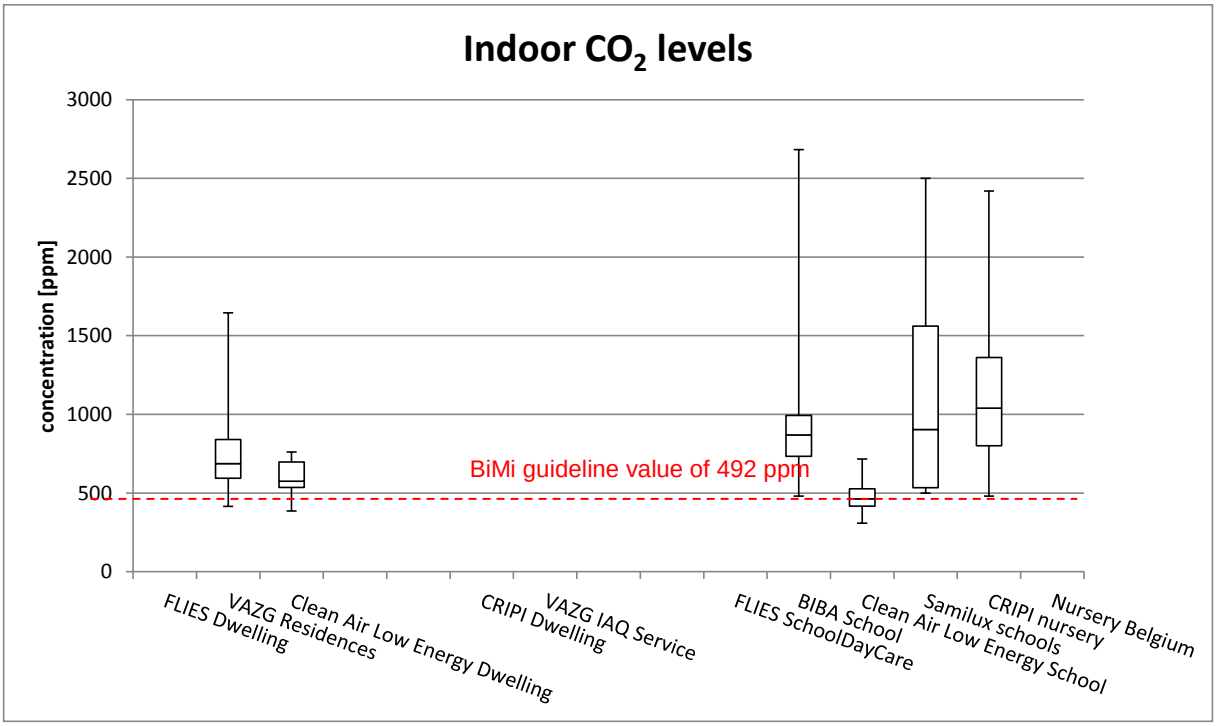

Figure 7. Box and whiskers plot of indoor CO_2 levels in residences and schools/nurseries with and without health complaints. The box frames represent the upper and lower quartile, the line represents the median, and whiskers denote range.

In general it is concluded that for pollutants for which toxicological impact is well established and sampling methods for IAQ monitoring are available, a considerable knowledge on IAQ, indoor sources and indoor exposures is available in Belgium. These include VOCs such as BTEX, formaldehyde, acetaldehyde, trichloroethylene, tetrachloroethylene, pinene and limonene, and also PM, CO, CO_2, and radon.

For compounds that have more recently been prioritised or for which health impacts and exposure pathways are currently still being studied, there is a **need for reference information on indoor exposures in Belgium**. These compounds include biocides, such as triclosan or permethrin, or chemicals, such as methylene-di-isocyanate, glycol ethers, vinylchloride and brominated flame retardants. In fact for some of these compounds, more generally termed SVOCs, important reasons for this lack of knowledge in indoor air are the currently available sampling methods and techniques which are not always adapted for indoor monitoring. Mainly because of the noise nuisance (e.g. in case large volume air sampling is a necessity) they produce or because of the large dimensions of the equipment. **Research on the development and optimisation of new indoor sampling devices, methods and analysis tools for the trace analysis of new compounds is needed,** in order to develop suitable tools that allow noiseless monitoring at the desired detection limits. A valuable example is the development and optimisation of a noiseless and small sampling volume method for the detection of SVOCs (PAH, phthalates and flame retardants) by means of active air sampling on PDMS-Tenax loaded cartridges (Lazarov et al. 2013).

This new method is advantageous compared to traditional alternatives for indoor air monitoring, and therefore allows monitoring on larger scales in the future. Further optimisations of this method for other chemicals (e.g. chemicals resulting from ozone-induced secondary reactions in indoor air) have been initiated (Officair, Deliverable 3.4, 2014), but a further exploration of the possibilities is needed. Passive sampling also offers a suitable solution for noiseless and easy to use indoor air sampling, without the need for electricity supply.

It is based on the selective adsorption of a chemical with a controlled uptake rate by diffusion to a substrate. A wide variety of diffusive samplers is yet commercially available to collect a range of chemicals, but also in this field there is a lot of potential for new developments. E.g. varying the uptake rate would make the passive sampler adjustable to expected concentration levels and would allow longer or shorter exposure durations; varying or combining coatings of the adsorbing surface would make a sampler multifunctional and the optimisation of new adsorption substrates would expand the range of chemicals to be monitored by passive sampling.

Because of the different institutes involved, and because of the many research objectives, various sampling methods and protocols have been applied to monitor a chemical in the inventoried Belgian studies. However, aiming at larger scale data mining and use of existing IAQ data on a national level, there is a **need for harmonized monitoring protocols and methods**. On EU level, initiatives have been taken to harmonize actions on IAQ in the INDOOR-MONIT & PILOT INDOOR AIR MONIT project (Harmonisation and implementation of criteria and protocols for monitoring key indoor air pollutants in EU; DG SANCO – JRC, 2009-2012). The overall objective of this action was to ensure consistency and to increase comparability of IAQ measurements across the European Union. Protocols were defined for (1) the design of an indoor air monitoring study, for (2) indoor air quality monitoring techniques, and for (3) data collection, evaluation and reporting. The adoption of such a common strategy on a national level would favour comparisons, further use and analysis of the data, and thereby respond to the **need for the development of large-scale databases for data mining and health impact assessments**.

1.3 Health impact evaluation of IAQ in Belgium

This paragraph assesses the health risk and impact, related to the available data on IAQ in Belgium. It compares and evaluates the monitored IAQ levels (reported in paragraph 1.2.2) to existing health based reference values and estimates the health impact hereof.

We focused on health impact due to chronic exposures and not to acute exposures. The majority of the monitoring data described in section 1.2 involves monitoring periods up to 1 week. These weekly-average data are generally considered as a good proxy for long term (chronic exposure) and thus used for the evaluation of health risks related to chronic exposure (Sarigiannis et al., 2011). Evaluating the risk due to acute exposure would have required shorter term exposure episodes with a higher time resolution of the exposure episodes and the impact of this variability on health risks, focused on periods with peak emissions from sources. Health impact due to chronic exposure is generally used for health impact assessment for indoor environments (e.g. eBoDE study (Hänninen and Knol, 2011)). In contrast, acute exposure to carbon monoxide is an important issue for the health impact of IAQ – however, this could not be addressed in this review since the database on IAQ monitoring data doesn't list monitoring data for short, high peak episodes of carbon monoxide.

1.3.1 Health risk of IAQ in baseline datasets

1.3.1.1 Method for health risk assessment

In a classical substance by substance risk evaluation approach, measured indoor air concentrations are compared with substance specific health based reference values (RV) for non-carcinogenic effects. This RV is defined as a threshold level below which chronic exposure to an individual substance is unlikely to provoke adverse non-genotoxic effects. Therefore, if measured concentrations are below the RV, no harmful effects are likely. For substances provoking genotoxic carcinogenic effects, additional cancer cases attributable to exposure are calculated as a measure for risk (on condition that risk coefficients are available for this substance).

On the one hand, there is no single information source available that provides RVs for all or even most of the priority compounds which are the focus of this review. On the other hand, for several substances, health based reference values have been derived by more than one agency, resulting in sometimes largely different RVs for one substance. For example, for formaldehyde INDEX (JRC, 2005) derives a RV of 1 µg/m³, while the WHO (2010) guideline is 100 µg/m³. Both sources support that their value is protective for a long-term exposure to formaldehyde. Differences in RVs established by different bodies for the same substances are caused by differences in choices of key studies, critical effects and assessment factors selected by the assessors.

In order to overcome both issues, a step-wise approach is applied here to retrieve a uniform list of RVs for non-genotoxic effects of chronic exposures from an array of data sources (WHO, Agency for Toxic Substances and Disease Registry Atlanta US (ATSDR), US Environmental Protection Agency (EPA) IRIS, US EPA PPRTV, Joint Research Centre (JRC) (INDEX), *Rijksinstituut voor Volksgezondheid en Milieu* (RIVM, The Netherlands), Health Canada, *Agence française de sécurité sanitaire de l'environnement et du travail* (AFSSET/ANSES), *Ausschuss zur gesundeheitlichen Bewertung von Bauprodukten* (AgBB, Germany), or Lowest Concentration of Interest (LCI) values, ECA, 2013). It is noted that most of these sources do not pertain specifically to indoor air, but may be used in the context of indoor air since they are developed for inhalation exposure in general (being outdoor as well as indoor air). This approach consists of the following steps:

> The consulted sources were ranked by date (priority was given to evaluations issued within the last 5 years), and grouped into the categories “primary sources”, “secondary sources” and “tertiary sources”. Primary sources were international, national and state agencies with established peer review procedures (WHO, ATSDR, US EPA IRIS, US EPA PPRTV and JRC (INDEX)); secondary sources were judged to have less intense peer review and/or transparency (Health Canada, RIVM, individual scientific publications), while the tertiary sources were the LCI values used for evaluation of emissions from building materials which are in place in Germany (AgBB) and France (AFFSET/ANSES) (ECA, 2013).

Reference values from above mentioned sources were only used on condition of an open and transparent technical basis and standard setting process. The process of ranking sources and selecting RVs is summarized in the flow chart presented below and is described more in detail in De Brouwere et al.(2014).

The selected reference values for priority compounds, based on the outlined procedure, are listed in Table 7 (note that occupational safety limits are excluded from this list, because this review is focussed to the exposure of the general population, including susceptible population groups).

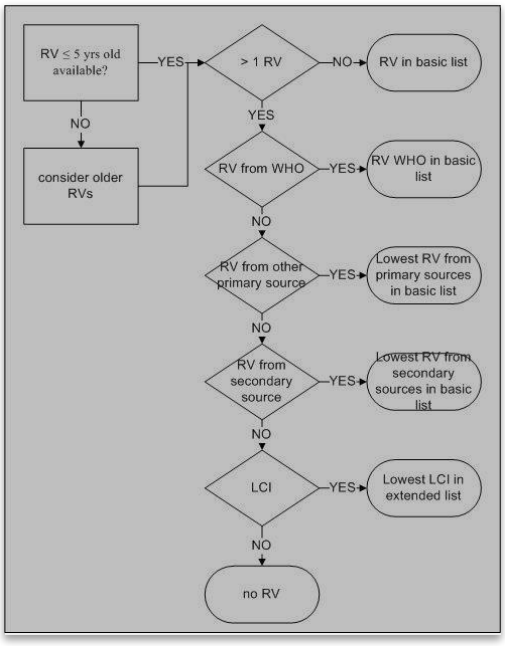

Figure 8. Scheme for selection of reference values (RV) for chronic exposure

Table 7. Selected chronic reference values (RV) for substances provoking non-genotoxic effects

substance	selected reference value (RV)	Unit	Agency of selected RV	other RV (from other sources)***
Benzene	10	µg/m³	ATSDR, 2007a	60 µg/m³ (JRC (INDEX) & OEHHA, 2000)
Formaldehyde	100	µg/m³	WHO, 2010	1 µg/m³ (JRC (INDEX), 2005)
Naphthalene	10	µg/m³	WHO, 2010	3 µg/m³ (US EPA, 2000)
Nitrogen dioxide	40	µg/m³	WHO, 2010	
Benzo(a)pyrene				
Trichloroethylene	2	µg/m³	US-EPA IRIS, 2011	600 µg/m³ (OEHHA, 200)
Tetrachloroethylene	250	µg/m³	WHO, 2010	40 (US EPA, 2012) – 360 µg/m³ (Health Canada)
Acetaldehyde	140	µg/m³	OEHHA, 2008	9 (US EPA, 1991) – 200 µg/m³ (JRC (INDEX), 2005)
Total (other) aldehydes	*No value*			
Toluene	260	µg/m³	WHO, 2000	5000 µg/m³ (US EPA, 2005b)
Total VOC	*No value*			
$PM_{2.5}$ (airborn particles)	10	µg/m³	WHO, 2005	
PM_{10} (airborn particles)	20	µg/m³	WHO, 2005	
Xylenes	200	µg/m³	ATSDR, 2007b	100 (US EPA) – 7000 µg/m³ (OEHHA)
Styrene	850	µg/m³	ATSDR, 2010b	260 (WHO, 2001) – 1000 µg/m³ (US EPA, 1993)
Alfa-pinene	450	µg/m³	JRC (INDEX) 2005	
Limonene	450	µg/m³	JRC (INDEX) 2005	
1,2,4 trimethylbenzene	220	µg/m³	Ontario AAQC, 2007	9.8 µg/m³ (Vermont Air Quality Guidelines)
MTBE**	2500	µg/m³	ATSDR, 1996	
Ethylbenzene	260	µg/m³	ATSDR, 2010	2000 µg/m³ (OEHHA, 2000) – 0.4 µg/m³ (OEHHA 2008)
m- + p-Xylene	200	µg/m³	ATSDR, 2007b	100 (US EPA, 2003) – 700 µg/m³ (OEHHA, 2000)
o-Xylene	200	µg/m³	ATSDR, 2007b	100 (US EPA, 2003) – 700 µg/m³ (OEHHA, 2000)
1,4-Dichlorobenzene**	60	µg/m³	ATSDR, 2006	
Hexane**	700	µg/m³	US EPA, 2005a	7000 µg/m³ (OEHHA, 2000)
Heptane**	21000	µg/m³	AgBB, 2012	
Cyclohexane**	6000	µg/m³	US EPA IRIS, 2003	
n-Butyl acetate**	4800	µg/m³	AgBB, 2012	
3-Carene**	1500	µg/m³	AgBB, 2012	

*** not considered as priority compound for this review (Table 1)*

**** RV given by other agencies (WHO, ATSDR, US EPA IRIS, US EPA PPRTV, JRC (INDEX), Health Canada, RIVM, (Office of Environmental Health Hazard Assessment) OEHHA) than the RV selected by the scheme given in*
Figure 8 *values only given if considerably different from the selected RV.*

Note that in Table 7 no health based reference values are listed for total aldehydes and TVOC. This is because from a toxicological point of view, the assumption that all VOCs (or aldehydes) within the sum parameters would have the same health endpoint and thus should be treated in the same manner, cannot be supported. The sum parameters however, can be used for the characterisation of exposure and when searching for sources and also in risk assessment as a screening parameter for a possible sensory irritation (Mølhave et al., 2003). Because of the difficulties in deriving an individual guide value for TVOC, the German *Umwelt Bundesamt* has applied measured concentration ranges for indoor air as reference values. Therefore, a daily stay, at least in the short term, is reasonable in rooms with TVOC concentrations of 10-25 mg/m^3 (such concentrations may arise during home improvement work). In rooms intended for longer-term residence, the TVOC value in the range of 1-3 mg/m^3 should not be exceeded. And ideally, TVOC concentration in indoor rooms should reach a maximum long-term average of 0.2-0.3 mg/m^3 or lower if possible (www.umweltbundesamt.de).

For substances that provoke non-threshold effect (in this case genotoxic effects), limits below which no effects are likely, cannot be recommended. Instead risk is expressed as a "unit cancer risk", which expresses the additional number of cancer cases per µg/m^3 for lifelong exposure. For substances classified as group 1, 2A and 2B by the International Agency for Research on Cancer (IARC), unit risk values derived by one of the above mentioned agencies (WHO, ATSDR, etc.) are listed in Table 8. Similar to the ranking of sources for non-cancer endpoints, in this ranking priority is given to WHO (2010) IAQ unit risk values over older values established by other agencies. The relevant metric used for assessing the risk posed by the carcinogenic compounds was the estimated lifetime cancer risk (***R***), and given by the formula:

$$R = C \cdot IUR$$

where ***C*** is the exposure concentration in µg/m^3 and ***IUR*** is the Inhalation Unit Risk, which is the upper-bound excess lifetime cancer risk estimated to result from continuous exposure to an agent at a concentration of 1 µg/m^3 in air. IUR is the expression of the cancer potency factor for inhaled compounds. The cancer potency factor is a linear extrapolation from the high-dose animal or human studies to the low doses of environmental exposure using either a maximum likelihood estimate (for epidemiological data) or the upper 95 % confidence limit (for animal studies) on the dose exposure function.

Table 8: Selected Inhalation Unit Risk values for substances provoking non-genotoxic effects

substance	**selected IUR value**	**unit**	**agency**	**remark**
Benzene	6×10^{-6}	per µg/m³	WHO, 2010	leukaemia
Benzo(a)pyrene	8.7×10^{-5}	per ng/m³	WHO, 2010	lung cancer
Formaldehyde	No value	per µg/m³	WHO, 2010	formaldehyde is a mutagenic carcinogen, recognized by IARC as a carcinogenic to humans; however, WHO considers 100 µg/m³ sufficiently protective, also concerning cancer effects caused by formaldehyde
Trichloroethylene	4.3×10^{-7}	per µg/m³	WHO, 2010	hepatic tumours
Tetrachloroethylene	No value	per µg/m³	WHO, 2010	probably not genotoxic
Acetaldehyde	2.2×10^{-6}	per µg/m³	US EPA, 1991	nasal adenocarcinomas and squamous cell carcinomas
Styrene	-			no data
Naphthalene	No value		WHO, 2010	long-term guideline assumed to prevent potential malignant effects in airways

1.3.1.2 Discussion of the IAQ health risk in Belgium

Evaluation of compliance or exceedance of exposure data against selected reference values for non-carcinogenic effects was verified for each reported Belgian study and priority compound (supplemented with few additional compounds for which exposure data have been reported in chapter 1.2).

IAQ health risk for non-carcinogenic effects in Belgian indoor settings

Basically, in health risk assessment, an indoor environment is evaluated as of 'high concern for health' when the exposure to a substance exceeds the health based reference value of that substance. The other way around, an indoor environment is evaluated to have 'limited health concern caused by IAQ' if the exposure to a substance is below the reference value of that substance.

It should be noted that only benzene, TVOC and formaldehyde have been quantified in the major part of the Belgian studies using a variety of air sampling techniques. All other compounds were only assessed in a selection, sometimes a very small fraction, of studies and thus are considerably less representative for overall indoor settings in Belgium.

In summary, the following considerations were formulated based on an evaluation of the available Belgian IAQ data to the selected RVs:

- *NO_2 and PMx*

  Indoor levels of NO_2 were exceeded in more than 5 % but in less than 25 % of indoor environments. This observation was persistent across the 3 databases where NO_2 was monitored (except for the 365 complaints free houses 2008-2012 in Flanders; where less than 5 % exceedances were observed).

  In the vast majority (> 75 %) of the monitored indoor environments, WHO (2005) RVs for PM_{10} and $PM_{2.5}$ were exceeded.

- *VOCs*

  For the majority (e.g. above 95th percentile in each database) of the monitored indoor environments (dwellings, schools and nurseries) all individually monitored priority VOC compounds (benzene, formaldehyde, tetrachloroethylene, acetaldehyde, formaldehyde, toluene, xylenes, styrene, alfa-pinene, limonene, 1,2,4-TMB (1,2,4-Trimethylbenzene), naphthalene) occurred below the selected health based RVs for that compound, and thus individual indoor levels can be considered as of 'no concern' in 95 percent of the monitored indoor environments.

  In the other 5 % percent of the cases, considerable exceedances of the RVs are observed. These exceedances of the respective RVs are most often identified in indoor settings with reported health complaints. A substance by substance health impact evaluation to RVs in health complaint indoor settings, should however be considered as non-representative in this review. The fact that each health complaint case is treated individually, leads to variable measuring plans and thus various quantified compounds, what in several cases leads to very small group sizes. Still, for compounds that have been quantified in the majority of the reviewed cases (benzene, TVOC and to a lesser extent formaldehyde) a clear distinction between indoor levels in health complaint and health complaint-free settings can be noticed (as illustrated in Figures 5, 6 and 7).

Magnitude of the health concern and the underlying reasons (sources) of the exceedances of RVs in this upper 5 % of the indoor environments (with exceeding the RV of at least one compound) cannot be evaluated based on available data. It is also likely that stressors causing the health complaints differ from the priority compounds listed in this review.

An exception to the relatively high compliance of indoor environments to RVs for VOCs is for trichloroethylene: the 25th percentile value of the monitoring data from the Samilux schools exceeds the selected RV for this compound, and the 75th percentile value of CRIPI health complaint dwellings exceeds the RV as well. In other (health complaint-free) databases this only occurs in a small fraction (above the 95th percentile) of the datasets. The reason for this higher frequency in exceeding RV in this specific study might be found in the fact that both databases are based on health-complaint indoor settings.

For some VOC compounds no exceedances could be identified in any of the reviewed databases. This is the case for MTBE, ethylbenzene, 1,4 dichlorobenzene, hexane, heptanes, cyclohexane, n-butylacetate and 3-carene. This finding would indicate that these substances should not be considered as priority compounds. However, it is important to note that these compounds were monitored in several (Flemish) datasets, but not in any other dataset. It should therefore be concluded that the overall compliance of these compounds to the respective RV's cannot be generalized at a national level.

- *TVOC*

  In a majority of the samples (> 95 %; except in BiBa (2010) classrooms and CRIPI nurseries) TVOC levels exceed the guideline value of 200 µg/m³ from the Flemish Indoor Decree. Although from a toxicological point of view, no RV can be assigned to TVOC, literature confirms its use as a screening parameter for possible sensory irritation (Mølhave et al., 2003; Salthammer and Uhde, 2011). The concentration ranges, proposed by the German *Umwelt Bundesamt*, offer a suitable tool to evaluate TVOC in this database. In fact, a comparison of the Belgian database with the German concentration ranges learns that in all health complaint-free settings, quantified TVOC levels are within the recommended concentration ranges for rooms intended for longer-term residence (except for one house). On the contrary, in indoor settings with reported health complaints, the 75th percentile exceeds the long-term exposure recommendations considerably and the maximum TVOC concentrations reach or exceed the acceptable levels for short-term exposures (10-25 mg/m^3).

- *Formaldehyde*

  Conclusions about the compliance with RV for formaldehyde are very sensitive to the choice of the RV for individual substances: in this evaluation an RV of 100 µg/m³ (WHO, 2010) for formaldehyde was chosen based on a transparent decision tree approach for selecting RV. Based on that RV, almost no exceedances were found. However, if the most conservative RV from the array of existing RVs would have been selected, which in the case of formaldehyde is a value of 1 µg/m³ (JRC (INDEX), 2005), the conclusion would be that in none of the monitored indoor dwellings, schools or nurseries formaldehyde levels were below this value, and consequently, all indoor environments would have been judged as 'of concern'.

The impact of the choice of RV is most pronounced for formaldehyde; for other substances, the effect is much less drastically, since selected RV are in most cases at the lower end of the range of RV (see Table 7). In addition to formaldehyde, also for xylene and styrene an RV which is more stringent than the one selected was found; however, applying the more stringent value for xylene (100 µg/m³) and styrene (260 µg/m³), this would have hardly affected the outcome.

It is important to note that indications and conclusions about the compliance of Belgian IAQ levels to RVs are limited to the substances listed in Table 1. In fact the IAQ data of several priority compounds (defined in Table 1) on a Belgian, representative level is currently missing. E.g. in none of the surveys, indoor levels of asbestos, ozone, ammonia, triclosan, methylene-diisocyate, glycolethers, permetrin, vinylchloride and brominated flame retardants were monitored. Furthermore, only in one survey indoor air levels of naphthalene and benzo(a)pyrene were monitored.

Carcinogenic effects

As an estimate of cancer risk attributable to indoor exposures to benzene, trichloroethene and acetaldehyde, the range of the median values from the reviewed IAQ studies is used as an approximation for population-representative exposure data, which is the basis for the prediction of cancer cases based on IUR's.

- *Benzene*

  Based on the range of the median benzene concentrations in Belgian surveys (0.77 – 5 µg/m³), due to benzene exposures, the risk of indoor benzene induced cancers is 4.6 – 30 per 1 million, assuming lifelong exposure to these benzene levels. These numbers are based on WHO (2010) IUR of 6 $\times 10^{-6}$ per µg/m³ and correspond to about 0.5 – 3 % of leukaemia incidence in Belgium (incidence of 625 per 5 years in a population of 11 million inhabitants in Belgium).

  In a review on cancer risk related to VOC exposure across Europe, Sarigiannis et al. (2011) calculated comparable numbers for cancer risks due to indoor benzene exposure, based on a smaller and older set of IAQ monitoring data for Belgium (i.e. Stranger et al., 2007). The regional comparison made by Sarigiannis et al. (2011) shows that risk of benzene induced cancer is situated at the lower end when compared to other EU countries (see Figure 9).

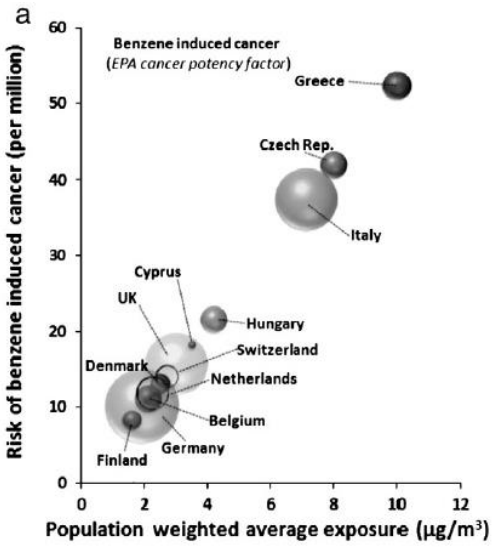

Figure 9. Risk of benzene induced cancer (per million) in several European countries, Sarigiannis et al. (2011). Note: EPA cancer potency factor used by Sarigiannis et al. (2011) has the same numerical value (6 $\times 10^{-6}$ per µg/m³) as the WHO IUR value applied in this review.

- *Trichloroethylene*

  Based on the range of the median trichloroethylene concentrations in Belgian surveys (0.1 – 7 µg/m³), the risk of trichloroethylene induced cancers is 0.04 – 3 per 1 million exposed individuals, assuming lifelong exposure to these trichloroethylene levels. These numbers are based on WHO (2010) IUR of 4.3×10^{-7} per µg/m³. It should be noted that the median value of 7 µg/m³ (Samilux schools) is considerably higher than median trichloroethylene concentrations from other surveys, and thus the calculated cancer cases are significantly influenced by this study. If this survey is not considered, the median values of the 6 other surveys, lead to a cancer risk of less than 1 per 1 million due to trichloroethylene exposure.

- *Benzo(a)pyrene*

  Based on the median benzo(a)pyrene value of 0.7 ng/m³ (originating from only one study with 48 samples of 25 residences), the risk of benzo(a)pyrene induced cancer is 60 per 1 million (for lifelong exposure). These numbers are calculated based on WHO (2010) IUR of 8.7×10^{-5} per ng/m³.

- *Acetaldehyde and formaldehyde*

  Based on the range of median acetaldehyde concentrations in the reviewed Belgian surveys (5 – 23 µg/m³), the acetaldehyde induced cancer risk is 11 – 50 per 1 million (for lifelong exposure). These numbers are calculated based on US EPA (1991) IUR of 2.2×10^{-6} per µg/m³ This number for cancer risk due to acetaldehyde exposure should be interpreted with caution since the EPA value is not recently established (dates from 1991) and it might be questionable whether linear extrapolation to low doses is justifiable. OEHHA (2000) does perform an extrapolation to low doses for acetaldehyde. Moreover, acetaldehyde is classified by IARC as Group 2B (there is inadequate evidence in humans for the carcinogenicity of acetaldehyde; there is sufficient evidence in experimental animals for the carcinogenicity of acetaldehyde), which is a less stringent evaluation by IARC as compared to the classification of formaldehyde (group 1: known human carcinogen); for the latter compound, no cancer cases were calculated because WHO (2010) considers formaldehyde as a threshold carcinogen, and all formaldehyde exposures found are below that threshold. However, it should be noted that formaldehyde is a mutagenic carcinogen recognized by IARC as a human carcinogen class 1, it is highly unlikely that for mutagenic carcinogens a critical dose exists below which the agent has no effect at all. WHO (2010) also didn't include acetaldehyde in the report on IAQ guidelines.

  The latter again points towards sensitivity to the way that risk values for carcinogenicity are selected. Applying the US EPA (1991) IUR of 1.3×10^{-5} per µg/m³ (squamous cell carcinoma and nasopharyngeal cancer) instead of the WHO threshold approach (2010), we would predict a substantial number of additional cancer cases caused by formaldehyde. Based on the range of median formaldehyde concentrations across the Belgian surveys (16 – 25 µg/m³), the formaldehyde-induced cancer risk is 210 – 320 per 1 million (for lifelong exposure). These numbers are surprisingly high compared to the results bases of the WHO (2010) approach considering that the RV of 100 µg/m³ is protective enough for carcinogenicity.

In conclusion, from the available data, benzene and benzo(a)pyrene seem to be the chemical stressors having the largest impact on cancers caused by poor IAQ. Impact from exposure to trichloroethylene is negligible, while the impact of formaldehyde and acetaldehyde on cancer prevalence is very sensitive to the applied method, and as a consequence very uncertain.

Is there a concern for health effects driven by mixtures present in indoor air?

Next to the classical substance by substance evaluation, it is important to note that indoor air contains a variable and diverse mixture of chemical substances to which people may be simultaneously exposed.

Combined risk assessment, taking into account that several indoor occurring substances may act on the same target organ/endpoint, they should be evaluated together. Therefore, a substance by substance evaluation of the risk as elaborated in the previous paragraphs might underestimate the risk of indoor air 'cocktails'. Assessing the risk of mixtures is a resource intensive process and no in depth investigation of cumulative risk assessment of indoor air in Belgium is available in literature.

A screening exercise for the evaluation of cumulative effects was recently applied on indoor air mixtures, including 180 samples of the Flemish Surveillance of complaint-free houses (2008-2012) and 90 Flemish school data originating from the BiBa study (2008-2009) (De Brouwere et al., 2014). In this screening exercise, the Maximum Cumulative Ratio (MCR) approach, which determines when cumulative risk assessments are most required, was applied. The aim of using MCR was to assess whether the risk of an indoor air mixture is dominated by one single compound or by the contribution of many chemicals. As an outcome, it was concluded that in about 30 % of the Flemish schools there is concern for combined effects due to exposures to several substances. Those 30 % indoor settings would have been wrongful evaluated as of 'limited health concern caused by IAQ' when using a classical substance by substance approach. This illustrates **the need to go beyond the classical substance by substance risk assessment in the field of indoor air**. Yet, the MCR approach should be considered as a ***screening tool*** for mixtures. A further in depth investigation, including endpoint communalities, is currently lacking and would be needed for the 30 % of the indoor samples. Such an assessment is needed to identify in which of the 30 % 'concern for combined effects' samples, the concern is driven by over-conservative assumptions (i.e. dose addition of all investigated compounds) and in which samples cumulative risk is effectively present and caused by common endpoints / mode of action of substances present in the indoor sample (Meek et al., 2011).

In conclusion, the area of combined assessment is relatively new in the field of indoor air. First results indicate a concern for combined exposures to multiple substances, and should be further explored in terms of communalities in endpoints, and common indoor sources.

1.3.2 Impact assessment of IAQ in Belgian indoor settings

The classical risk assessment approach, as described in paragraph 1.3.1.2., evaluates the compliance of IAQ data to health based RVs and inhalation unit risk factors. The latter allows predicting the number of additional cancer cases caused by indoor exposure, but the evaluation of threshold effects is limited to a qualification of IAQ as "below" or "above" reference values. The technique therefore cannot make any predictions of impacts of exceeding a threshold: what is the severity of the health effects, what is the health burden and how much is the associated cost?

Methods to quantify the impact and to express the burden of indoor pollution do exist: DALYs. The DALY measures health gaps (i.e. years of life lost due to death or disability) as opposed to health expectancies. It measures the difference between a current situation and an ideal or alternative situation. The DALY combines the time lived with disability and the time lost due to premature mortality in one measure.

Human populations experience a certain burden of disease (BoD). Part of this burden is caused by exposure to environmental stressors (Environmental Burden of Disease (EBoD)). Estimates show that 10-20 % of the total burden in Europe is caused by environmental stressors (Prüss-Ustün and Corvalán, 2006). A methodology to calculate the EBoD is presented by De Hollander (1999).

The unit used in the DALY which was initially introduced by WHO and the Worldbank to compare the BoD worldwide (Murray and Lopez 1990, 1996). The DALY is a measure of health life years lost and is the sum of years of life lost (YLL) due to mortality before life expectancy and years lost due to disability (YLD). With DALYs, diseases are weighted against each other by a severity factor (disability weight) so that comparison is possible. Both YLL and YLD are in the simplest way (not discounted; not age-weighted) presented as a multiplication of 3 variables: number of people × severity weight × duration. With DALYs relative comparisons between different scenarios are possible. Given absolute value to the DALYs is not recommended seeing the different variables influencing health (lifestyle, food, smoking behaviour, genetic predisposition, etc.) (Dahlgren and Whitehead, 1991).

For chronic exposure to benzene and mortality due to leukaemia a static calculation was made in the EBoDE study (Hanninen and Knol, 2011). The unit risk of 6×10^{-6} per µg/m³ for lifelong exposure was applied (WHO, 2000). The yearly average benzene concentration to which persons in Belgium (Flanders) indoors are exposed to was equal to 1.5 µg/m³ (Swaans et al., 2008). Average age of dying from leukaemia in the total population is around 70 years, at which the life expectancy is 84, which means a loss of 14 years per individual. Severity factor for dying is 1. A similar calculation was done for Flanders with a population of 6 million by Buekers et al. (2012):

> DALYs per year = 1.5 µg/m³ × (6×10^{-6} / 70) × (6×10^{6} persons) × 1 × 14 years = 10.8
> or per million people in Flanders 1.8 DALYs per year.

Up to date, DALYs have only been applied on scattered Belgian IAQ data: in the EBoDE project, the EnVie project (2009) and its follow-up study IAIAQ (Jantunen et al., 2010).

In the EBoDE project, the health impact associated with exposures to formaldehyde, benzene and PM2.5 in Belgium was assessed (Hänninen and Knol, 2011). The EBoDE report calculated 3.3 DALYs per million inhabitants per year due to benzene; 0.1 DALYs per million inhabitants per year due to formaldehyde and 7642 DALYs per million inhabitants per year caused by PM2.5 in Belgium. For several other indoor stressors (several VOCs, etc.) no predictions of DALYs were made in the EBoDE report, mainly because of the lack of appropriate dose-response functions, which are essential for DALYs predictions.

In the EnVie-study, total BoD caused by indoor air (including radon) exposures in Belgium was estimated in the range of 980-1230 DALY/year × million inhabitants (Jantunen et al., 2011).

The EBoDE project used the ‘exposure-based approach’ (initiating calculations with exposure data), while the EnVie study used the ‘outcome-based approach’ (initiating calculations with health outcome data). Ideally, the results of both approaches should match. According to Jantunen et al. (2011) the EBoDE and EnVie results, both obtained by independent and differently performed environmental BoD assessments for 6 countries, matched surprisingly well; especially when considering that EBoDE considered the total exposure and EnVie - IAIAQ only considered indoor exposures.

In contrast, Schram-Bijkerk et al. (2012) compared both methods for indoor air impact assessment in the Netherlands, and concluded that outcomes were not comparable. They recommended a careful evaluation of burden of disease estimates before using them in policy making. Such an in depth comparison of both methods is up to now not available for IAQ in Belgium.

According to Jantunen et al. (2011) in the follow up study of EnVie (IAIAQ), ambient air is responsible for 2/3 of the total BoD from indoor air exposures in Europe (mostly fine PM and bio aerosols, but also some VOCs). The other 1/3 of the BoD related to indoor air exposures is caused by heating and combustion equipment (cooking and heating with solid fuels), water systems, and water leaks. Condensation and underlying soil as source of radon are other important sources for the IAQ associated BoD. According to the EnVIE study, the most important indoor contaminants in terms of BoD were: fine PM, dampness, bio aerosols, radon, CO, VOC's.

It is very likely that the burden of disease caused by VOCs is underestimated, both in EnVie and EBoDE calculations because of two reasons: 1) the lack of epidemiological data on specific disease dose/response that can be credibly extrapolated to indoor air levels for several VOCs (only available for benzene, naphthalene and formaldehyde); this burden of disease caused by other VOCs is ignored in DALYs calculations ; 2) the health problems of VOCs appear mostly in new, newly renovated or refurbished buildings, which – at any time – represents only a few percent of the total building stock occupied by the population.

In summary, methods to calculate the health impact caused by non-ideal IAQ do exist in literature, and have been applied on scattered IAQ exposure data from Belgium. The more complete picture on IAQ in Belgium that we have collected in this study (as discussed in section 1.2.2) could be used to improve the existing DALYs calculations. In fact the Belgian data used in the EBoDE and EnVie study were based on a few scattered studies; while the data collected in this review could provide information to take a major step forward to better, more accurate predictions of DALY's related to IAQ in Belgium.

The next step forward is an in depth comparison of the 2 DALY calculations methods (comparable to the study of the Netherlands, published by Schram-Bijkerk et al., 2012), and the application of more complete datasets on IAQ in Belgium. Also, the application of the EnVie model for the calculation of health benefits of IAQ policies in Belgium will be a valuable next step forward. In the EnVie model, the economic impacts of several IAQ policies (such as harmonized labelling protocols, outdoor air pollution penetration policy, integration of IAQ in EPBD procedure, heating and combustion installations policy) in terms of DALYs are incorporated, and could serve as a powerful tool for the prediction of benefits of IAQ policies in Belgium.

1.3.3 Discussion and conclusions on the IAQ impact in Belgium

In the traditional substance by substance evaluation of the health risk associated to IAQ, the selection of the health based reference value has a considerable impact on the overall evaluation of the heath impact; for the considered priority compounds (NO_2, PM, VOC, TVOC, and formaldehyde) in this review (Table 1), this impact is most pronounced for formaldehyde.

Based on the available data on IAQ in Belgium, the traditional substance by substance risk evaluation learned that in 95 % of the studied indoor settings IAQ is to be considered 'of limited health concern caused by IAQ'. However, three important considerations have to be made: (1) there is **a need to estimate the magnitude of the health impact** in the 5 % of indoor settings exceeding the RVs, (2) **many more VOCs** occur in indoor air, which are not considered in this review, (3) there is a **need for more complete reference databases in IAQ in Belgium**. Furthermore benzene and benzo(a)pyrene were, among the indoor stressors, identified as having the largest impact on cancer incidence.

Exceedances of RVs are most pronounced in indoor settings with reported indoor related health complaints. This is confirmed by the sensory irritant TVOC, of which considerably higher concentrations are quantified in health complaint indoor settings.

Besides the substance by substance risk assessment, a **cumulative risk assessment is needed** on a Belgian level. In order to do so, complete datasets on IAQ, representative for Belgian indoor settings in general are needed.

In order to estimate the severity and associated costs of indoor air, there is a **need for a more accurate calculation of DALYs**, but to do so, **large and representative datasets on IAQ in Belgium are needed**.

1.4 State-of-the art on product emissions

1.4.1 Context

The objective of this section is to link the chemical compounds listed on the priority list to potential indoor contaminant sources. The scope is limited to the following indoor sources: building materials including coatings, furniture, household and consumer products. Human activity controlled measures (e.g. indoor smoking), HVAC components, combustion devices and air cleaning devices are excluded from this review. Radon and moulds are discussed in different chapters of this review. The indoor environments considered are non-industrial buildings.

Most of the priority compounds are VOC, SVOC or VVOC components. The other compounds listed are respirable particles and the inorganic compound ammonia. Due to the scope of this study the compounds CO, CO_2 and NO_2 are not considered in this analysis. Since the European Union has banned all uses of asbestos, its occurrence doesn't result from new materials, and is therefore also excluded from this review.

To reduce exposures to pollutants affecting health, source control and ventilation are usually applied. The HealthVent project (www.healthvent.eu, 2013) recommends in terms of strategy to focus primarily on controlling the sources of air pollutants both outdoors and indoors. Ventilation should be considered as the ultimate (last resort) strategy. Hence it is very important to establish the link between the priority compounds and the (potential) sources in Belgian non-industrial buildings.

1.4.2 Literature review from 2005 – present

The review of Belgian data concerning IAQ and chemical indoor contaminant sources included studies from 2005 until May 2013. Most of the publications with Belgian data however are focussed on IAQ without specific attention for source contributions. In order to be able to make the link between Belgian priority compounds and potential sources, information was compiled from European and international peer-reviewed journal articles, technical reports from governmental institutions and organizations, test standards, on-line databases, website resources provided by governmental institutions, certified laboratories, recognized certification systems and major organizations on low-emission materials. The availability of up to date data was crosschecked with available information from the ongoing EOTA (European Organisation for Technical Assessment) (EOTA PT9) and CEN (European Committee for Standardization) activities (CEN/TC 351, CEN/TC139, etc.) dealing with material emissions. Due to the limited public availability of recent material emissions, also data from older (than 2005) "reference" reports were included for the industrial data part.

Belgian references
Legislation (in Belgium & European trend)

This section gives a brief overview of the indoor air and product policy measures and regulations in Belgium. In Belgium products are regulated at the federal level. Buildings are a regional authority and health is dealt with at community level (Goelen et al, 2003).

The Federal Product Standards Law (1998) and the related implementing orders state that all products, that are brought on the Belgian market, have to be designed in such a way that their production, use and removal do not cause any harm to human health and contribute as low as possible to environmental pollution. The main aims of this law are the creation of an integrated, sustainable product policy and the implementation of the European Directives, as well as the integration of dangerous substances into the Belgian policy (Law of 21 December 1998).

Two other policy documents are the strategic product plan 2009-2012 (Belgian strategic product plan 2009-2012) and the strategic plan air 2009-2012 (Belgian strategic plan Air 2009-2012):
- The strategic product plan 2009-2012 mentions as action 18: adapt legislation in relation to the ongoing developments of the construction products directive;
- furthermore, it also mentions:
    - action 27: criteria for the emissions of construction products,
    - action 28: limiting the emissions of benzene and formaldehyde of air fresheners,
    - action 29: create a database with emission data of products used indoors,
    - action 33: establish an agreement with the sector to decrease VOC emissions of consumer products.

In 2008 the Federal Minister of Environment decided to organise a major stakeholder consultation related to the environment identifying new policy actions. Instead of trying to solve all the complex indoor air problems at once, it was decided to focus on what was manageable, realistic and possibly ready for consensus: tackling the sources, as complement to efficient ventilation as it falls within the competencies of the federal government. As a result a Royal Decree concerning floor coverings and adhesives was drafted and published in 2013 (“Royal Decree establishing threshold levels for the emissions to the indoor environment from construction products (Royal Decree 8th May 2014; published in Belgium’s Official Gazette Bulletin of Decrees 18.08.2014; notification N°2012/568/B). This Royal Decree is an national implementation of Requirement 3 “Hygiene, health and environment” of the European Construction Products Regulation (305/2011/EU). This regulation stipulates provisions with respect to the emissions from construction articles to the indoor environment, as a function of the intended use of these construction products. The goal is to protect the public health against harmful effects or to lower the risk on harmful effects. For air fresheners similar federal actions are expected (the EPHECT project, www.ephect.eu).

Specific regulations on the indoor environment in Flanders are given in the Flemish Indoor Environment Decree of 2004. This decree states that everyone who is responsible for the construction, management and equipment of public buildings is obliged to reduce as far as possible all health risks of the indoor environment on inhabitants and users. Therefore, this decree regulates research and measures on the indoor environment in dwellings and public buildings, as well as all competences of the Flemish Health Inspection (*Vlaamse Gezondheidsinspectie*) and of all medical-environmental experts. Furthermore, within this decree, quality standards on the indoor environment in Flanders are set. In the Walloon Region and in the Brussels Capital Region no regulations exist on the indoor environment.

Emissions testing, certification and labelling programs exist in several European Union Member States (Lor et al., 2010). The European Commission is currently creating (by means of mandate to CEN: CEN/TC 351) a harmonized emissions test standard for use in evaluating product emissions of VOCs into indoor air for the implementation of the "Basic Requirement for Construction Works N°3" of the Construction Products Regulation (CPR) on Hygiene, Health and Environment that includes consideration of emissions to indoor air (CEN/TC 351; C. Daümling, 2012; Harrison et al., 2011; ECA-IAQ Report No 27, 2012). The purpose of this regulation is to facilitate international commerce and reduce trade barriers within the 27 Member States of the European Union. The European initiative focusses on developing product policy to improve indoor air quality and its health effects on building occupants.

Another ongoing European initiative is the establishment of a working group for developing harmonized European Life Cycle Inventory (LCI) values by devising a harmonised procedure for establishing these values taking into account the existing German (AgBB) and French (ANSES) procedures (http://ihcp.jrc.ec.europa.eu/our_activities/public-health/outcome-workshop-emissions-building-materials). Under the Belgian Presidency in 2010 also initiatives were undertaken to develop a Commission product policy that will enhance indoor air quality (http://www.health.belgium.be/eportal/Aboutus/eutrio/environment/In). The importance of indoor air was re-emphasized during the workshop "Better indoor air for better health" during the Green Week Conference 2013 (http://ec.europa.eu/environment/greenweek/).

Industrial data

Table 9 gives an overview of the correlation between (1) chemical compounds of the priority list as shown in Table 1, their appearance in (2) product legislation, voluntary product testing protocols, green codes and guidance documents for indoor air and (3) the potential (emission) sources of these compounds.

The table indicates that, although a considerable list of national and international product legislations, voluntary product testing protocols, green codes and guidance documents for indoor air are available, not all compounds are marked in section 2 (compounds considered in policy) of Table 9 (Lor et al., 2010; Levin, 2010). The selection that is presented assures maximum overlap between the Belgian target compounds and the considered importance in other countries.

Table 9. Overview of the relation between (1) chemical compounds on the priority list, their appearance in (2) product legislation, voluntary product testing protocols, green codes and guidance documents for indoor air and (3) the potential (emission) sources

(1) Priority list indoor air	(2) Compounds considered in							(3) Sources			
	product legislation			product testing protocols & green codes			guidance document indoor air	household and consumer products			
# Target (priority)compounds (S)VOC	DIBt/AgBB 2012	French emissionlabel (2013)	Belgian K8 floor coverings/adhesives (2014)	Greenguard (AgBB+) (2012)		M1	Agoff (2008)	building materials incl coatings	furnishing/furniture	consumer products	electronic devices
1 TVOC		x	x	x		x	x	x	x	x	x
2 total aldehydes				x *				x	x	x	
3 formaldehyde	x	x	x	x		x	x	x	x	x	x
4 acetaldehyde	x	x	x	x			x	x	x	x	
5 benzene	x	x	x	x		x	x	x	x	x	x
6 naphthalene	x		x	x			x	x	x	x	
7 benzo(a)pyrene	x		x	x		x		x	x	x	
8 trichloroethylene	x	x	x	x		x	x	x	x	x	
9 tetrachloroethylene	x	x	x	x			x	x	x		x
10 toluene	x	x	x	x			x	x	x	x	x
1 styrene	x	x	x	x			x	x	x	x	x
12 alfa-pinene	x		x	x			x	x	x	x	
13 limonene	x		x	x			x	x	x	x	
14 1,2,4 trimethylbenzene	x	x	x	x			x	x	x		x
15 triclosan (= 5-chloro-2-(2,4-dichlorophenoxy)phenol)											
16 methylene-di-isocyanate	x		x	x and 91-08-7 Toluene-2,6-diisocyanate				x	x	x	
17 permethrin						x		x	x	x	
18 vinylchloride	x		x	x				x	x	x	
19 xylenes (mix)	x	x	x	x				x	x	x	x
p-Xylene	x		x				x	x	x	x	x
m-Xylene	x		x				x	x	x	x	x
o-Xylene	x		x				x	x	x	x	x
20 glycolethers	x		x	x			x	x	x	x	
21 brominated flame retardants (PBDE, ...)	*VOC content*							x	x	x	x
OTHER											
inorganic compound											
22 ammonia				x		x		x		x	
particles				x				x	x	x	x
23 PM10								x			
24 PM2,5								x	x	x	x

* includes 2-Butenal, Acetaldehyde, Benzaldehyde, Benzaldehyde 2,5-dimethyl, Benzaldehyde 2-methyl, Benzaldehyde 3- and/or 4-methyl, Butanal, Butanal 3-methyl, Formaldehyde, Hexanal, Pentanal, and Propanal

1.4.3 Compounds and Sources

1.4.3.1 Priority compounds and their sources

All the Belgian priority compounds (Table 1) can be related to building materials and/or furniture and/or consumer products and/or electronic devices (see Table 9).

When looking more in detail at the priority compounds in other national and international product legislations, voluntary product testing protocols and green codes, it is observed that the compounds triclosan and permethrin are never considered. Requirements for brominated flame retardants are limited to VOC content requirements. This is due to the more difficult analytical determination of such material emissions (SVOCs) as evidenced by the ongoing development of an ISO (International Organization for Standardization) standard for the measurement of polybrominated diphenylether, hexabromocyclododecane and hexabromobenzene as well as ongoing research projects investigating the causes and impact of indoor contamination with flame retardant chemicals (ISO/CD 16000-35; INFLAME project).

The inorganic compound ammonia is only considered in the Finnish M1 system and the American Greenguard label. Ammonia is usually a secondary emission compound (secondary emissions are chemical compounds formed by the interactions between oxidants in indoor air and chemicals on surfaces, and by hydrolysis). See also section 'Organic compounds in indoor air', due to moisture induced degradation of materials (Gustafsson, 1992). The only references where the measurement of particulate matter emissions during the use phase of a product are included, are the Danish Indoor climate Label (Danish Society of Indoor Climate, 1997) and the American Greenguard label (total particles ≤ 10 µm or respirable particles) (Greenguard GGTM.P056.R3, 2007; Greenguard GGTM.P066.R6, 2008; Greenguard UL2819, 2013; in Greenguard 'particles' is applicable to fibrous particles releasing products with exposed surface area in air streams, it consists of a forced air test with specific test method).

1.4.3.2 Organic compounds in indoor air

A myriad of compounds can be found in indoor air. Some substances may have adverse effects on their own, while others become harmful when they interact with each other. In addition, people are known to react differently to the same exposure (Jungsoo et al., 2013). Apart from the compounds covered by the 'Belgian priority list' (Table 1), many (S)(V)VOCs (German AgBB list) and other intermediary organic compounds such as e.g. radicals, hydroperoxides and ionic compounds as well as species deposited onto particles are not listed. A schematic and tentative visualisation of the organic compounds in indoor air by Wolkoff and Nielsen (2001) is shown in Figure 10.

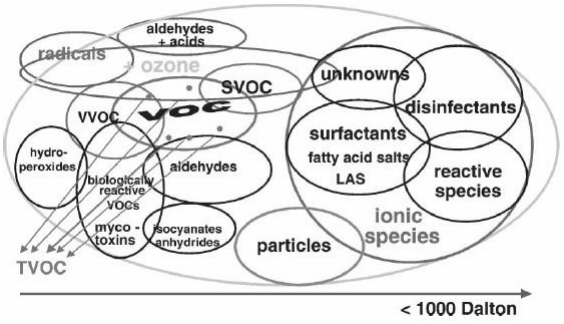

Figure 10. Presentation of organic compounds in indoor air (from Wolkoff and Nielsen, 2001)
Indoor air contains organic compounds and organic compounds on particles, in addition to intermediary species (e.g. organic radicals) and ionic species. The molecular weights of the compounds are tentatively less than 1000 dalton.

According to Wolkoff and Nielsen (2001) four types of organic compounds can be distinguished in indoor air – according to their expected health effect, including odour annoyance, different compounds (Wolkoff et al., 2006):

- chemically non-reactive (stable) organic compounds, e.g. butanol;
- chemically "reactive" organic compounds like alkenes (e.g. limonene) that react with ozone alone or with nitrogen dioxide in presence of light to produce new oxygenated products;
- organic compounds that form chemical bonds to receptor sites in the mucous membranes , i.e. biologically reactive e.g. formaldehyde;
- organic compounds with (known) toxic properties e.g. pentachlorophenol, these compounds are characterized by effects developed over long duration of exposure.

The variety of chemical compounds in building materials, furniture, household and consumer products provides potential for chemical reactions in the material, on the material's surface and in the gas phase. This indoor chemistry is known as one of the main reasons for primary (the physical release of compounds present in a product) and secondary emissions (compounds produced by chemical reaction in the product or in the indoor environment) (Levin, 2008; Uhde and Salthammer, 2007; Nicolas et al., 2007; Weschler, 2004; ECA-IAQ Report No 26, 2007).
A non-exhaustive list of possible reaction products and their reactants in indoor air is given by E. Uhde and T. Salthammer in Table 10.

Table 10. List of possible reaction products and their reactants in indoor air (from Mendell M.J., Mirer, A.G., Cheung, K. Tong, M. and Douwes, J., 2011)

Reactants	**Products**
α-pinene	Pinene oxide, pinonaldehyde
Limonene	Limonene oxide, carvone, formaldehyde
Oleic acid	Heptanal, octanal, nonanal, decanal, 2-decenal
Linolenic acid	2-pentenal, 2-hexenal, 3-hexenal, 2-heptenal, 2,4-heptedienal, 1-penten-3-one
Linoleic acid	Hexanal, heptanal, 2-heptenal, octanal, 2-octenal, 2-nonenal, 2-decenal, 2,4-nonadienal, 2,4-decadienal
Hermicelluloses	Furfural, acetic acid
1-phenyl-2-hydroxy-2-methyl-propane-1-one (PHMP)	Benzaldehyde, acetone, benzil
1-Hydroxycyclohexyl phenyl ketone (HCPK)	Benzaldehyde, cyclohexanone, benzil
2-ethyl-hexyl acetate	Acetic acid, 2-ethyl-1-hexanol
Zn-2-ethylhexanoate	2-ethyl-1-hexanoic acid
n -butylacrylate	n -butanol
Bis(2-ethylhexyl) phthalate (DEHP)	2-ethyl-1-hexanol
Dibutyl phthalate (DBP)	n -butanol
Di-isobutyl phthalate (DIBP)	2-butanol
Tris (chloroisopropyl) phosphate (TCPP)	1-chloro-2-propanol, 2-chloro-1-propanol
Tris(1,3-dichloro-2-propyl)phosphate (TDCPP)	1,2-dichloropropane, 1,2-dichloropropanol
Tris(2-chloroethyl) phosphate (TCEP)	2-chloro-ethanol
Tris(2,3-dibromopropyl) phosphate (TDBPP-TBPP)	2,3-dibromo-1-propanol, 1-bromo-2-propanol, 2-bromo-1-propanol
Styrene + cis-1,3-butadiene	4-phenyl-cyclohexene (4-PCH)
Cis-1,3-butadiene+trans-1,3-butadiene	4-vinyl,cyclohexene (4-VCH)
2-chloro-1,3-butadiene	1-chloro-4-(1-chlorovinyl)-cyclohexene 1-chloro-5-(1-chlorovinyl)-cyclohexene
Zn-diethyldithiocarbarnate	CS_2, diethylamine
Azodicarbonamide	Semicarbazide
Adipinic acid +1,4-butanediol	1,6-dioxa-cyclododecane-7,12-dione
Dimethylarninoethanol + formic acid	Dimethylformanide
1-triptophane	o-aminoacetophenone
2,3,4,6-tetrachlorophenol	2,3,4,6-tetracholoroanisole
2,4,7,9-tetramethyl-5- dicyne-4,7-diol (T4MDD)	Methyl isobutyl ketone (MIBK), 3,5-dirnethyl-1-hexyne-3-ol
Azobisisobutyronitrile (AIBN)	Tetramethyl succinonitrile

There is a clear trend to reduce and/or remove certain (S)(V)VOCs from building materials, furniture, household and consumer products. Whilst this leads to decreased VOC emissions, the overall number of chemicals emitted from building materials, furniture, household and consumer products still increases.

Research has shown that huge qualitative and quantitative differences exist between the chemical releases of similar product sources. In fact no existing criteria or priority list captures all product emissions as a result of frequent modifications in raw materials and manufacturing processes. This tendency is illustrated for paints in figure 11 and figure 12.

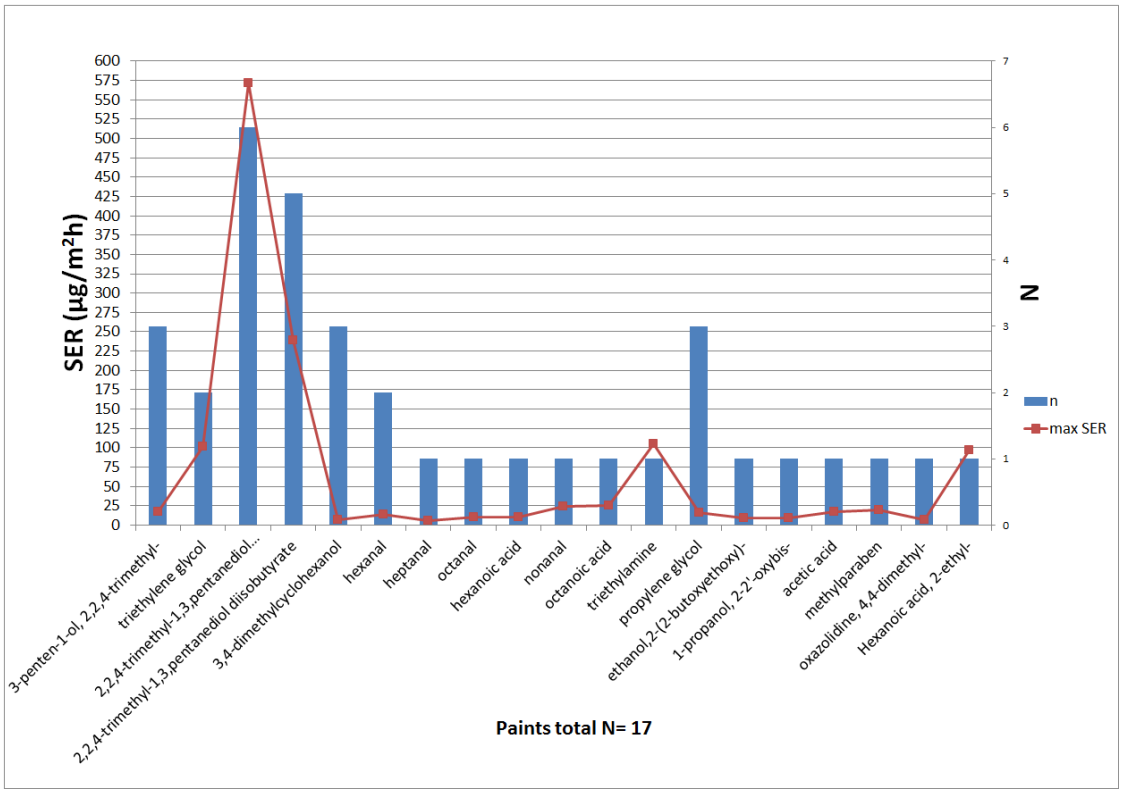

Figure 11. Volatile organic compounds emitted by a selection of indoor paints currently on the Belgian market (from: Lor M., Graindorge, F. Piens, M., Wolfs L. and Remontet P. Conference Emission and odours from materials, Brussels, 2012)

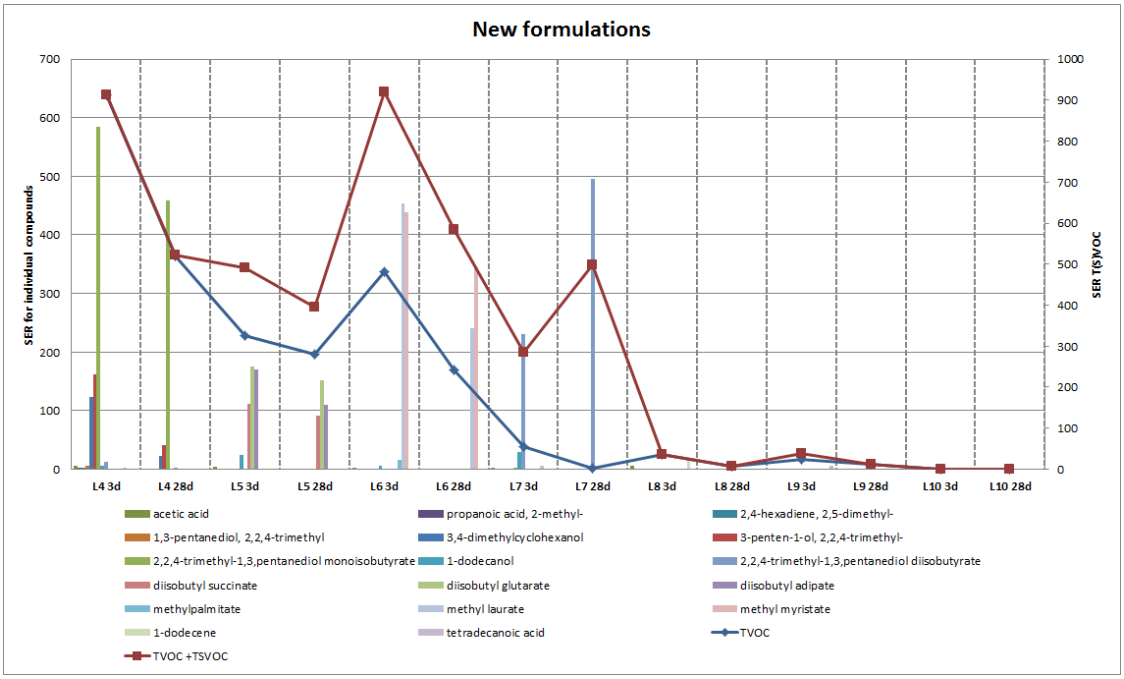

Figure 12. Volatile organic compounds emitted by a selection of new indoor paint formulations (from: Lor M., Graindorge, F. Piens, M., Wolfs L. and Remontet P., 2012)
The horizontal axis pictures 7 different paints, with emission testing after 3 and 28 days.

Health-based ventilation

The importance of ventilation as a factor influencing indoor air quality is widely recognized (Q-INTAIR, 2009; HESE-project, 2002-2005). Good ventilation is necessary to limit the accumulation of emissions that cannot be avoided, such as bio effluents from building occupants (California Environmental Protection Agency, 2009).

Outdoor pollution is an important contributor to indoor pollution, and therefore clean outdoor air and if necessary, a protection against outdoor pollution, are equally important for achieving a healthy indoor air quality (http://www.lne.be/themas/milieu-en-gezondheid/onderzoek/BiBa). Outdoor air used for ventilation can thus be a source of pollution containing particulate matter and various gases such as ozone (O_3), NO_2 and VOCs. Additionally, HVAC (Heating, Ventilation and Air-Conditioning) components and ventilation ductworks themselves can also be sources of VOC emissions (Bluyssen, 2007). Poor condition and maintenance of HVAC systems has been identified as risk factors (Mendel et al., 2006).

Recently (2013) guidelines have been developed for setting health-based ventilation for public and residential buildings, as part of the EU HealthVent project (http://www.healthvent.byg.dtu.dk/). The appropriate health-based ventilation rate for a building assumes that the outdoor air quality meets the WHO outdoor air quality guidelines and is defined by a reference minimum health-based ventilation rate (= 4 L/s per person) and a suitable multiplication factor. This factor cannot be smaller than one, and equalizes one in case measures for indoor source control are taken when selecting used building materials and furniture. In case no source control measures are taken, the factor equals the value two.

This approach proposes to firstly apply source control measures and only then establish a minimum required ventilation rate, based on the effectiveness of the initial source reduction initiatives that were taken (http://www.healthvent.byg.dtu.dk/).

1.4.4 Discussion and conclusions on indoor sources

To be able to assess the emissions of materials and products used indoors and their resulting exposures and associated acute and chronic health effects this information has to be readily available. This information is clearly missing as demonstrated by the limited public availability of recent material and product emissions data even more so in the Belgian context.

In contrast to the U.S., European certification and rating schemes do not report detailed chemical emissions data for their new materials and products. Moreover it is demonstrated that as an increasing number of products are tested an increasing number of chemicals are detected and that (VOC) priority lists do not always cover all chemicals detected, especially in recent years of testing.

Existing recent European databases such as BUMA database (and the BUMAC database) are promising but can't be considered as exhaustive or representative for the entire portfolio of products used indoors and such databases are only updated during the period of the projects lifespan.

Hence there exists a need **for the development of a Belgian emissions database - of materials/products used indoors** - that should be routinely updated to be able to assess the "new" compounds and adjust the policies accordingly. More complete reporting of emissions test results would enable both researchers and manufacturers alike to engage in an on-going process of product improvement that is not limited to the criteria for a particular certification, label or compliance scenario but focussed on the improvement of healthy indoor air in general.

To ensure effective implementation of an IAQ policy, **harmonisation** - at European level - is needed as well as a **careful mapping and combining of already existing legislations and policies** aimed directly or indirectly at chemical substances. The technical issues related to the testing - of ambient air quality itself and the material emission tests - are respectively being tackled in the INDOOR-MONIT project (INDOOR-MONIT and Pilot Indoor Air Monitoring, DG Sanco – JRC, 2009-2012) and in CEN/TC 351 concerning the building materials. The same progress still has to be made for other sources (for instance consumer products for which the current knowledge is at pre-normative level (https://esites.vito.be/sites/ephect/Pages/home.aspx) as well as for the monitoring of chemicals outside the scope of the high priority compounds of the INDEX project. To be able to adequately measure and monitor the new emerging pollutants more research is needed. Another gap in knowledge is the important difference in the way how a material/product is currently **evaluated for labelling/certification and how it behaves in a real indoor environment** where secondary emissions occur on top of the primary emissions. Also in this field more research is needed (DO-IT Houtbouw, 2012-2016; Järnström et al., 2008)**.**

Aside from harmonisation of the technical issues, **harmonisation is also needed for health-based target concentrations for indoor air pollutants of concern** (INDEX report, 2005).
Possibilities for these harmonised criteria are shown in the ECA Report No 27 (EUR 25276 EN, 2012) but this framework should be extended to include evaluation protocols of other countries and also extended to other sources than only building materials. The harmonisation of the LCI values needed for the health based evaluation of indoor product emissions is currently ongoing (Kephalopoulos and Kotzias, 2011).

In order to obtain good IAQ in buildings it is not only necessary to select low-emission products, but also to properly design, operate and maintain ventilation systems and to stimulate a responsible behaviour of occupants (by means of sensibilisation and information of citizens) (Bluyssen et al., 2010). As already mentioned by the EnVIE project IAQ should be incorporated in the energy efficient procedures of the Energy Performance of Buildings Directive (EPDB) (EnVIE Co-ordination Action on Indoor Air Quality and Health Effects, Deliverable 0.1.4, 2009).

The same discrepancy can be observed in most of the green building assessment schemes (BREEAM, Valideo, LEED, etc) which rise in influence and where IAQ has a relatively light weighing (Yu and Kim, 2011; *Referentiekader voor duurzame woningen*, WTCB, 2010).

1.5 Conclusions and recommendations on chemical indoor air priority pollutants in Belgium

Since 2005, a wide variety of chemicals was assessed in at least 788 Belgian indoor sites, mostly health complaint-free residences, schools and nurseries. Based on this work, a considerable knowledge is available on the indoor occurrence of chemicals, characterised by well-established sampling and analysis methods and by known toxicological impacts (such as BTEX, formaldehyde, acetaldehyde, trichloroethylene, tetrachloroethylene, pinene, limonene and also PM, CO, CO_2 and radon). However, considerably less is known about the indoor occurrence of chemical agents with less well established sampling and analysis methods. A traditional health impact evaluation of NO_2, PM, VOC, TVOC and formaldehyde in this review, indicates that 95 % of the studied Belgian indoor sites can be classified as of "limited health concern caused by IAQ", but also that 5 % of the studied sites is of high concern. Based on the available Belgian data, exceedances of health based reference values and high TVOC concentration levels are found to most likely occur in health complaint buildings. Benzene and benzo(a)pyrene are identified as potentially causing the largest impact on the cancer incidence in the studied indoor sites. It is important to note that this conclusion is based on a traditional substance-by-substance evaluation of a few compounds and on a selection of available health based reference values. In order to achieve a reduced health risk of indoor exposure, a dedicated source control is needed. However the limited public availability of emission data still hampers an accurate assessment of the impact of material emissions on IAQ and on the associated health risk.

The overall analysis of current knowledge on IAQ in Belgium led to the identification of knowledge gaps and needs for further research. Needs are situated in the field of IAQ characterisation and assessment, exposure and health impact assessment, as well as product emissions and source identifications. There is also a need for harmonisation on a national level.

1. **Baseline levels**. More data on baseline levels of recently prioritised indoor air pollutants (e.g. based on product emission data), or pollutants of which the health impact and exposure pathways are being studied, will lead to a more accurate health risk assessment and to the definition of suitable preventive actions. One way to obtain representative data sets is to initiate the operation of a continuous IAQ monitoring network based on voluntary cooperation of building owners and/or selected dwelling owners.

2. **Reference database on IAQ and indoor sources**. The establishment of a reference large-scale database on IAQ in Belgium, representative for indoor settings and sources in Belgium, and suitable for data-mining. This database should then include various indoor settings, (future) prioritised compounds as well as emission data of any type of product used in indoor environments. The initiation of this action could be implemented by the establishment (under public authorities) of a permanent Belgian IAQ commission.

3. **Updated listing of priority compounds**. Regularly tuning of priority compound lists with new chemicals, identified in product emission testing. E.g. the Belgian priority list does not include compounds such as phthalates (SVOC, suspected endocrine disruptors) (Carlstedt et al., 2013), for some substances already on the list (e.g. flame retardants and ammonia) the test method still needs to be developed or optimized.

4. **Harmonised sampling strategies for source apportionment**. Harmonisation of strategies for suitable source apportionment tools for IAQ assessments in health complaint (source apportionment) and health complaint-free indoor settings will lead to a more targeted anticipation on sources and health complaints.

5. **Harmonised analysis methods and tools**. IAQ data are comparable when based on harmonized sampling and analysis methods and strategies. Harmonisation will thus increase the validity and use of a reference database on IAQ and indoor sources. This need is applicable for (1) prioritised compounds in table 1, focus on emerging pollutants, (2) new compounds beyond INDEX, WHO and Flemish IAQ guidelines (e.g. SCHER opinion IAQ, listed in IAQ guidelines from other countries), prioritised compounds by other countries (e.g. French OQAI (*Observatoire de La Qualité de L'Air Intérieur*), German GerES (German Environmental Survey), etc.) and substances identified as "of concern" (such as acrolein etc.), and (3) compounds prioritized based on material emission data, substitutes for banned substances, secondary reaction products.

6. **Harmonised health-based target concentrations and reference values.** Harmonisation is needed in the assessment of health-based target concentrations for indoor air pollutants of concern. Furthermore, a wider range of chemicals emitted by products beyond building materials and beyond the scope of WHO is needed. Additionally, a comprehensive and harmonized list of RV, including emerging pollutants will lead to a more accurate assessment of the impact of IAQ. Currently this work exists of a "patchwork" of RV's with diverse use of assessment factors.

7. **New sampling methods and analysis techniques**. The development and optimisation of new sampling devices, methods and analysis techniques suitable (and dedicated) for indoor sampling of new and emerging pollutants.

8. **Long-term follow-up of IAQ**. The establishment of a long-term follow-up scheme of IAQ in a representative dwelling stock (cf. UK Homes in England – time trends over decade) will learn about the impact of building trends and occupant behaviour on IAQ and will allow a demonstration of appropriate data management tools. Special attention should be given to IAQ in energy-efficient housing, building renovations, new (sustainable) building products, airtightness and mechanical ventilation and to the impact of human behaviour on IAQ. Also long-term follow-up studies focussing on environments where vulnerable populations reside and on micro-environments with expected increased concentration levels of emerging pollutants are needed.

9. **Cumulative exposures and health risk assessment**. A complex mix of substances can be found in indoor air due to the huge qualitative and quantitative differences in the releases of the sources of indoor air contamination and their potential health effects. A more in depth analysis of effects that result from combined exposures to various substances in indoor air (e.g. grouping of substances provoking same/similar effects) is necessary, in order to have a more refined answer in the follow-up of screening. More research is needed to expand the limited understanding of the health and comfort effects of exposure to the complex mixtures found in indoor environments.

10. **Certification and secondary emissions**. More knowledge is needed on how a material/product is currently being evaluated for labelling/certification in relation to its indoor use and to occupant behaviour in a real indoor environment. Combined uses of products and reactive chemistry are also part of this. In a second stage

one should also take into account that secondary emissions occur on top of the primary emissions.

11. **Estimated cost of IAQ:** An exploratory study of the socio-economic cost of the indoor air quality is needed, including a more accurate calculation of DALY's.

12. **A good IAQ in buildings.** To achieve a good IAQ in buildings, the use of low-emission products should be maximized, but also a proper design, operation and maintenance of the ventilation systems (Bluyssen et al., 2010) is indispensable. IAQ has to be incorporated in the energy efficient procedures of the Energy Performance of Buildings Directive (EPDB); furthermore there is a considerable need for a more thorough integration of IAQ in green building assessment schemes (BREEAM, Valideo, LEED, etc.).

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- *le Service CRIPI de la Région Bruxelloise.*

2. Indoor microbiological pollutants in Belgium

2.1 Overview of indoor microbial pollutants

2.1.1 Introduction

Common biological indoor contaminants include bacteria, viruses, moulds, fungi, house dust mites and allergens of animals. They are often found in areas that provide moisture or water. Still waters, water-damaged materials or wet surfaces may serve as a breeding ground for moulds, mildews, bacteria and insects. Biological pollutants may have their sources inside buildings or outdoors. Contaminated central air handling systems may be even more problematic because they can distribute these contaminants throughout the building. By controlling the air relative humidity level, the growth of some biological contaminants can be minimized.

On the other hand, socio-economic problems, global warming and profound behavioural modifications could indicate in the future great changes of indoor environments, with maybe new adverse effects on human health.

2.1.2 Main microbial pollutants

2.1.2.1 Natural sources

The origin of most microbial indoor pollutants is natural. Airborne dust of external origin is regularly introduced, accumulates in our houses (Horner et al*.,* 2004) and may constitute a reservoir with a great biodiversity.

Presence of animals, plants and human beings inside the building is an important source of allergens. Sebaceum glands, saliva and urine of animals contain specific proteins that are allergenic to humans. These proteins are deposited on the animal's dander where they dry-out and become airborne. Cat and dog allergens are carried by small airborne particles, and may remain suspended in the air for long periods of time. Due to the adherent nature of cat and dog dander, these allergens may also be transported easily from room to room and from one building to another. Clothing can thus be an important source of cat and dog allergens indoors. This explains why cat and dog allergens are even present in settled dust of dwellings without pets, although concentrations found in homes housing these animals are clearly higher (Wood et al., 1992; Custovic et al., 1998; Macher et al., 2005).

Presence of animals, plants and human beings inside the building is an important source of allergens.

Bacteria are naturally present in indoor environment. Most of them originate from humans and pets, but may also originate from outside air, vegetation and soil. Indoors, the predominant natural bacteria are Gram-positive, and belong to the *Micrococcaceae* and especially *Staphylococcus* species (Gorny et al., 1999, 2002; Bouillard et al., 2005; Stryjakowska-Sekulska et al., 2007; Golofit-Szymczak & Gorny, 2010).

In a study made in Poland, it was found that the typical level of bacterial aerosol indoors, determined using a six-stage Andersen impactor, was about 10^3 CFU (Colony Forming Unit)/m^3 in homes and 10^2 CFU/m^3 in offices. *Staphylococcus epidermidis* was found to be the second most frequent occurring species (after *Micrococcus spp*.), present in 76 % of homes.

In a study concerning 100 large US office buildings (Tsai et al., 2002) the Gram-positive cocci was the only group that occurred significantly higher indoors (39 vs 24 CFU/m^3 with a single-stage multiple-hole Agar impactor), especially in summer (116 vs 87 CFU/m^3). Rintala et al. (2008) also concluded that the bacterial flora of indoor dust is complex and dominated by Gram-positive species. But in public buildings, some Gram-negative bacteria may also be present on surfaces. In shopping, day-care and office environments, total and faecal bacteria for instance were detected on 20% and 7% of the surfaces, respectively (Reynold et al., 2007).

The bacterial flora of indoor dust is complex and dominated by Gram-positive species. But in public buildings, some Gram-negative bacteria may also be present on surfaces.

Outdoor air is also a considerable source of natural airborne fungal spores, which present an important seasonal character and may be collected in high concentrations. According to the fungal calendar of outdoor air in Brussels (Air Allergy, 2014), this is mainly the case for three allergenic moulds: *Alternaria alternata* (June-September) and *Cladosporium spp*., mainly *C. herbarum* and *C. cladosporioides* (May-October). They are moulds that typically live on plants, which explains their increase during the vegetation season. Sterile mycelia on agar cultures are also well represented during this season.

Outdoor airborne moulds can be introduced inside buildings and accumulate in settled dust. The analysis of dust for cultivable fungal colonies (Horner et al., 2004), shows that leaf surface fungi constitutes a considerable portion (> 20 %) of the total colonies in at least 85 % of the samples. The two *Cladosporium* species origin mainly from outdoors but the analysis of fungal flora in indoor dust by ribosomal DNA sequence (Pitkäranta et al., 2008), indicates that *C. cladosporioides* and *C. herbarum* are among the dominant species. *Alternaria alternata* antigens in US homes were also common; 95 % to 99 % of the collected dust samples had detectable levels of *A. alternata* antigens (Salo et al., 2006).

Other airborne fungal spores, also present outdoors, and found in indoor settled dust, are basidiospores for example, produced mainly in autumn but found all year long in indoor settled dust (Pitkäranta et al., 2008). In the case of seasonal clinical symptoms in the patient, the calendar of the main outdoor airborne fungal spores may help the doctor to find a possible link between health and natural environment. But, exposure to seasonal moulds accumulated in indoor settled dust may be prolonged throughout the year.

Settled dust thus contains many microbial pollutants in varying amounts (Macher et al., 2005). Taking into account dust resuspension in the air (Gomez et al., 2007; Rajah et al., 2010), the accumulation phenomenon of settled dust may be a significant source of harmful effects all year long.

Outdoor air is also an important source of natural airborne fungal spores which can be introduced inside buildings and accumulate in settled dust.

Settled dust contains many materials in varying amounts. Taking into account dust resuspension in indoor air, the accumulation phenomenon of settled dust may be a significant source of harmful effects all year long.

2.1.2.2 Anthropogenic outdoor sources

In addition to the natural airborne moulds and bacteria outdoors, specific contaminations may be produced by human activities. These contaminations can be introduced into neighbouring buildings and accumulate in settled dust. In cities, the demolition of an old building always constitutes a temporary but often significant source of dust containing a variety of moulds, especially from genus *Penicillium* and *Aspergillus*. A garbage dump, a public waste sorting or an industrial composting centre release lots of bacteria and moulds in a permanent way.

In the surrounding of composting centres for example, the thermophilic mould *Aspergillus fumigatus* and some thermophilic bacteria such as *Bacillus stearothermophilus*, *Thermus thermophilus* or *Thermoactinomyces vulgaris* (Strom, 1985, Beffa et al., 1996) were well represented. In a study (Albrecht et al*.,* 2008) the authors noted that, under the wind, abnormal microbial concentrations were still measurable at a distance of 800 to 1400 meters. The thermotolerant moulds and *Thermoactinomyces* were at this distance still one to two orders of magnitude higher than the natural microbial background levels. Some Microbial Volatile Organic Compounds (MVOCs) were also produced. Heer et al. (2003) carried out measurements of bacteria, moulds and *Thermoactinomyces* in the air nearby a composting centre. They noted that up to a distance of 1400 meters, the microbial concentration, especially for thermophilic bacteria, was higher than the natural background levels. As regards health, the highest prevalence of complaints corresponded to the people living closest to the composting centre (150 to 200 m). The period of residence near the site also seemed a significant factor.

In addition to the natural airborne moulds and bacteria outdoors, specific contaminations in the surrounding of the dwellings may be produced by human activities (anthropogenic sources). These contaminants can be introduced into neighbouring buildings and accumulate in settled dust.

2.1.2.3 Microorganisms developments due to moisture sources in buildings

In our areas, moisture excess in buildings is frequently occurring and is responsible for the development of specific microorganisms. Moisture in buildings may have different origins. Origins can be external to the building, such as rainwater leakage or seeping groundwater. It can also be produced indoors, for example due to the leakage in water pipes, human activities like breathing, cooking, washing, perspiration, etc. in combination with insufficient building ventilation. Moisture is an essential element for microbiological development, which is characterized by a phenomenon of amplification of specific microorganisms.

Table 11. Examples of human moisture production sources in building

Human sources of moisture	***Moisture production***
People at rest	*40 g/hour*
People with a moderate activity	*60 g/hour*
Cooking	*2 Kg/day*
Laundry drying	*1.5 Kg/day*

Visible fungal developments due to water damages are often considered as the major microbiological contamination in the habitat. However, these contaminated surfaces can accommodate an unsuspected biodiversity (Park & Cox-Ganser, 2011). Other microorganisms, more discreet by their size, cohabit with these moulds. It is the case of fungi eating mites and many bacteria (Mehrer et al., 2005; Anderson et al., 2003).

More than one hundred moulds species were listed on water damaged building materials. The most frequent species identified in dwellings are *Cladosporium sphaerospermum, Aspergillus versicolor,* several species of *Penicillium*, followed by *Alternaria, Chaetomium* and *Stachybotrys chartarum* (Beguin & Nolard, 1994; Reboux et al., 2009).

Some bacteria, mainly *Streptomyces spp*., co-occur with moulds in moisture-damaged residences. They produce several toxic metabolites like monoactin, nonactin, staurosporin and valinomycin, which were exclusively detected in building wet materials (Täubel et al., 2011).

It should be noted that a fungal development, with all related microorganisms such as bacteria and mites, is not always visible. Moulds can develop in hidden wet places for example under floors, behind boardings, inside hollow partitions, etc. Mattresses, fabric armchairs, carpets, cloths, and shoes may also constitute a privileged substrate for mould and mite (*Dermatophagoides*) development.

Cockroaches also require a detailed attention. Concentrations of cockroach allergen are typically at their highest in kitchens and bathrooms, and humidity seems to be an important determinant in cockroach infestation (Eggleston and Arruda, 2001).

Moisture in buildings is frequent and may have various origins. In our areas, visible fungal developments due to moisture excess are frequent and often considered as the major microbiological contamination in the habitat. But other microorganisms, more discreet by their size, often cohabit with these moulds: it is the case of fungus eating mites and many bacteria. Humidity also seems to be an important factor in mites or in cockroach infestation.

2.1.2.4 Central air conditioning system and other varied ventilation systems

A number of health complaints and pathologies have been reported with the generalization of heating, ventilation and air-conditioning (HVAC) systems and some of them were found to be related to specific contaminations present in the installations.

The filtration of air supply may for instance cause an accumulation of dust in the ducts and cause an impact on the quality of the indoor air. However in office buildings equipped with HVAC, the most important source of microorganism development is the water in the tank in the humidifier and surfaces inside cold humidifiers.
The most common moulds isolated in humidifiers are *Exophiala jeanselmei, Acremonium strictum, Phoma spp., Phialophora spp*. (Heinemann et al., 1994). Bacteria concentrations are sometimes also very high.

If technical maintenance of air conditioning systems is performed on a regular basis, microbiological contamination due to HVAC systems is usually absent. However the absence of guidelines (standard procedures) and only limited studies (Chasseur et al. 2003; Chasseur et al, 2000; Malchaire et al, 1999) on cleaning protocols for an effective microbiological maintenance still contribute to this fact.

Other mechanised systems for air treatment and heating (or cooling) are more common in collective and individual habitats. The ground-air heat exchangers (also called Canadian airshafts or "*puits canadiens*") for example, may be a significant source of microorganism development because of the high risk of condensation inside the airshaft.

✎ *In indoor environment, several origins of microbial contaminations must be taken into account. The natural and anthropogenic outdoor sources, accumulated in settled dust, are sometimes enriched with specific microorganisms originating from indoor sources. These developments are always due to water presence, as damage sources in buildings which are frequent in our areas. But multiple and varied other sources of water exist, as, for example, during the humidification process in the HVAC system or because of condensation in ground-air heat exchangers (also called Canadian airshafts or "puits canadiens").*

2.1.2.5 Societal changes

Forced by new regulatory standards to achieve an enforced energy-efficiency of buildings, our indoor environment has greatly changed over the past few years, sometimes leading to adverse effects on human health. This evolution is likely to accelerate in the next decades due to various factors. Socio-economic problems for instance, force more and more people to live in increasingly reduced and badly adapted spaces, meanwhile the scale and frequency of floods are likely to increase in the future as a result of climate change.

Other behaviour changes may also contribute to pollute the air we breathe, such as the need to be surrounded by pets, plants or by a lot of technological gadgets which are supposed to improve our environment and our health.

Resulting from the increasing awareness of the role of our environment on our health, new products or concepts are introduced to the market, benefitting from a legal vacuum imposing to justify their utility or effectiveness, but especially the absence of health risks. Among doubtable examples are acaricides or other sophisticated concepts meant to avoid mites in mattresses or carpets. Also the useless variation of biocides intended to cleanse mouldy areas and even the pulverisation of "good" bacteria, so-called probiotics, under the pretext to cleanse the environment, are in seldom supported by any scientific study that guaranties their harmlessness.

✎ *With the increasing awakening of the role of environment on health, new products or concepts appear on the market, benefitting from a legal vacuum imposing to justify the utility, the effectiveness, and especially the absence of health risks.*

2.1.3 Sampling methods

Sampling procedures have greatly evolved in recent years due to new microbiological techniques. Consequently, microorganisms are no longer identified and counted under the microscope or after culture. Different biochemical, immunological and molecular identification and quantification techniques are now available, although they are still academic.

Furthermore, this growing number of new techniques does not favour the formation of a consensus on sampling procedures and analyses standardization, and consequently contributes in the difficulty of establishing standards and guidelines.

At present, methods based on cultures remain the most studied and developed for field investigations. Since they are limited to the viable germs, a consensus on standardized protocols remains difficult. The choice of agar medium, the temperature and incubation duration are critical. For pathologies of allergic, irritating or toxic nature, the non-viable microorganisms must be taken into account as well; the contribution of their fragments is difficult to estimate but could reach up to 90 % (Alvarez et al., 1995).

There is also a large variety of sampling strategies. Air is the most commonly characterised matrix, although its composition is often unstable. This instability leads to the requirement of a longer sampling duration and the need for repetitive samplings, which is difficult to perform using agar media. Moreover many types of air samplers are available, with various characteristics and performances and different use instructions (in terms of sampling duration, use of different agar media, variable incubation temperatures). These differences hamper a comparative evaluation of results available in literature and do not facilitate the formulation of a consensus on air sampling of microbiologic pollutants. Nevertheless, air sampling can provide useful information, but, because of its instability, it must be supported by the analysis of other matrices such as settled dust on furniture and other horizontal surfaces or accumulated dust in carpets, armchairs and mattresses.

✎ *Presently, there is no consensus about the large variety of sampling strategies. During a microbiological audit, air sampling can provide useful information, but is not sufficient in itself because of air instability. Air sampling data must be consolidated by the analysis of other matrices such as settled dust on furniture and other horizontal surfaces or accumulated dust in carpets, armchairs and mattresses.*

2.1.4 Laboratory analyses

As for sampling strategies, a consensus for standardized laboratory analysis protocols remains difficult. In the laboratory, microbial analysis is not always performed with the same precision. Concerning moulds for instance, the identification is sometimes limited to the genus (*Cladosporium spp., Penicillium spp*.), and even only to some groups of species with simple macroscopic criteria (Black yeasts). In other cases, the identification may be performed up to species level. It is then important to apply a uniform nomenclature of the species. For instance *Penicillium chrysogenum* and *Penicillium notatum* are not two distinct species but synonyms.

In recent studies, the development of new molecular techniques such as sequencing ITS (Internal Transcribed Spacer) of the ribosomal DNA (DeoxyriboNucleic Acid) and the use of PCR methods have allowed to refine identifications, from the more traditional means to the identification of not easily cultivable species and/or dead in cultures. These novel molecular tools are promising, especially for bacteria, but they still remain very academic and expensive for environmental screenings of microorganisms.

✎ *The variety of the samplers' performances and sampling procedures for moulds and bacteria adds up to the diversity of the methods in the different levels of analysis, making a consensus of standardization even more complicated.*

2.1.5 Standards, guidelines, results interpretation

2.1.5.1 No Health Based standards

At present it is not possible to give health-based standards on the acceptable number of microorganisms in indoor environments. Little is known about the exact causal relationships between certain microorganisms and their effects on human health. Microorganisms are part of the normal living environment, they have always been present both in indoor and outdoor air. Where exposure to microorganisms or their by-products is much higher than in a normal living environment, their presence may be hazardous to health.

✎ *At present it is not possible to formulate health-based standards on the acceptable number of microorganisms in the indoor environment, but some threshold values have been calculated and used by the different laboratories. These values are related to a specific methodology used by the laboratory and permit to detect microbial anomalies in environments.*

On visible mould areas, the presence of mites has also often been reported (33.1%). This microscopic element is generally not taken into account in epidemiologic studies. In Taiwan, a significant dose-dependent relationship was found between the severity of indoor visible mould growth and the serum total IgE (Immunoglobuline E) level in resident children (Hsu et al., 2010). However, the IgE that is specific to commonly examined fungal allergens didn't explain this correlation, while the IgE specific to mite allergen was found to be better associated with the ranked severity of indoor mould growth. This study suggests that mite allergen seemed to play a crucial role whereby, additionally, fungal exposure can enhance sensitization in indoor environments (Chasseur et al., 2014).

In fact, the exposure to mould can be accompanied by simultaneous exposure to other microbial and chemical agents in the indoor environment. It is one of the reasons why specific causal relationships between mould exposure and health effects are not yet understood and need more in-depth study (Hossain et al., 2004; Park & Cox-Ganser, 2011).

2.1.5.2 Federal Legislation

The well-being of workers

Concerning indoor microbial contaminants and health, we can draw on information in the work regulation.

The Welfare Act (Act of 4 August 1996 on the welfare of people at work) is the basis for the legislation on health and safety at work in Belgium. This Act transposes into Belgian law the framework Council Directive 89/391/EEC of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work.

But microorganisms that can be manipulated and used are also taken into consideration. The Royal Decree of the 4th of August 1996 referring to" Biological agents " (Welfare at Work Code, Title V, Chapter 3) specifies the regulations/rules for the protection of workers against biological agents. This decree specifies the legal framework concerning the exposition to biological agents and divides it into 4 categories depending on the potential danger. The decree also describes different management measures to be taken into account by the employer, to respect the basic principles of avoiding any exposure. Workers exposed to biological agents have to undergo a medical examination, at least once a year (or more frequently, depending on the advice of the consultant/occupational physician).

✎ *In the Decree of the 4th of August 1996, always implemented, the biological agents are classified in four groups according to the infectious diseases risks. But the health risks of environmental and non-infectious germs are completely forgotten. The definition of the biological agents of group 1, defined as not being able to cause a disease to people, is not conceivable for allergy.*

Specific Recommendations for Legionella spp.

In Belgium, several institutions contribute to the control of exposure to *Legionella*: the Federal Public Service for Employment, Work and Social Solidarity for occupational health and safety matters, the Superior Health Council for public matters and the Environmental authority. Belgium is also a member of the European Study Group for *Legionella* Infections (ESGLI, 2014).

The Superior Health Council has produced two reports concerning *Legionella* and has formulated an advisory report for health care facilities in order to prevent *Legionella* infections (HGR, 2002).

2.1.5.3 Legislation in the different regions: Flanders, Wallonia and Brussels Region

Table 12. Overview of the Regional Regulations on micro-organisms

	Overview of the Regional Regulations on microorganisms			
Community	Biological agents	Legislation	Contents	SHC comments
Flanders	*Legionella*	*"Besluit van de Vlaamse Regering van 9 februari 2007 betreffende de preventie van de veteranenziekte op **publiek toegankelijke plaatsen**. (B.S. 4 mei 2007)"*	Replaces the earlier regulation on *Legionella* in the sanitary system, cooling towers and humidifiers. Identifies different rules for institutions with high or moderate risk for patients. Expresses the importance of a control plan, supported by *Legionella* analyses in water: *L. pneumophila* in sanitary water samples, *Legionella* species in samples from cooling towers	**+**
	Biotic factors in the indoor air (Dust mites Microorganisms Moulds Cockroach Rat / Mouse Mites)	***"Vlaams Binnenmilieubesluit*** *Besluit van de Vlaamse Regering houdende maatregelen tot bestrijding van de gezondheidsrisico's door verontreiniging van het binnenmilieu (11 juni 2004)"*	Specifies orientation values for biotic factors in the indoor air of domestic and public buildings **- Dust mite** ≤ 0.2 mg guanine/g dust **- Microorganisms** ≤ 500 CFU/m³ **- Moulds** ≤ 200 CFU/m³	**+** **-** **-** No methodology, no references, no microorganisms definitions
Wallonia	*Legionella*	*« Arrêté du Gouvernement wallon déterminant les conditions sectorielles relatives aux bassins de natation couverts et ouverts utilisés à un titre autre que purement privatif dans le cadre du cercle familial, lorsque la surface est inférieure ou égale à 100 m² ou la profondeur inférieure ou égale à 40 cm utilisant un procédé de désinfection autre que le chlore ou en combinaison avec du chlore (M.B. 12 juillet 2013) »*	Only specifications for public swimming pools: • 2 sanitary water analyses a year of *Legionella pneumophila* (every 6 months) + each sampling: 2 samples are taken, one without flushing, second after flushing 2 till 3 minutes • Hot water production temperature for the showers is 65°C Requirements for cooling towers are specified in the environmental licence/permit	**+**

	Moulds / Fungi	*« Code wallon du Logement 30.08.2007 - Arrêté du Gouvernement wallon déterminant les **critères minima de salubrité**, les critères de surpeuplement et portant les définitions visées à l'article 1er, 19à22bis du Code wallon du logement (M.B. du 30.10.2007) »*	Presence of mould >1m² in one room or in a sanitary room could be harmful, the investigator has to take samples for further analyses (by authorised laboratories) The presence of *Serpula lacrymans* or similar fungi could bring in danger the security of the structure	**+/-** Easy, but the simplicity can underestimate the situation **+**
Brussels Region	*Legionella*	*"Besluit van de Brusselse Hoofdstedelijke Regering van 10 oktober 2002 tot vaststelling van de exploitatievoorwaarden voor **zwembaden** (B.S. 8.11.2002)"* For cooling towers: see environmental permit	Specifications for swimming pools. • Analyses of *L. pneumophila* in the water from the showers . • Minimum once a year. The requirements for cooling towers are specified in the environmental licence/permit	**+/-** Only specifications for swimming pools. **+**
	Moulds/Fungi	*« Code Bruxellois du logement (28. 07.2013) "*	The salubrity requirement consists on the absence of fungi, parasites, insects volatiles and rodents dangerous or harmful for the health of the occupants	**+/-** The word "absence" is not defined.

Comments from the Belgian Superior Health Council (SHC)
+ Sufficient approach and based on scientific studies
+/- Insufficient approach able to lead to errors of evaluation
- Incorrect, and leading to errors of evaluation

In the different guidelines and regulations, details or references concerning the recommended sampling and analysis methodologies are frequently missing, making them unusable, and sometimes leading to a wrong environmental diagnosis.

It is the case with the *"Besluit van de Vlaamse Regering houdende maatregelen tot bestrijding van de gezondheidsrisico's door verontreiniging van het binnenmilieu"* (June 11, 2004). The absence of references or details concerning sampling and analyses and the use of non-precise terminology, as total microorganisms (bacteria, protozoa, etc.) or total moulds (mesophilic, thermophilic, xerophilic, etc.), makes this regulation unusable. Moreover, without precise methodology and studying only the quality of air, known to be an instable matrix, a serious undervaluation of microbiological contamination is possible.

A simple and arbitrary approach is often preferable, even if it proves to be insufficient for an exhaustive evaluation of the biocontaminants. It is the case of an only visual evaluation of mould suggested in the «*Code wallon du Logement*» (August 30, 2007). It is a simple visual approach based on an arbitrary evaluation of mouldy surfaces.

However, too much simplicity may lead to a tool which is difficult to use. In the «*Code Bruxellois du logement*» (July 28, 2013), the salubrity requirement stipulates absence of fungi, parasites, flying insects and rodents, dangerous or harmful for the health of occupants. The definition of "absence" for fungi, insects or bacteria in indoor environments is however unclear, and one should question whether it could even be possible for a dwelling to have no moulds or bacteria indoors.

Within the different threshold values concerning microbiological agents proposed in regional regulations, an imprecise terminology and a lack of detail or references concerning sampling and analysis methodology prevails, making the values unusable and a source of misinterpretation of results.

2.1.5.4 Guidelines in the different regions: Flanders, Wallonia and Brussels Region

Table 13. Overview of the Regional Guidelines on micro-organisms

	Overview of the Regional Guidelines on micro-organisms			
Community		Guideline	Contents	SHC comments
Flanders	Moulds	*"Brochure Wonen gezondheid, 3e editie, Ministerie van de Vlaamse Gemeenschap 2005/2009"*	Interpretation for the occurrence of moulds in indoor air: • very low < 50 CFU/m³ • low < 200 CFU/m³ • moderate < 1000 CFU/m³ • high < 10.000 CFU/m³ • very high > 10.000 CFU/m³ (= maximum value) Table biotic factors : • orientation value total moulds: < 200 CFU/m³ • recommended value for individual moulds < 50 CFU/m³ (exception *Cladosporium*), *Alternaria sp* < 500 CFU/m³, *Cladosporium sp* < 500 CFU/m³, • Toxic moulds: recommended absence (*Aspergillus sp, Fusarium sp, Penicillium sp, Stachybotrys sp*)	**-** No precision or references on sampling and impactor type, and approach only quantitative. **-** No precision or references on sampling and impactor type. Still a good methodological approach for mould results' interpretations, because it has a qualitative approach.
	Bacteria	*"Brochure Wonen gezondheid, 3e editie, Ministerie van de Vlaamse Gemeenschap 2005/2009"*	Interpretation for the occurrence of bacteria in indoor air: • very low < 100 CFU/m³ • low < 500 CFU/m³ • moderate < 2500 CFU/m³ • high < 10.000 CFU/m³ • very high > 10.000 CFU/m³ (= maximum value) Table biotic factors: • recommended value for bacteria: 10.000 CFU/m³ (overload of gram+)	**-** No precision or references on sampling and impactor type. **-** No references on methods, arbitrary.

			• Bacterial toxins: maximum value < 100 ng/m³ • *Legionella* in the air: advise absence	- unspecified toxins - unspecified method
	Dust mites	*"Brochure Wonen gezondheid, 3e editie, Ministerie van de Vlaamse gemeenschap 2005/2009"*	• Dust mite: ≤ 0.2 mg guanine/ g dust • Maximum value 0.6 mg guanine/ g dust	**+** **+** But no cited references.
Brussels Region	Moulds	*« Info Fiches Bâtiment Durable Recommandation pratiques CSS11 Limiter les sources de pollution intérieure : Biocontaminants, (07.2010) »*	Interpretation for the occurrence of moulds in indoor air (dwellings): • very low < 50 CFU/m³ • low < 200 CFU/m³ • medium < 1000 CFU/m³ • high < 10.000 CFU/m³ • very high > 10.000 CFU/m³ (= maximum value) Interpretation for the occurrence of moulds in office indoor air: • very low < 25 CFU/m³ • low < 100 CFU/m³ • moderate < 500 CFU/m³ • high < 2.000 CFU/m³ • very high > 2.000 CFU/m³ Classification based on the contaminated surfaces • Low risks< 0.3 m² • Moderate risks 0.3 – 3 m² • High risks :> 3 m²	**-** No precision or references on the sampling and impactor type. Only quantitative. Unusable. **-** No precision or references on the sampling and impactor type. Only quantitative. Unusable (Used neither by CRIPI/RCIB nor WIV-ISP) **+/-** Easy, but the simplicity can bring underestimation of the situation. Arbitrary scale and not a "risk" scale.
	Dust mites	*« Info Fiches Bâtiment Durable Recommandation pratiques CSS11*	Risk on allergy 100 dust mites/ g Risk on asthma 500 dust mites / g	**+/-** Presently, the evaluation is based on the allergens

		Limiter les sources de pollution intérieure : Biocontaminants, (07.2010) »		or guanine and not on the mites numbers. Used neither by CRIPI/RCIB nor SAMI/LPI nor WIV-ISP
	Legionella pneumophila	*« Info Fiches Bâtiment Durable Recommandation pratiques CSS11 Limiter les sources de pollution intérieure : Biocontaminants, (07.2010) »*	• >50 CFU/l : surveillance • >1000 CFU/l : contamination: actions are needed • >10.000 CFU/l important contamination: closing the installation actions are needed (disinfection and control)	**+**

Comments from the Belgian Superior Health Council (SHC)

+ Sufficient approach and based on scientific studies

+/- Insufficient approach able to lead to errors of evaluation

- Incorrect, and leading to errors of evaluation

✎ *Within the different threshold values concerning microbiological agents proposed in regional documents, imprecision in terminology and absence of details or references about the sampling and analysis methodology prevail, making them often unusable or a source of misinterpretation of results. This is often expressed by contradictions between proposals in official recommendations and what is experienced by local field actors.*

2.1.5.5 Declaration of insalubrity: Flanders, Wallonia and Brussels Region

The different Regions have specified a policy on how to deal with the presence of visible mould/fungi in dwellings and declare a dwelling inhabitable.

- **Flanders:** The "presence" of visible mould growth on ceilings and walls is also taken into account in the document "*Wonen Vlaanderen*" to declare a dwelling unfit for human habitation. The evaluation scale for mould growth refers to the specification 'generalised or not generalised', in relation to different humidity problems (condensation, capillarity, etc.). The presence of visible mould contributes to the final evaluation score to declare the dwelling unfit to live in. (*Technisch Verslag voor woningen*, January 01, 2013)

- **Wallonia**: Within the « *Code Wallon du Logement* » the presence of visible mould in dwellings is considered as an 'intrinsic characteristic' of the building that harms the health of the occupants. The presence of moulds exceedance 1m² in one single room of the habitation or in a sanitary room should be submitted to further analysis (at the investigator's request).

- **Brussels Capital**: The «Code Bruxellois du Logement, July 17, 2003, Art 3 §3» declares the evaluation of the presence of fungi, parasites, insects,… harmful for the health of building occupants. By selecting "Yes or No", in the evaluation grid (*Région de Bruxelles-Capitale*, 2006), the presence of fungi in the dwelling is taken into account. The document «*Normes de Qualité des logements, notice explicative, édition 2013» (Direction du Logement,* 2013) stipulates that lodgings should be clean and dry without any trace of fungi or humidity.

2.1.5.6 International guidelines

Currently, there are no health based standards on the acceptable number of microorganisms in the indoor environment and there are no international regulations for airborne concentrations of mould or mould spores**.** Several international organisations (WHO, EPA, *Santé Canada*, Centers for Disease Control and Prevention US (CDC), American Conference of Governmental Industrial Hygienists (AGCIH), etc.) have made up guidelines in order to facilitate results' interpretation.

Many publications provide data about total concentrations of fungi encountered in the indoor air. These values help for the interpretation of measurement results but are no threshold values for health effects. Other important tools include visual inspection of the building for evidence of water damage and mould growth. Basing remediation decisions on the amount of visible mould contamination is an approach based on practical considerations that has been accepted in the field and adopted by almost all guidelines. Between the different guidelines, there is some variation in size classification of visible mould.

✎ *Currently, there are no health based standards on the acceptable number of micro-organisms in the indoor environment and there are no international regulations for airborne concentrations of mould or mould spores.*

2.1.5.7 Tools for interpretation of the sample results: consensus from investigators

- ***Moulds***

The presence of any mould, either alive or dead, in any area or location within a building, presents a health risk and must be eliminated. The level of risk and mitigation is primarily dependent on the extent of the contamination, but the presence of potentially toxic moulds is also taken into consideration. Currently, there are no international regulations for airborne concentrations of mould or mould spores**,** but in practice, some consensus exists to characterize the fungal contamination in an indoor environment.

The most evident and easiest tools include a visual inspection of the building for evidence of water damages and mould growth. Basing remediation decisions on the amount of visible mould contamination is an approach founded on practical considerations that are accepted in the field and adopted by almost all guidelines.

Table 14. Assessment of visual mould growth, reference: AGCIH

Classification	**Description**
Small	Total area < 0.3 m² of visible mould growth
Moderate	Total area between 0.3 m² and 3 m² of visible mould growth
Large	Total area > 3 m² of visible mould growth

Most guidelines also recommend that occupants clean up areas of less than 1m², without special training, but with personal protective equipment (US Environment Protection Agency EPA, 2012).

Hidden contaminations may also often be present and request sampling methods such as air or settled dust examination. These quantitative and qualitative methods are highly dependent on the method used and on other environmental conditions. Concerning airborne contamination, for example, instability of airborne mould concentration, the choice between different impactors, and consequently of sampling methods are the most difficult factors to establish a consensus. Presently, threshold value proposals are avoided (WHO, 2009) or sometimes become rather complicated to use (WHO, 2003).

This is unfortunate because the quantitative aspect remains crucial to evaluate the exposure and consequently the risks for health that it represents.

And thus, in practice, different quantitative threshold values are used but it obviously implies an interpretation depending on the expert's experiment and judgement, i.e. a subjective contribution, which can consequently be quite variable.

To reduce this part of subjectivity, a benchmarking from beginning to end is essential for final conclusions establishment. For environmental moulds, this benchmarking had already been proposed for airborne mould at the beginning of the 1990s and could be a starting point for the establishment of a consensus.

In 1995 (Table 15) in «The fungal contamination in Public buildings: a guide to Recognition and Management» published by Environmental Health Directorate Health Canada, Ottawa, Ontario, thresholds are given but they are integrated in a protocol benchmarked in 9 points (Annex B). This document should serve as the basis for the fungal contamination assessment in non-industrial indoor environments because its environmental approach taking into account the qualitative criteria can be extended to other microorganisms such as bacteria for example. The methodology was firstly described (RCS, 4 minutes for sampling).

Then, the audit began with the observation (Annex B, §1), followed by search for specific moulds (§2, what requires identification in a specialized laboratory), the persistence of the detected contaminations was taken into account *(*§3: the air is unstable). And concerning threshold values *(*§5, 6, 7*),* the emphasis on the specificity was made, which allows for example to distinguish indoor from outdoor sources.

Table 15. Threshold values proposal for airborne moulds in houses, taking into account to the mould specificity (Env Health Directorate Health Canada, Ottawa, Ontario, 1995)

Moulds in indoor air of dwellings	**"Normal"**	**Weak**	**Acceptable**	
Concentration CFU/m³ (RCS device, 4-minute sampling)	< 50*	>50	>150	>500
<u>BUT</u>:	if indoor and outdoor air are qualitatively and quantitatively similar	acceptable BUT IF only one single species other than *Cladosporium* and *Alternaria* further investigations are needed		acceptable in summer IF only one single species other than *Cladosporium* and *Alternaria* further investigations are needed

Following the same process used in Canada and using a rather similar protocol (RCS+, 80 liters, 25°C) an index with threshold values for specific moulds was recently proposed by CRIPI for Brussels Habitat. This index is based on several airborne concentration percentiles obtained for some specific moulds (Table 16) (Chasseur et al, 2015).

Table 16. Threshold values proposal for specific airborne *moulds in Brussels Habitat (Chasseur et al, 2015)*

Percentiles	**0-P75**	**P75-P85**	**P85-P90**	**P90-P95**	**P95-P99**	**>P99**	**Origin**	**Main substrates**
Aspergillus versicolor	0-25	25-38	38-75	75-200	200-2550	>2550	Frequent indoor and high amplification potential on damp building materials	Plaster, wood, tissue
Cladosporium sphaerospermum	0	0-25	25-38	38-88	88-765	>765		
Penicillium spp.	0-113	113-225	225-338	338-838	838-2550	>2550	Frequent indoor and high amplification potential on various substrate	Plaster, wood, tissue, leather, but also fruits, cheese, etc.
Chaetomium spp.	0	0	0	0	0-13	>13	Less frequent but with high amplification potential on cellulose	Damp paper (wallpaper, books, archives, cardboard boxes, etc.)
Stachobotrys chartarum	0	0	0	0	0-25	>25		
Cladosporium herbarum, Cladosporium cladosporioides, Alternaria	Not to be taken into account						Important natural outdoor origin, with important seasonal variations (highest in June-September)	Mainly plants
Aspergillus fumigatus	0-7	7	7-14	14-20	20-47	>47	Important natural or anthropogenic outdoor origin (thermophilic species)	Garden soil and potting, compost, natural humus
Sterile mycelia	0-50	50-75	75-100	100-138	138-288	>288	Fungus not able to sporulate on synthetic media; often epiphytic fungus	Mainly plants
Yeasts	0-13	13-25	25-38	38-63	63-250	>250	Mainly epiphytes, but also some dermatophytes, intestinal or drug related	Mainly plants, but also diverse origins
Other species	0	0	0	13	13-75	>75	Special indoor contamination or anthropogenic one	/
	Satisfactory	**Average**	**Bad**	**Alert**	**Unacceptable**			

To illustrate the importance of the sampling protocol, especially the type of impactor, the example in Table 15 presents threshold values obtained with a more powerful impactor than with the RCS, the 6-stage-Andersen impactor (COST, EUR14988EN, 1993).

Table 17. Threshold values proposal for airborne moulds in houses (EUR14988EN, 1993)

Moulds in indoor air of dwellings	**Very limited**	**Weak**	**Medium**	**High**	**Very high**
Concentration CFU/m³ (6-stages Andersen device, MEA)	< 50	< 200	< 1000	< 10 000	> 10 000

The values (Table 17. 7) are very different between an RCS and an Andersen impactor. But used with the same approach and the same benchmarks as previously stipulated (Table 15), the interpretation of the results becomes more rigorous and should in principle reach the same conclusions concerning the patient's exposition. However, all available categories are only based on the range of values obtained in indoor environments and not on a health evaluation!

Currently, there are no official threshold values for airborne concentrations of mould or mould spores, but in practice, some consensus exists to characterize the microbial exposition in an environment. The results interpretation gathered over a microbiological sampling must under no circumstances be limited to a solely quantitative aspect.

2.1.6 Situation in Belgium

2.1.6.1 Structures and resources

In Belgium, in the early 1980s, the section of Mycology in WIV–ISP (*Wetenschappelijk Instituut Volksgezondheid – Institut Scientifique de Santé Publique*, previously named Institute of Hygiene and Epidemiology), was already focused on health issues due to airborne fungal exposure, including those from home environments. With doctors' collaboration, the first fungal surveys were conducted in the homes of patients suffering from respiratory disorders. Later, different kinds of environments were investigated such as offices with air conditioning systems, hospitals, schools, etc. Presently, the laboratory continues to conduct these investigations in the occupational environment and, concerning houses and public environment, works with the regional structures (Indoorpol, 2012). Research projects are also implemented.

Late 1990s, to reduce health complaints related to the indoor environment in dwellings, local governments in Wallonia and Brussels created indoor air services, also called "green ambulances" (APW, 2014; IBGE-BIM, 2008). The aim of these services was to detect sources of pollutants in dwellings and to propose appropriate mitigation methods. Analyses in dwellings are carried out on a physician's request when an influence of indoor environment on health of its occupants is suspected. The indoor air services follow a common protocol that includes a specially developed questionnaire, inspection of the building, measurements and relevant analyses, as well as proposition of mitigation actions.

At about the same time, the Flemish Government also took steps to combat health risks due to contaminated indoor environments (MMK, 2014). Upon specific request, the environmental health experts and the Flemish Agency for Care and Health examine possible health hazards in homes or public buildings and offer advice or take measures to remediate these problems.

✎ In Belgium, there are public local structures which carry out interventions on site. The results help the doctors in their diagnosis and coordinated actions may contribute to a better comprehension of pathologies with an environmental etiology.

2.1.6.2 Some results

2.1.6.2.1 Regional Projects

Wallonia

Study in nurseries and primary schools in the Province of Luxembourg (SAMI-Lux, 2010)

The indoor air service of the province of Luxembourg (*SAMI-Lux* or *Service d'Analyse des Milieux Intérieurs de la Province de Luxembourg*) conducted a study of 72 (20 %) nursery and primary schools of the province.

Visible moulds were observed in 50 % of the schools, most often in basements and toilets. Signs of humidity were observed in 15 of the analysed classes (11 %). Visible moulds were observed in 18 classes (18 %). In general, mould development was limited and never exceeded $3m^2$. *Cladosporium*, *Penicillium* and *Aspergillus* were the most frequent species. In 34 classes (25 %) the quantity of spores in indoor air was higher than outside. *Penicillium* was the most frequent mould in indoor air. The quantity of spores in indoor air was positively correlated with relative humidity and with the quantity of spores on horizontal surfaces.

Dust mite allergens were detected using a colorimetric test (Acarex-Test). Pillows and carpets are the most frequent potential sources. About half (45.5 %) of the analysed objects may cause sensitization (contamination class 1 of Acarex-Test); 7.5 % of them may cause allergic symptoms (class 2 or 3). Mattresses and small armchairs in tissue were the most frequent sources of high level of dust mite allergens (class 2 or 3 of Acarex-Test).

Study in nurseries in the Province of Hainaut

In 2004, a regional public health authority in Belgium (Hainaut-Vigilance Sanitaire) is keen to learn more about the environmental health of young children in day-care nurseries. The concern was prompted by the "Green Ambulance" programme which undertakes investigations inside schools, nurseries and homes when an indoor environment is suspected to be the cause of a child's illness.

The indoor air service of the province of Hainaut (LPI: *Laboratoire d'études et de prévention des Pollutions Intérieures*) linked to the regional Public Health Institute, gained the agreement of 46 out of the 50 nurseries (ONE (*Office de la Naissance et de l'Enfance)* certified) in the Province of Hainaut for a study. The team took air samples to test for atmospheric humidity and toxics, made a systematic search for moulds, dust mites and dampness, and checked tap water for lead and *Legionella*. They also completed questionnaires with the parents on children's illnesses and medications.

The results showed that children in nurseries are exposed to a mixture of compounds that could be hazardous. About 30 % of the nurseries had moulds and dust-mites, and the tap water in 40 % of the facilities contained *Legionella* and lead. The *Legionella* was a surprise finding and the team believes that it may be responsible for a recent unusual respiratory problem in children. The medical community has been alerted.

Brussels (CRIPI-RCIB)

Until now, CRIPI-RCIB (*Cellule Régionale d'Intervention en Pollution Intérieure - Regionale Cel voor Interventie bij Binnenhuisvervuiling*) has investigated more than 1600 dwellings on a physician's request (with a partnership between the Brussels Administration Environment IBGE-BIM (*Bruxelles Environnement - Leefmilieu Brussel*), the Institute for Public Health and a NGO working on respiratory health problems (FARES – *Fonds des Affections RESpiratoires ASBL*)) (Chasseur et al., 2014). The patient's bedroom has the highest percentage of mould contamination: 9 % has more than 3m² of moulds. On visible mouldy surfaces, the examination of cello tapes indicates that *Cladosporium sphaerospermum* is present in 50 % of the samples, mites of faeces in 33 %, and *Acremonium* spp. and *Ulocladium* spp. in 10 % of the samples.

In the air, the most frequent airborne moulds are *Penicilium* spp. in 83 % of the samples, *Cladosporium spp.* in 48 %, *Aspergillus versicolor* in 40 % and *Cladosporium herbarum* in 38 %.

During investigations carried out by CRIPI/RCIB, the dust of 1.919 mattresses was also vacuumed and analysed. The xerophilic moulds among the genera *Penicillium* and *Aspergillus* were particularly frequent and abundant.

A project on the indoor air quality in nurseries in Brussels enabled to carry out enquiries in 31 nurseries. Concerning the microbiological contamination, the genus *Staphylococcus* was the most represented and could possibly be used as a hygiene indicator to evaluate the efficiency of cleaning. The dispersion is quite high with outliers reaching 228 CFU/25cm². 15 nurseries showed problems of humidity with sometimes development of moulds.

In 2012 new study started in primary-schools with a special attention concerning some allergens such as cat allergens.

Flanders (*Milieugezondheidszorg*)

In Flanders, the impact of anthropogenic sources in the surrounding of dwellings has been noticed several times. In 2010 for example, a housing near a site with mulch storage and another with linen were investigated because of respiratory problems. In the 2 cases, a high *Aspergillus fumigatus* spore load was measured in indoor settled dust. In 2011, the requests remained mainly centred on the problems of *Aspergillus*. Among the requests, the case of a patient suffering from a bronchopulmonary aspergillosis was investigated. The survey conducted by WIV-ISP initially excluded a fungal contamination in his residence. But a second intervention conducted at his workplace, revealed high level of *Aspergillus fumigatus* spores, particularly in the centralised air conditioning installation. This contamination originated in the neighbouring wood treatment facility (> de 500 000 CFU/m³ *Aspergillus fumigatus*). Also in 2011, several fungal measurement campaigns were carried out in the immediate vicinity of various composting facilities. In some cases, high levels of specific pollutants (*Aspergillus fumigatus, Thermoactinomyces,* etc.) were noticed at distances further than 1200m.

2.1.6.2.2 Belgian Projects

Indoor environment in Belgian nurseries: from the demand to the offer (Dewolf et al., 2008)

The purpose of the study was to identify problems in the indoor environment of nurseries, enhance the awareness of the staff, suggest efficient solutions to identified problems and support participating nurseries towards a better quality indoor environment. The project combined the use of an auto-assessment tool, extensive field analyses and awareness raising and training materials. The results showed that most of the nurseries are installed in buildings built for another purpose. This explains why about half of the participants had to manage important fitting works over time. Many participants identified humidity and mould problems.

The use of pesticides (occasionally) and deodorising products in rooms where children are living was quite common. Analyses confirmed some elements highlighted through the auto assessment tool, but also detected new ones. In order to increase the long term impact of the action, participating nurseries received targeted recommendations, trainings have been organized, and a toolkit was developed.

In conclusion, the action has been positively accepted by nurseries. Other children settings should be considered in the future.

2.2 Health effects of microbiological pollutants

2.2.1 Introduction

The cause of indoor air pollution is a combinatory effect of physical, chemical and biological factors and the adequacy of ventilation in the environment. There is a correlation between the concentrations of the pollutants and onset of health problems, predominantly respiratory symptoms such as a higher prevalence of respiratory diseases like asthma and allergies (Cartieaux et al., 2011).

The most frequent health problems related to the presence of microbiological pollutants are: respiratory irritation, allergies, asthma, airway infections and general symptoms like headache, fatigue or digestive troubles. Health effects depend on the microorganism present, its concentration in the air and the individual sensibility. Some persons are more vulnerable to microbiological pollutants indoors:

- atopic subjects;
- persons suffering from chronic respiratory diseases like asthma and chronic obstructive bronchitis;
- subjects with immune deficiency (patients on chemotherapy, AIDS);
- young children, because they inhale proportionally more air than adults, their immune system is not yet completely developed and their pulmonary maturation is critical during the two first years of life;
- elderly, because of different diseases and lower resistance towards pathogens in old age.

Children are particularly vulnerable to the impact of microbiological air pollution. Exposure to various air pollutants from early life might be associated with increased oxidative stress, inflammation and endothelial dysfunction which in turn might have long-term effects on chronic non-communicable diseases. Asthma exacerbations are commonly triggered by exposure to allergens and irritants within the home. Home-based, multi-trigger, multicomponent interventions with an environmental focus are effective for improving the overall quality of life and productivity in children and adolescents with asthma (Crocker et al., 2011).

2.2.2 Allergies and asthma

Allergies are abnormal reactions of the immune system that occur in response to otherwise harmless substances. Their development results from complex genetic and environmental interactions. Allergies are responsible for a variety of symptoms: allergic rhinitis, (sneezing, running nose, clogging/obstruction and anosmia in the nose), asthma, allergic conjunctivitis (watering/reddening eye) and atopic eczema (Medical-dictionary, 2014).

In Belgium, 11.7 % of persons declare being allergic (*Enquête de Santé*, 2004). Nearly half of them (45.5 %) are allergic to house dust mites and pollens.

2.2.2.1 Asthma

Asthma is a chronic inflammatory disease of the airways. Its main feature is exaggerated constriction of bronchi in response to a variety of nonspecific provoking stimuli. Asthmatic subjects with increased airway responsiveness may develop attacks of breathlessness, chest tightness, coughing and wheezing due to a variety of provoking factors. In most cases, asthma is caused by inhaling an allergen, but continuing inflammation makes the airways hyper-responsive to stimuli such as cold air, exercise, infections, certain pollutants and even stress and anxiety (Kelley, 1989; Medical-dictionary, 2014).

The prevalence of asthma in Belgium is 4.7 % for men, and 3.9 % for women (*Enquête de Santé*, 2001). Children aged 0–18 years have higher asthma prevalence (8 to 10 %) than adults. In children, asthma is the most frequent chronic disease (*Education Santé*, 2014). However, many cases of asthma are not diagnosed (FARES, 2014). A study conducted in Brussels (Michel et al., 1999) revealed that asthma prevalence among school children was 13.8 % while only 6.8 % of them had diagnosed asthma.

2.2.2.2 Atopic dermatitis or atopic eczema

Atopic dermatitis or atopic eczema is an inflammation of the skin. It often occurs together with other atopic diseases like asthma or allergic rhinitis. Symptoms may vary from person to person but they are usually present as a red, inflamed, and itchy rash. Some of the most common allergens that can cause atopic eczema include: food allergens, house dust mites, and animals.

The prevalence of eczema is higher in early age. In Belgium, it concerns between 15 and 30 % of children and between 2 and 10 % of adults (*Mutualité Chrétienne*, 2012).

2.2.2.3 Indoor allergens

The relationship between allergen exposure and subsequent disease development is complex, and is confounded by a number of important factors. Individuals are exposed to a mixture of different pollutants and allergens that may interact and we know very little about the impact of these mixtures and their possible synergistic effect. The dose-response relationship between allergen exposure and allergic disease may not be linear. It may be different for various allergens as well as the underlying genetic susceptibility (Arshad, 2010; Brussee et al., 2005; Chen et al., 2007; Cole et al., 2004; Custovic & Woodcock, 2001). House dust mite and cockroach allergens appear to have a positive linear relationship, whereas cat allergens cause maximum sensitisation developing at moderate exposure levels. Very low levels of cat allergen exposure are likely to induce no response, and very high levels are likely to develop a form of tolerance (Murray et al., 2001).

In genetically susceptible children, exposure to allergens (with the exception of pet allergens) during postnatal period may lead to sensitisation in early childhood. Consistent evidence indicates that children sensitised to common indoor allergens are at higher risk of asthma and allergy. Childhood asthma was associated with exposure to early life environmental factors, such as cockroaches, visible mould (OR (Odds Ratio) = 1.75; 95 % CI (Confidence Interval), 1.15-2.67), mildew odours (OR = 5.04; 95 % CI, 2.42-10.50), carpet (OR = 2.36; 95 % CI, 1.38-4.05), pets (OR = 2.11; 95 % CI, 1.20-3.72), and more than one hour of exposure to tobacco smoking (ETS) per day (OR = 1.93; 95 % CI, 1.16-3.23) (Chen et al., 2011).

A wide range of indoor allergens have been identified in indoor environment. The most common are those of house dust mite, animal dander, mould and cockroach.

House dust mites

House dust mites are major indoor allergens. They are the most frequent causes of allergy and asthma in Belgium and in the world. *Dermatophagoides pteronyssinus* and *Dermatophagoides farinae* are two predominant species. The main protein responsible for allergy from dust mite is Der p I which is found in mite faeces and in decomposed body parts. Sensitised persons may develop asthma, allergic rhinitis, conjunctivitis and eczema. A threshold level for sensitisation to house dust mites allergen has been found to be 2 µ/g dust or 100 mites/g dust. Sensitised persons may develop an allergic response at concentration of 10 µg/g dust or 500 mites/g dust. (Platts-Mills et al., 1997).

Pets

Animals are the second frequent source of indoor allergens. The impact of pets on health is being discussed controversially in the literature (Salo, 2009). On the one hand, findings suggest that animals are associated with an increase in sensitisation towards allergens but, on the other hand, allergy-protective effects have been reported. Other authors report marginal effects of animal allergens or no effect at all. Nevertheless, pets with a proven effect on sensitisation rates mainly concern cats and dogs.(Baseline Report on respiratory health in the framework of the European Environmental and Health Strategy, 2003).

The allergens from cats are secreted by sebaceous glands and saliva. Allergen within cat saliva is transferred to the fur during grooming. Once the saliva is dry, the allergen and the particle on which it is carried can become airborne. As the particles have a degree of 'stickiness' they easily attach to soft furnishings and fabrics (chairs, curtains, clothing, bedding, carpet and alike) (Kelly et al., 2012). Cat allergen concentrations of 2 µg/g may be enough to initiate sensitisation (Ahlbom et al., 1998).

The major dog allergen, called Can f 1, is primarily found in dog saliva. The fur by itself rarely causes an allergic reaction; a short-haired dog potentially causing just as many allergy problems as a long-haired dog. The symptoms of dog allergens are thought to be not as severe as those resulting from cat allergens (Ahlbom et al., 1998).

Cockroach

Cockroach is thought to be one of the most important of all the insect allergens. Most common in Europe is the German cockroach *Blattella germanica.* Cockroach allergens are found in their excrements as well as in shed skins and different body parts. They are involved in allergic asthma, allergic rhinitis and atopic eczema. Cockroach allergies are especially common in crowded multifamily dwellings in deprived urban areas. The prevalence of sensitisation to cockroach in atopic patients is about 10 % in Europe (Van Lynden-Van Nes et al., 1996). Exposure to cockroach allergen early in life may contribute to the development of asthma in susceptible children (Litonjua et al., 2001).

Principal allergenic moulds

Principal allergenic moulds are *Alternaria*, *Aspergillus*, *Cladosporium* and *Penicillium*. Mould allergens are found mainly on their spores. Mould spores can deposit on the lining of the nose or reach the lungs. The symptoms of mould allergy are very similar to the symptoms of other allergies, such as sneezing, running nose, nasal discharge, congestion, cough and wheezing or itchy eyes. Evident dampness or melds have consistent positive associations with multiple allergic and respiratory effects (Mendell et al., 2011).

Cladosporium herbarum represents one of the most important world-wide occurring allergenic fungal species. The prevalence of IgE reactivity to *C. herbarum* in patients suffering from allergy varies between 5 and 30 % in different climatic zones.

Alternaria alternata is well known for seasonal respiratory allergies. Already in 1991, O'Hollaren et al. presented a study concerning 11 patients (11 to 25 years old) with asthma and sudden respiratory arrest. Ten out of 11 patients presented specific IgE to *Alternaria* and the episode of respiratory arrest occurred during the *Alternaria* season. Andersson et al. (2003) also showed that the proportion of children atopic to *Alternaria* reporting symptoms of rhinitis was significantly higher in summer, when airborne concentrations of *Alternaria* were higher than in winter, when airborne concentrations were low (66.2 % vs. 38.2 % for nasal symptoms at night, p = 0.0001, 70.6 % vs. 51.52 % for nasal symptoms during the day, p = 0.02). The prevalence of current symptomatic asthma increased with increasing *Alternaria* concentrations in US homes (Salo et al., 2006).

A multicentre epidemiological study sponsored by the European Commission and based on the analysis of more than 18 000 adults with allergy living in different European countries (Zureik et al., 2002) has clearly demonstrated that the severity of asthma was strongly associated with the sensitisation to two moulds of outdoor environment, *Alternaria alternata* and *Cladosporium herbarum*. A meta-analyse of about 30 studies (Fisk et al., 2007) showed that moisture in buildings and exposure to moulds were associated with an increase of approximately 30 to 50 % of respiratory problems such as upper respiratory symptoms (OR = 1.7), cough (OR adults = 1.52; OR children = 1.75), wheezing (OR = 1.5) and asthma (OR = 1.56), whereas another meta-analysis covering 61 studies (Tischer et al., 2011) confirmed a positive association between visible moulds and asthma (OR = 1.49), wheezing (OR = 1.68) and rhinitis (OR = 1.28) among children. Other studies have also demonstrated the association between exposure to specific moulds (particularly *A. alternata*) and fatal exacerbations of asthma (Black et al., 2000; O'Driscol et al., 2005). In the United States, 16 million cases of asthma were recorded in 2002, including 10 to 20 % classified as "severe asthma"; 30 to 70 % of these severe cases were sensitised to at least one species of moulds while the frequency of sensitisation to moulds in general population is usually between 2 and 5 %. Similar associations were also demonstrated between sensitisation to moulds and other allergic diseases such as rhinitis and conjunctivitis.

Green plants

Some green plants are responsible for occupational allergies in plant keepers but sensitisation is also found in non-occupationally exposed patients. The allergen of *Ficus benjamina* is located in the plant sap, also-called latex, but it is found also in dust collected from leaf surfaces and from the floor of rooms where the plant was placed (Bircher et al., 1995). The main route for sensitisation is probably by inhalation of airborne dust emanating from the leaves of the plant. The main symptoms include conjunctivitis, rhinitis, asthma, and eczema (Axelsson et al. 1987; Schenkelberger et al., 1998; Karimain-Techerani et Hentges, 2002).

2.2.3 Hypersensitivity pneumonitis

Hypersensitivity pneumonitis, called also extrinsic allergic alveolitis, refers to an inflammation of the lungs caused by repeated breathing in of animal or vegetal particles. It is linked to exposure to thermophilic *Actinomycetes*, moulds and animal proteins. The body's immune system reacts by producing acute inflammation, which can develop into chronic lung disease. Symptoms include fever, chills, malaise, headache, cough, and chest tightness. The chronic response is marked by increasing shortness of breath, weight loss, and general fatigue. Some of the more common forms are: farmer's lung, pigeon breeder's lung, and humidifier fever (Kelley, 1989; Medical-dictionary, 2014).

Outbreaks of hypersensitivity pneumonitis in office buildings have been linked to air conditioning and humidification systems contaminated with bacteria and moulds (Consumer Product Safety Commission CPSC, 2014). In dwellings, hypersensitivity pneumonitis is infrequent and most often caused by contaminated humidifiers or by pigeon or pet bird antigens (EPA, 2014).

Humidifier fever has been related to exposure to various bacteria, endotoxins and moulds found in humidifier reservoirs, air-conditioners and aquaria. The symptoms usually begin a few hours after exposure. Humidifier fever is a flu-like illness marked by fever, headache, chills, muscle aches, and fatigue. Humidifier fever usually subsides in 24 hours and medical care is rarely needed.

2.2.4 Respiratory irritation

An irritant is a non-corrosive compound that causes a reversible inflammatory reaction upon direct contact with the skin, eyes, nose or respiratory system. The actions of irritants are non-specific and do not entail an immunological mechanism (Brooks, 2005). They cause loss of the protective epithelial cells, increased permeability and chronic inflammation of the mucous membrane. Symptoms of an irritant reaction are similar to an allergy and include eye dryness, runny nose, cough, voice hoarseness, itchy skin. Long term exposures to irritants result in heightened respiratory and systemic symptoms in response to low concentrations of irritants.

Any microbial particle may provoke airways irritation by its mechanical action on mucous membranes but also due to chemical composition. Concerning moulds, the β-1,3-glucans (Pasanen, 2001) play a role in triggering inflammatory reactions of mucous membranes (macrophage activation), as well as some of irritating volatile organic compounds (MVOCs) (Matysik et al., 2008; Moularat et al., 2008; INSPQ, 2002; Kim et al., 2007; Vojta et al., 2002).

2.2.5 Airway infections

Airway infections associated to indoor microbial exposure may be of bacterial, viral or fungal origin. They include upper and lower respiratory tract infections and otitis media. Upper respiratory tract infections include common colds, pharyngitis and sinusitis. Lower respiratory tract infections include pneumonia, acute bronchitis, acute exacerbation of chronic bronchitis, and invasive pulmonary aspergillosis (Fisk et al., 2010).

The increase in respiratory infections in association with mould exposition might result from impairment of immune defences. Studies both *in vitro* and *in vivo* have demonstrated inflammatory and immunosuppressive responses to the spores, metabolites and components of specific microorganisms found in damp buildings. Repeated activation of immune responses and inflammation from microbiologic exposures may contribute to inflammation-related diseases, and the inflamed mucosal tissue may provide a diminished barrier to respiratory infections. In result, increased number of infections or more serious infections can be observed (Fisk et al., 2010).

2.2.5.1 Aspergillose

Invasive pulmonary aspergillosis occurs in subjects with immune deficiency. It is a rapidly invasive and usually fatal form of pneumonia. The causative agents are *Aspergillus* species. *Aspergillus fumigatus* is the most frequent pathogenic species but *A. niger* and *A. flavus* are not uncommon. Aspergilloma is a localized *Aspergillus* infection occurring in chronic lung cavities. It is usually a silent disease, but it may cause cough, intermittent fever, local pleuritic chest pain and hemoptysis.

2.2.5.2 Legionellose

Legionella spp. is probably the most common bacteria mentioned in association with indoor expositions. It may provoke illnesses called Legionnaires' disease. The disease is not contagious and cannot be spread directly from person to person. It is caught by breathing in small droplets of contaminated water.
Different forms are distinguished and include a severe form of pneumonia (Legionnaires' disease or legion fever), as well as a less serious infection of upper airways (Pontiac fever).

The symptoms are similar to those of flu, i.e. fever and chills, cough, muscle pains and headache. Persons with Pontiac fever generally recover in 2 to 5 days without treatment. Persons with Legionnaires' disease develop diarrhoea, vomiting, mental confusion and a potentially fatal form of pneumonia. Some people are at higher risk: people over 50 years old, smokers, heavy drinkers, people suffering from chronic respiratory or renal diseases or with an impaired immune system (WIV-ISP, 2009; HSE, 2013).

Legionnaires' disease is rather rare: 2 % of non-hospitalised pulmonary diseases, but the mortality rate is relatively high: 12 % (https://indoorpol.wiv-isp.be/fr/methodologie/microorganismes/Microorganismes/Bact%C3%A9ries.aspx?PageView). In Belgium, from 50 to 100 cases of Legionnaires' diseases were recorded every year between 1999 and 2010.

2.2.6 General symptoms

A spectrum of nonspecific complaints is often linked to the presence of microbial agents in the indoor environment. These complaints may include headache, inability to concentrate, memory loss, irritability, articulation pains, gastro-intestinal troubles, and general malaise. Several recent studies associate different health symptoms with damp indoor environment and the exposure to moulds and bacteria (Haverinen et al., 2001; Pasanen, 2001; INSPQ, 2002; Bornehag et al., 2004; Nevalaines et Seuri, 2005).

2.2.6.1 Endotoxins

Inhaled endotoxins induce an inflammatory response in the lungs. The systemic effects like fever, malaise and headache occur at higher exposure levels. The inflammatory reaction can lead to acute (respiratory and systemic) effects including fever, shivering, dry cough, chest tightness, dyspnae, joint aches and influenza-like symptoms, which are all symptoms of the Organic Dust Toxic Syndrome (ODTS). Epidemiological and animal studies suggest that chronic exposure to endotoxins may lead to symptoms indicative of chronic bronchitis and asthma and reduced lung function, most likely via chronic inflammation. In case of prolonged exposure, an accelerated decline in lung function and increased bronchial reactivity can lead to chronic obstructive pulmonary disease *(Health Council of the Netherlands, 2010).*

2.2.6.2 Mycotoxins

Mycotoxins and other secondary metabolites are also present in fungal spores and fragments of mycelium (Jarvis et al., 1998). Many moulds produce more than 300 mycotoxins that can have toxic effects (Reboux, 2006), best known from ingestion of contaminated food. This is the case of aflatoxins, tricothecenes, etc., which can cause serious health problems leading even to death. The toxicity of inhaled mycotoxins remains controversial. However, the research of mycotoxins inside buildings is not useless. In a recent study (Blomme et al., 2013), one hundred samples of materials and 18 dust samples collected in damp buildings were analysed. Several mycotoxins were investigated (trichothecenes and trichodermin, sterigmatocystin, gliotoxin B and satratoxin G and H). Some 66 % of materials and 11 % of dust samples were positive for at least one of the mycotoxins. Macrocyclic trichothecenes were measured in the air (Brasel et al., 2005), and the sterigmatocystins in the presence of *Aspergillus versicolor* in carpet dust (Engelhart et al., 2002). Biomonitoring provides also heckling elements. This is the case for the presence of trichothecenes (Brasel et al., 2004; Straus, 2009) or stachylysin (Van Emmon et al., 2003) in the serum of patients highly exposed to *Stachybotrys chartarum*.
This is also the case for patients with chronic fatigue syndrome; in 104 of 112 patients, urine contained at least one mycotoxin among aflatoxins, ochratoxins and macrocyclic trichothecenes (Brewer et al., 2013).

2.3 Conclusions et recommandations sur les polluants microbiologiques intérieurs en Belgique

Certaines bases existent dans le domaine des polluants microbiologiques :

- La présence d'animaux, de plantes et d'êtres humains à l'intérieur du bâtiment est une source importante d'allergènes. L'air extérieur est également une source importante de spores fongiques naturels en suspension qui peuvent s'introduire dans les bâtiments et former des dépôts de poussière.
- Des bactéries provenant de l'extérieur et des pollutions spécifiques autour des habitations, produites par l'activité humaine, peuvent s'introduire dans les bâtiments voisins et former des dépôts de poussière.
- Si l'on tient compte de la remise en suspension des poussières, le phénomène d'accumulation des poussières peut être une source importance d'effets nocifs tout au long de l'année.
- L'humidité est fréquente dans les bâtiments et peut avoir diverses origines. Dans nos régions, la formation de moisissures visibles dues à un excès d'humidité est fréquente et souvent considérée comme la principale contamination microbiologique de l'habitat. L'humidité semble également être un facteur important de l'infestation de cafards et acariens.
- En Belgique, il existe des structures publiques locales qui effectuent des interventions sur site. Les résultats peuvent aider les médecins dans leur diagnostic, et des actions coordonnées contribuent à une meilleure compréhension des pathologies grâce à une étiologie environnementale.
- Il n'est pas possible de définir des normes sanitaires sur le nombre admissible de microorganismes dans l'environnement intérieur, mais certaines valeurs seuils sont calculées et utilisées par différents laboratoires. Ces valeurs sont liées à la méthodologie spécifique d'analyse et d'échantillonnage utilisée par chaque laboratoire et permettent de détecter des anomalies microbiologiques dans l'environnement.

Plusieurs points méritent néanmoins d'être développés :

1. **L'efficacité et les effets secondaires potentiels des nouveaux produits :** Avec les changements sociaux (prise de conscience croissante du rôle de l'environnement sur la santé), de nouveaux produits ou concepts font leur apparition sur le marché, profitant d'un vide juridique à l'égard des justifications à apporter sur l'utilité et l'efficacité du produit et surtout l'absence de risques pour la santé.
2. **Stratégies d'échantillonnage harmonisées :** Il n'y a pas de consensus sur la grande variété de stratégies d'échantillonnage. De plus, au cours d'un contrôle microbiologique, les échantillons d'air peuvent fournir des informations utiles, mais ne suffisent pas en soi en raison de l'instabilité de l'air. Ils doivent être consolidés par l'analyse des autres matrices, telles que les dépôts de poussière sur le mobilier et les autres surfaces planes, ou la poussière accumulée dans les tapis, fauteuils et matelas. La variété des performances des échantillonneurs et des procédures d'échantillonnage pour les moisissures et les bactéries viennent s'ajouter à la diversité des méthodes dans les différents niveaux d'analyse, rendant plus complexe encore l'obtention d'un consensus autour d'une uniformisation.
3. **Classification actualisée des agents biologiques** : Dans le décret royal du 4 août 1996, toujours en vigueur, les agents biologiques sont divisés en quatre groupes selon leur risque de transmission de maladies infectieuses. Les risques pour la santé dérivant de germes environnementaux non infectieux sont complètement ignorés. La définition des agents biologiques du groupe 1, définis comme n'étant pas capables de provoquer des maladies, n'est pas envisageable pour les allergies.

4. **Transparence** : Parmi les différentes valeurs seuils relatives aux agents microbiologiques, proposées dans les règlements régionaux, des imprécisions persistent dans la terminologie ainsi que le manque de détails ou l'absence de références sur la méthodologie d'analyse et d'échantillonnage, les rendant inutilisables et les transformant en une source d'erreurs dans l'interprétation des résultats. Ce qui se traduit souvent par des contradictions entre les propositions des recommandations officielles et l'expérience des acteurs de terrain locaux.
5. **Besoin de normes sanitaires et de règlements internationaux** : Il n'existe aucune norme sanitaire sur le nombre admissible de microorganismes présents dans l'environnement intérieur, et il n'existe aucun règlement international sur les concentrations de moisissures dans l'air ou de spores de moisissures. Ce besoin est étroitement lié à l'importance des recommandations sur la conception, la construction et l'entretien (rénovation) de logements sains et de systèmes de ventilation.
6. **Il n'existe aucune valeur seuil pour les concentrations atmosphériques de moisissures ou les spores de moisissure,** mais, dans la pratique, un consensus existe pour caractériser l'exposition microbiologique dans un environnement. L'interprétation des résultats recueillis grâce à un échantillonnage microbiologique ne doit en aucun cas se limiter à l'aspect quantitatif.

Par conséquent, il est recommandé ce qui suit :

1. Il est nécessaire de fixer un **cadre consensuel** concernant les échantillonnages microbiologiques et les interprétations des résultats en termes de **risques pour la santé**.
2. La **législation** sur les contaminants microbiologiques doit être revue et clarifiée, sur la base d'un **consensus méthodologique**.
3. **Des spécifications** devraient être rédigées pour les principaux types de réparation microbiologique, en prenant en compte les dangers associés. Viendra ensuite la mise en place de pratiques tenant compte des aspects sanitaires.
4. Il est nécessaire de mettre sur pied une **cellule de vigilance** au niveau de la Belgique permettant de signaler les aspects sur lesquels il convient de légiférer, tels que, par exemple, dans le cas d'une demande d'autorisation de commercialisation de nouveaux produits ou concepts (probiotiques).

Une attention toute particulière devrait être accordée aux appareils de nettoyage à vapeur qui provoquent de l'humidité dans les matelas, tapis, etc., et contribuent à l'augmentation des acariens. D'autres aspects qui méritent également plus d'attention sont les traitements chimiques pour combattre l'humidité, tels que les traitements des murs contre les remontées d'humidité (technique ou injection dans les murs). Les substances utilisées peuvent nuire à la santé.

3. Radon in indoor air in Belgium

3.1 Problem

Radon is a radioactive gas coming from radioactive decay of radium in the uranium and thorium series, naturally present in soil, rock and building materials. The decay products of radon are alpha- and beta-emitting particles of lead and polonium that can irradiate the respiratory system when inhaled. That is why the WHO IARC Agency has classified radon as a certain carcinogen since 1988 (IARC, 1988). The ventilation of buildings leads to a concentration indoor that is at least as high as the concentration in outdoor air. The higher values measured in indoor air result from the infiltration and accumulation of radon from soil and building materials. The main cause of high radon concentrations in (the Southern part of) Belgium is the soil and its rock substratum. That is why the indoor radon concentrations are generally higher in areas where the pre-Tertiary geological basement is close to the surface (in the Ardennes, parts of the Condors, the area between Sombre and Meuse and the Brabant massif) than in areas covered by thick Tertiary and Quaternary deposits. Radon from building materials is an important but less variable source of exposure for the population, while radon in drinking water is seldom an important radon source. There is an exposure-effect relationship between the indoor concentration of radon and the incidence of lung cancer; therefore efforts to improve indoor air quality (IAQ) are welcome to help reducing the incidence of lung cancer, which is associated with substantial mortality. Contrarily to other pollutants, radon is of natural origin and not man-made. Its presence in our environment can be man-enhanced, associated with activities, such as the way private and public buildings are designed and constructed, or by using or recycling materials (such as fly-ash) that may contain small concentrations of radioactive materials. At local scale, efforts to reduce radon indoor concentrations are simple and relatively cheap, especially for new buildings. At nation scale, this requires more efforts, not only in technical terms but also in terms of policy making. These aspects, together with the current evolution to more air-tight buildings with the risk of lower ventilation rates, make radon an important indoor air pollutant that has to be considered in public health policies regarding indoor air quality. The current text gives a review of the current relevant knowledge on radon in Belgium, and formulates some recommendations to the way how to deal with radon in public health policies. The subject is important in the medium term health context, since the only way the problem can be tackled over the next decades is at the policy level. The framework of the current document limits itself to residential exposure and exposure in public buildings and does not address occupational exposure.

3.2 Outline and current status (review)

3.2.1 International context

The first extensive reports mentioning the important health effects of the exposure to radon have been published in 1977 and 1982 by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 1977 and 1982), as well as in 1984 and 1987 by the International Commission on Radiological Protection (ICRP, 1984 and 1987), in the BEIR IV report (BEIR, 1988) and the IARC publication of 1988 (IARC, 1988). In 1990, ICRP 60 (ICRP, 1990) stated that 'action levels' should be introduced, for which an appropriate intervention is always justified when passed. The ICRP recommends protective measures for new buildings in radon-prone areas. In 1993, ICRP dedicates its full publication n° 65 (ICRP, 1993) to the radon problem, proposing the delimitation of '*radon prone areas*', and proposing policies for radon prevention (in new buildings) and remediation (in existing buildings). The commission judges that for an annual dose of 10 milliSievert (mSv), intervention is almost always justified. Dose conversion coefficients have been derived from epidemiological studies, leading to a value for residential exposure of 6.1 nanoSievert (nSv) per Bqh/m³ (Becquerel hour per cubic meter) equilibrium equivalent concentration. This dose conversion factor was implemented in the European and Belgian legislation and is still used today.

The United Nations in the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000 report (UNSCEAR, 2000) adopted a higher dose conversion factor based on the combination of dosimetric calculations and epidemiological studies. The UNSCEAR dose conversion value of 9 nSv per Bqh/m³ equilibrium equivalent concentration leads to 400 becquerel (Bq)/m³ corresponding to 10 mSv per year for residential radon exposure (7000h).

The European Commission published its first recommendations regarding radon in 1990 (90/143/EURATOM, 1990). The text was based on the early publications of ICRP (ICRP, 1987) and proposed 400 Bq/m³ as an action level for existing buildings and 200 Bq/m³ as a design level for new buildings. Although Directive 96/29/Euratom (96/29/EURATOM, 1996) explicitly deals with radon in workplaces (including public buildings), the practical implementations, treated in the publication Radiation Protection 88 (Radiation Protection 88, 1997), conclude that occupational exposure and residential exposure are clearly linked and that a common approach dealing with both situations should be followed.

The drinking water directive of 2013 (Council Directive 2013/51/EURATOM) sets maximal values of 100 Bq/l for public water supplies and 1000 Bq/l for private wells.

During the early years of the third millennium, several pooled epidemiological studies have been completed providing new and strong evidence of increased radon risk for domestic exposures (Baysson et al., 2004; Lubin et al., 2004; Darby et al., 2005; Krewski et al., 2005). Importantly, for the first time at such a scale, radon concentrations `measured at individual homes, rather than averaged regional data, were used for studying a potential dose-relationship between individual radon exposure and health effects (Darby et al., 2005). International organisations have therefore recently strengthened their positions on the indoor radon issue. ICRP published its new recommendations in 2007 (ICRP, 2007), proposing to treat residential radon as an existing exposure situation and apply the source-related concepts of radiation protection (reference levels, optimisation, etc.). UNSCEAR published in 2009 a report on levels of radon exposure and health effects, concluding that radon exposure leads to increasing the underlying risk of lung cancer (UNSCEAR, 2009). This is particularly relevant for smokers (or previous smokers) as the combined effect of smoking and radon was found to be almost multiplicative. The WHO 2009 handbook on indoor radon focuses on the exposure from a public health perspective and provides recommendations and policy options for reducing health risks (WHO, 2009). The handbook recommends a national reference level of 100 Bq/m³. However, if this level cannot be reached under the prevailing country-specific conditions, the reference level should not exceed 300 Bq/m³. ICRP issued also in 2009 a statement recommending a dose conversion factor almost twice the value previously used by the ICRP in publication 65 (ICRP, 1993) and regulatory authorities worldwide. The ICRP statement on radon has been published in Publication 115 related to the lung cancer risk from radon and progeny (ICRP, 2010).

The European Commission has recently published the Basic Safety Standards (BSS) directive (2013/59/EURATOM, 2014) taking into account the most recent general recommendations of the ICRP in publication 103 (ICRP, 2007). The new BSS directive incorporates the Commission Recommendation of 1990 on the protection of the public against indoor exposure to radon (90/14/EURATOM, 1990). The Directive introduces the use of a reference level for radon in dwellings and in workplaces, implying optimisation of the protection above as well as below the reference level (Article 7). Regarding the higher risks (ICRP, 2007; ICRP, 2010), the European Commission proposes to lower the maximum value for the reference level in existing dwellings to 300 Bq/m³. Member States also have the obligation to establish a national radon action plan to address all radon exposure in both an integrated and graded approach. Also building materials are considered in the new BSS as an existing exposure situation and should be characterised by the activity concentration index for gamma radiation[3].

[3] The gamma activity concentration Index $I = \frac{C(Ra-226)}{300\ \mathrm{Bq/kg}} + \frac{C(Th-232)}{200\ \mathrm{Bq/kg}} + \frac{C(K-40)}{3000\ \mathrm{Bq/kg}}$

Complying to this index (<1) should also limit the derived contribution to the indoor radon concentration to values below the reference level under normal ventilation circumstances. The Directive has to be transposed into national legislation by February 2018.

3.2.2 National context

In Belgium, regulations on ionising radiation are a federal competence, with the competent authority being the Federal Agency for Nuclear Control (FANC). Following the European and international recommendations, a national radon action plan is in application since 1995. After several reconnaissance studies (Vanmarcke et al., 1988; Poffijn et al., 1990) highlighting the presence of affected areas in the south of the country and the low radon concentrations in the north, a first national indoor radon measurement campaign selecting representative dwellings homogeneously spread over the territory produced the first national radon maps (Zhu et al., 1998; Zhu, 2001) and revealed the average indoor exposure of the Belgian population of around 50 Bq/m³. Subsequently, municipal measurement campaigns in the affected areas lead to higher levels of detail, allowing more detailed mapping of the radon-prone areas. The FANC decree of August 10, 2011, has classified the Belgian territory in three risk levels (FANC, 2011) on the basis of the percentage of dwellings above the action level of 400 Bq/m³, the reference level recommended by the European Commission to reduce radon concentrations in existing dwellings (UNSCEAR, 2000). Radon measurements (and if necessary remediation) have to be carried out in workplaces and public buildings in radon class 2 (the highest risk level where more than 5% of the measured houses exceed the action level of 400 Bq/m³).

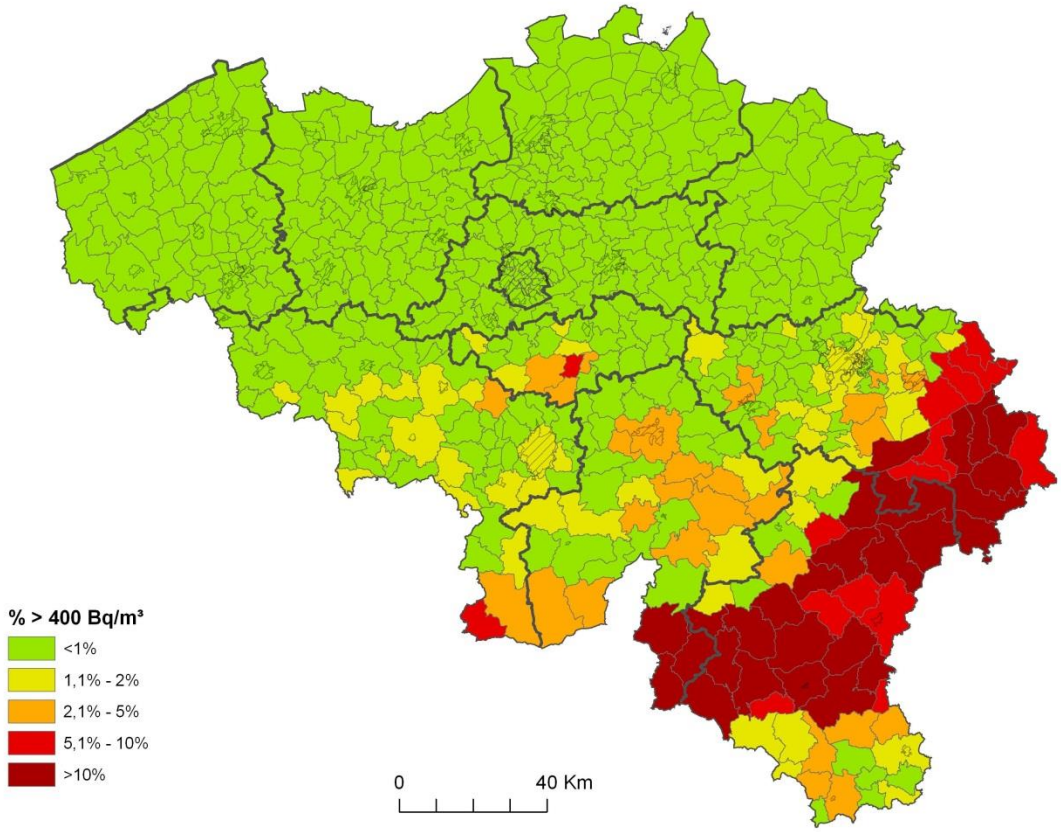

Figure 13. Distribution of indoor radon risk (percentage above the action level of 400 Bq/m³) for the Belgian municipalities (situation 2012). Radon class 0 (< 1 %), radon class 1 (1.1 to 5 %) and radon class 2 (> 5 %).

In the frame of the radon action plan, FANC, in collaboration with the local authorities, has initiated over the last few years a series of projects to increase public awareness on radon, especially in the radon prone areas of Belgium.

The main communication tool is an extensive website (part of http://www.fanc.fgov.be/) available in French, Dutch and German with information on the health risk, the average radon concentration in each municipality, the Belgian radon action plan, radon in workplaces, how to measure and mitigate, and prevention for new buildings. There are several leaflets and brochures about radon published, with advice for reducing radon exposure in existing buildings and for preventing radon ingress in new buildings.

An important aspect of the radon action plan is the collaboration with local and regional authorities, competent for related issues such as preventive health, building regulations, education and land management. The municipalities, provinces and federated entities (i.e. regions and communities) all have a specific role in the management policy of radon, especially in the affected areas.

As a matter of continuous public awareness effort, radon information and measurement campaigns are organised annually (during the winter season) in different regions in order to inform the public, the employers and the local authorities, to provide low-level measurement possibilities to the population and to public buildings, and to stimulate and promote preventive measures for new buildings.

Based on the available indoor radon measurements, an estimate can be made concerning the exposure of the Belgian population to radon. This estimate is influenced by the lack of detailed and representative measurements in flats and apartments located not on the ground floor. However, based on all available measurement data it can be deduced that these types of dwellings, characterized by average ventilation rates, almost never have high radon concentrations, and therefore they have never been the subject of detailed study. Indoor radon measurements taken into account for mapping purposes and for the estimation of the indoor radon exposure are purely based on ground-floor measurements of single-family houses. Since in Belgium about 75 % of the population lives in these kind of dwellings, it nevertheless gives a good and conservative estimate of the population exposure. Table 18 shows the statistical variations (population weighted) in the different regions and for the radon prone areas (RPA). Table 18 gives an estimate of the number of dwellings (single family houses) for each category of radon exposure. As the population of radon measurements generally (as it is the case in Belgium) have a log-normal distribution, the geometric mean (and geometric standard deviation) is used in this estimation.

Table 18. Average radon exposure of the Belgian population (population data for 2010). AM: arithmetic mean, MED: median, GM: geometric mean, GSD: geometric standard deviation. Values are in Bq/m³. RPA: radon prone areas. % gives the percentage of single family houses above the indicated radon concentration (in Bq/m³)

	Population	**dwellings**	**AM**	**MED**	**GM**	**GSD**	**% >100**	**% >200**	**% >300**	**% >400**	**% >800**
Belgium	10584534	3742000	57	44	46	1.7	10.0	2.1	0.9	0.6	0.2
Wallonia	3435879	1325000	84	60	75	1.7	26.0	4.5	2.6	1.6	0.4
Flanders	6117440	2191000	44	37	36	1.2	3.2	0.1	0.05	0.0	0.0
Brussels	1031215	226000	44	37	36	1.2	4.0	0.1	0.1	0.0	0.0
RPA	376568	130000	220	127	137	1.9	43.0	33.0	17.0	13.0	4.3

In the radon prone areas, about 43 % of the dwellings have indoor radon concentrations above 100 Bq/m³ (Table 18), corresponding to about 56.000 dwellings (Table 19). In this area, we find nearly all of the very high radon concentrations (about 5.600 dwellings with concentrations above 800 Bq/m³). The vast majority of dwellings with radon concentrations above 200 Bq/m³ are situated in the southern part of the country.

Table 19. Estimate of the number of dwellings (single family houses) in the different categories of radon exposure (Bq/m³)

	dwellings	**>100**	**>200**	**>300**	**>400**	**>800**
Belgium	3742000	360000	84000	36000	21000	5600
Wallonia	1325000	280000	79000	35000	21000	5600
Flanders	2191000	70000	some	some	0	0
Brussels	226000	9000	5000	some	0	0
Radon prone areas	130000	56000	43000	22000	17000	5500

The Belgian population is clearly not homogeneously exposed to radon, due to the highly significant regional variations of the soil- and rock composition. The very high values are almost exclusively restricted to the radon prone areas (although very local hot-spots do occur in some places), and the Walloon region is in its entity much more exposed than the Brussels and Flemish regions. Only a few buildings are thought to have radon concentrations above 200 Bq/m³ in these last two regions. Activities to reduce radon therefore have to be adapted to the regional differences and specific situations.

Detailed measurement campaigns in schools and public buildings have highlighted the same regional variations in these types of buildings as in dwellings. In the case of schools, high radon concentrations often coincided with other IAQ problems such as high carbon dioxide (CO_2) concentrations. Remediation solutions in these cases should always aim at a general improvement of IAQ.

Concerning radioactivity of building materials, a recent research project B-NORM investigated the situation in Flanders (B-NORM, 2013). All of the 120 bulk building materials had activity indexes below 1, classifying them as sufficiently safe for use from a gamma radiation point of view. All surficial materials (tiles) had activity indexes below 6, indicating that they will not lead to gamma doses above the reference level of 1 mSv/year.

For radon in drinking water, the available FANC measurements do not indicate concentrations above 100 Bq/l in water distribution networks. In specific situations, where local well water is used, the concentrations can reach several 100 Bq/l.

In general, apart from increasing the ventilation rate, there are two main groups of mitigation techniques. The first consists of improving the air-tightness of the contact zone between the ground and the building, or between basement (or crawl-space) and the rest of the building. Sealing conduits and ducts or installing air-tight basement doors are some examples. The second group of mitigation techniques consists of changing the pressure difference between the ground and the building. This can be achieved by creating a low pressure zone in the basement or crawl space using an fan, by depressurisation of the soil (using a fan) or by changing the pressure inside the inhabited rooms by mechanical ventilation or supplementary air-inlets. If properly done, these actions may have very limited energy costs. It is important to point out that the exposure to indoor radon can significantly increase when the ventilation is not well balanced or malfunctioning.

Very often, efficient mitigation in existing buildings with very high radon concentrations can be only achieved by active measures such as sub-floor ventilation or air extraction from basement or crawl-space, combined with passive measures of sealing pathways.

For new buildings, prevention techniques consist of assuring the air-tightness of the building with respect to the soil (sealed conduits and ducts, radon-proof membrane, air-tight basement doors) and by the installation of a permeable layer below the slab that can be depressurised if necessary by means of a fan. Radon prevention is in general less expensive and easier to achieve than radon mitigation.

3.3 Impact on public health

The short lived progeny from the decay of radon gas in air can deposit in the lungs. Since the biological clearance of the radon decay products in the lungs exceeds a few hours, there is time for decay to lead-210. In this process, two alpha particles are emitted from polonium-218 and polonium-214. These alpha particles can damage the stem cells of the respiratory tract. There is now compelling evidence from cohort studies of underground miners and from case-control studies of residential radon exposures that radon progeny can cause lung cancer. The linear increase without threshold of the relative risk with indoor radon concentration has been estimated in various recent studies (Baysson et al., 2004; Darby et al., 2005). The European pooled residential study (Darby et al., 2005) is in good agreement with the pooled North American (Krewski et al., 2005) and Chinese studies (Lubin et al., 2004). As the European study has a better statistical power, UNSCEAR (2009) and ICRP (2010) adopted the measurement corrected estimate of excess relative risk for developing lung cancer from the European pooled study of 0.16 per 100 Bq/m³. This would mean that indoor radon may have a role in a bit less than 10 % of all lung cancer in Europe (Baysson et al., 2004), of which a major part are smokers. One of the conclusions of the study (Darby et al., 2005) is that residential pooled studies may indicate a no-threshold effect of radon. Accordingly, following the "as low as is reasonably achievable" (ALARA) principle, any reasonable efforts to reduce the exposure and concentrations to levels less than 100 Bq/m³ should be considered.

Estimation of radon induced lung cancers in Belgium can be done based on the estimated mean of the radon concentration (Table 18). Applied to the different regions in Belgium and to the radon prone areas, this gives the distribution of the estimated lung cancer (LC) risk and estimated annual LC incidence rates (Table 20) in different parts of Belgium. The LC risk is given per thousand persons for non-smokers (NS) and for smokers (S), in function of different radon exposure levels. The basic risk, without exposure to radon, is taken to be 4.1 LC per thousand persons (for NS) and 101 LC per thousand persons (for S). The table is only indicative, taking into account the large uncertainties of the regional variations in smoking habits in the past.

Table 20. Estimated annual lung cancer (LC) incidence rate in Belgium for non-smokers (NS) and smokers (S). Lifetime LC risk (0.16% increase per Bq/m³) expressed per thousand. Lifetime =70 y*

	LC risk NS	LC risk S	LC NS	LC S	total	Due to radon
Belgium	4.4	108.4	399	6558	6958	477 (27 NS and 450 S) (7%)
Wallonia	4.5	113.1	135	2221	2356	252 (14 NS and 238 S) (11%)
Flanders	4.3	107.0	228	3740	3967	222 (13 NS and 209 S) (6%)
Brussels	4.3	107.0	38	630	669	37 (2 NS and 35 S) (6%)
Radon prone areas	5.0	122.0	16	263	279	48 (3 NS and 45 S) (17%)
No radon*	4.1	101.0				

**After Darby et al., 2005*

The number of lung cancers estimated corresponds well with the observed LC incidence rates for the years 2004-2005 (Belgian cancer registry), when the basic risk (LC incidence rate without radon) from Darby et al. (2005) is used, and when the smoking part of the general population is taken to be 40 %. This rather high value seems to be justified taking into account the importance (with respect to LC risk) of the long term exposure and the fact that the smoking percentage of the population has been higher in the past.

The estimation of the annual LC incidence rates show that about 7 % of the LC in Belgium can be attributed to radon. In the radon prone areas this increases to about 17 %. For smokers, the LC risk in absolute numbers increases strongly when they are exposed to high concentrations of radon. The data show that, if the average radon concentration in the radon prone areas could be reduced to levels close to the Belgian geometric mean (46 Bq/m³), about 30 LC (11 %) in this areas could be avoided every year. If the average radon concentration in the Walloon Region could be reduced to levels around the Belgian average, about 100 LC per year could be avoided.

This estimation illustrates the importance of the implementation of a general strategy in radon policy. If the objective is to have an impact on the LC incidence rate, the actions to reduce the radon exposure should not be restricted to radon prone areas, but also to reduce the average concentration in less exposed areas. This also illustrates the importance to avoid in the future an increase of the average radon exposure in areas where this exposure is still low today. Possible risk factors for such an increase are changing building techniques and a general trend towards low-energy building, implying possible risks of lowering ventilation rates to levels where indoor pollutants such as radon are no longer efficiently removed from the indoor air. In the context of low-energy building and energy-saving measures, the radon concentration in the case of a constant source-term (exhalation rate) is inversely proportional to the ventilation rate. Also, the use of new energy-friendly heating techniques such as air heat-pump systems can potentially increase the indoor radon concentration (and negatively influence the IAQ in general). Therefore, a close follow-up of these technological progresses is deemed necessary.

The general implementation of radon resistant building techniques for new buildings as discussed in chapter 2 is probably the only efficient tool to achieve this reduction of the general exposure (not only in the radon prone areas).

3.4 Conclusions et recommandations sur le radon pour l'air intérieur en Belgique

1. **Objectif.** Compte tenu du rôle important du radon dans l'exposition de la population belge et le lien clairement établi avec un risque accru de cancer du poumon, l'objectif sur le long terme est de réduire l'exposition moyenne de la population au radon. Dans la partie sud du pays, cet objectif peut être atteint en mettant en œuvre des initiatives de prévention du radon dans les nouvelles constructions et en appliquant des mesures et procédés d'atténuation dans les constructions existantes. Afin d'éviter une nouvelle augmentation de l'exposition au radon, la radioactivité des matériaux de construction doit faire l'objet d'une surveillance, et le radon doit être pris en compte dans la conception de bâtiments basse consommation (avec des taux de ventilation adaptés, en évitant le contact direct entre le sol et l'air, etc.). Pour la partie nord de la Belgique, cela se traduira par le statu quo de la situation actuelle en matière d'exposition. Il convient de noter qu'une réduction de la fumée de tabac entraînerait une diminution du risque présenté par le radon en raison de la relation presque synergique entre le radon et la fumée de tabac.

2. **QAI.** Le radon doit faire partie d'une approche intégrée générale en matière de QAI. Pour ce qui est des mesures de prévention, la garantie d'un environnement intérieur sain dépend largement de l'efficacité et de la pertinence du système de ventilation. L'exposition aux polluants de l'air intérieur (*c.-à-d.* le radon) augmente lorsque la ventilation des bâtiments basse consommation est mal réglée ou ne fonctionne pas correctement.

3. **Niveau de référence.** Dans le cadre des nouvelles normes européennes de base en matière de sécurité, et suivant l'approche générale de la publication 103 de la CIPR pour envisager le radon dans un cadre de protection radiologique, l'utilisation d'un niveau de référence est recommandée, défini comme étant le niveau de dose ou de risque au-dessus duquel on ne peut généralement permettre une exposition.

En dessous du niveau de référence, la protection devrait être optimisée. 3 mSv/an (soit près de 100 Bq/m³) est l'objectif proposé à long terme, avec un niveau transitoire pour les constructions existantes d'environ 10 mSv par an (soit près de 300 Bq/m³).

4. **Prévention et anticipation pour les nouvelles constructions.** Afin d'atteindre l'objectif de réduction de l'exposition moyenne de la population, la prévention du radon dans les nouvelles constructions doit s'appliquer de manière organisée et contrôlée. Il est recommandé d'établir un code de construction *à tous les niveaux législatifs*, y compris dans le cadre de la prévention contre le radon. Une approche progressive en matière de protection peut être utilisée, selon le niveau de risque de la zone de construction, avec une protection élargie aux zones à risque.

5. **Gestion des risques liés au radon dans les zones à risque.** Des activités de sensibilisation continues doivent être mises sur pied et le public doit avoir la possibilité d'effectuer des mesures du radon et de recevoir des informations sur les mesures correctives. Un système d'aide financière pour les mesures d'atténuation des effets du radon pourrait avoir un effet positif. Les mesures correctives qui ne sont pas conformes aux dernières publications en la matière, parfois proposées par des entreprises commerciales, ne doivent pas être prises en compte étant donné qu'elles peuvent n'avoir aucun impact ou peuvent même aggraver l'exposition au radon des occupants d'un bâtiment.

6. **Transactions immobilières.** Il est conseillé de créer un système d'information sur la concentration en radon d'un bâtiment dans le cas d'une transaction immobilière (vente ou location). Cela permettra au nouveau locataire/propriétaire du bâtiment de prendre les mesures correctives nécessaires (et ainsi de réduire l'exposition au radon des futurs occupants).

7. **Base de données sur le radon.** Il est recommandé d'établir une base de données centralisée pour recueillir toutes les informations relatives aux mesures de radon. Cela permet une mise à jour régulière de la cartographie des risques liés au radon et la conception d'un instrument permettant de mesurer et évaluer l'impact et l'efficacité du programme sur le radon sur le long terme.

8. **Matériaux de construction et eau**. Il est recommandé d'établir un système pour évaluer la tendance et l'évolution du radon provenant des matériaux de construction ou de l'eau potable pour être en mesure de définir des mesures d'optimisation selon le principe ALARA.

IV. CONCLUSIONS ET RECOMMANDATIONS

L'air ambiant serait responsable des 2/3 de la charge de morbidité totale découlant des expositions à l'air intérieur en Europe (Jantunen et al., 2011). Le 1/3 restant de la charge de morbidité liée aux expositions à l'air intérieur est causé par les installations de chauffage et de combustion (cuisson et chauffage à l'aide de combustibles solides), les systèmes d'approvisionnement en eau, et les fuites d'eau. La condensation et le sol sous-jacent sont deux autres sources importantes de radon dans la charge de morbidité liée à la QAI.

Pour atteindre une bonne QAI dans les bâtiments, une **approche globale et intégrée en matière de QAI** devrait être appliquée et consister en une série de mesures de contrôle des sources des polluants chimiques et microbiologiques, de prévention contre le radon ainsi que d'une ventilation intérieure efficace et adaptée et des stratégies visant à modifier le comportement des occupants. L'expérience a montré que l'exposition aux polluants intérieurs (chimiques, microbiologiques et radon) tend à augmenter lorsque la ventilation du bâtiment est mal réglée ou ne fonctionne pas correctement. Il est, par conséquent, recommandé d'intégrer la QAI dans les exigences et les procédures en matière d'efficacité énergétique et de ventilation de la directive européenne sur la performance énergétique des bâtiments (PEB) ; il est, de plus, nécessaire d'avoir une intégration plus poussée de la QAI dans les systèmes d'évaluation des bâtiments écologiques (BREEAM, LEED, etc.). Des données récentes ont souligné l'importance d'une QAI saine dans les bâtiments écologiques, après avoir réalisé des rénovations énergétiques, lors de l'utilisation de produits (durables) de construction, ou en modifiant l'isolation ou la ventilation mécanique du bâtiment.

Les mélanges complexes de substances chimiques dans l'air intérieur découlent de différences quantitatives et qualitatives notables entre les émissions provenant de sources de pollution intérieure et leurs effets potentiels sur la santé. Une analyse plus approfondie concernant la formation d'une réaction secondaire et les effets cumulatifs qui découlent d'expositions combinées à diverses substances (par ex., un regroupement de substances provoquant des effets semblables/identiques) est nécessaire pour mieux comprendre la question de la santé et du confort des occupants en intérieur. Une attention toute particulière devrait être accordée aux substances présentant un mécanisme d'action différent, mais complémentaire entraînant certains effets sur la santé, telles que les agents mutagènes déclencheurs du cancer et les agents exerçant des effets de formation des tumeurs. Dans le cas des polluants chimiques, l'utilisation de **produits à faibles émissions** devrait être renforcée. De plus, une mise au point régulière des **listes des composés prioritaires** des nouveaux produits chimiques, identifiés lors des mesures d'émission, est recommandée. Par exemple, la liste prioritaire en Belgique ne comprend pas certains composés tels que les retardateurs de flamme ou les phtalates (COSV, soupçonnés d'être des perturbateurs endocriniens) et pour certaines substances de la liste des composés prioritaires (par ex., l'ammoniac), il est urgent de mettre au point/optimiser une méthode d'essai de référence. Il est nécessaire de tenir compte de **la composition chimique de l'air intérieur** dans la caractérisation chimique de l'air intérieur et le contrôle des émissions. Davantage de recherches sont donc nécessaires sur la manière dont un matériau/produit est évalué actuellement dans le cadre de l'étiquetage/la certification par rapport à son comportement dans un environnement intérieur réel où des émissions secondaires viennent s'ajouter aux émissions primaires. **De nouveaux dispositifs d'échantillonnage, méthodes et techniques d'analyse** adaptés au prélèvement en intérieur de nouveaux polluants doivent être mis au point et/ou optimisés.

Il faut procéder à une **harmonisation des stratégies d'échantillonnage, des méthodes d'analyse et des stratégies de traitement des données**. Pour les polluants chimiques et microbiologiques, il a été conclu qu'un cadre consensuel devait être fixé, lequel envisagerait la très grande variété de stratégies d'échantillonnage, de méthodes d'analyse, d'instruments, et d'outils d'évaluation des données en termes de risques pour la santé, d'exactitude et de représentativité. La législation sur les contaminants microbiologiques doit être revue et clarifiée, sur la base d'un consensus méthodologique. Il est nécessaire de mettre sur pied un groupe de travail dédié à la QAI au niveau national, qui conduirait à l'identification des aspects devant être encadrés.

L'harmonisation des stratégies pour les outils de répartition des sources, dans le cadre des évaluations QAI dans les milieux intérieurs ayant fait l'objet de plaintes relatives à la santé (répartition des sources) ou non, permettra une anticipation plus ciblée des sources et de la santé des occupants. Les données nationales sur la QAI sont comparables et applicables à plus grande échelle lorsqu'elles se basent sur des stratégies et des méthodes d'analyse et d'échantillonnage (de référence) harmonisées. Cette harmonisation améliorera la validité et l'utilisation d'une base de données de référence sur la QAI et les sources intérieures.

Compte tenu des expositions relativement élevées au radon de la population belge, et le lien bien établi avec l'incidence du cancer du poumon, **une réduction de l'exposition** est l'objectif sur le long terme pour le radon. Dans la partie sud du pays, cet objectif peut être atteint en mettant en œuvre des initiatives de prévention du radon dans les nouvelles constructions et en appliquant des mesures et procédés d'atténuation dans les constructions existantes. Afin d'éviter une nouvelle augmentation de l'exposition au radon, la radioactivité des matériaux de construction doit faire l'objet d'une surveillance, et le radon doit être pris en compte dans la conception de bâtiments basse consommation (avec des taux de ventilation adaptés, en évitant le contact direct entre le sol et l'air, etc.). Pour la partie nord de la Belgique, cela se traduira par le statu quo des niveaux actuels d'exposition.

Il est recommandé d'établir une **base de données de référence à grande échelle sur la QAI en Belgique**, représentative des milieux et des sources intérieures en Belgique, et adaptée à l'exploration des données. Cette base de données devrait donc comprendre divers milieux intérieurs ; des (futurs) composés prioritaires (produits chimiques, radon et contaminants microbiologiques) ainsi que des données d'émission de tout type de produit utilisé dans un environnement intérieur. La base de données permettra une évaluation des tendances d'exposition au fil du temps, et fournira des données pour évaluer les **mesures (politiques) de prévention et de réduction de l'exposition** dans l'air intérieur et pour une étude préliminaire des **coûts socio-économiques** de la qualité de l'air intérieur, afin d'obtenir un calcul plus précis des années de vie ajustées sur l'incapacité (AVCI). Pour le radon, cela permettrait une mise à jour régulière de la cartographie des risques liés au radon et la conception d'un instrument permettant de mesurer et évaluer l'impact et l'efficacité du programme sur le radon sur le long terme. Pour les autres produits chimiques, davantage de données sur les niveaux de base des polluants intérieurs devenus récemment prioritaires (par ex., à partir des données d'émission du produit), ou les nouveaux polluants, conduiront à une évaluation plus précise des risques pour la santé et à la définition d'actions de prévention adaptées. À des fins de prévention, l'établissement d'un **suivi à long terme de la QAI dans un parc de logements représentatif** contribuera à quantifier l'impact des tendances de construction et du comportement des occupants sur la QAI et permettra de rassembler les outils appropriés en matière de gestion des données.

Une **validation et une communication approfondies par rapport aux mesures de réparation** sont nécessaires tant pour les contaminants chimiques que microbiologiques. Dans le cas des mesures de réparation contre les contaminants microbiologiques, des spécifications devraient être rédigées en tenant compte des risques associés des divers types de réparation. Pour la prévention contre le radon, il est recommandé d'établir un code de construction à tous les niveaux législatifs. Une approche progressive est recommandée en matière de protection des occupants, selon le niveau de risque de la zone de construction, avec une protection accrue dans les zones à risque. Un système qui fournit une aide financière pour les mesures d'atténuation des effets du radon pourrait avoir un effet positif. De même, pour l'exposition intérieure aux agents chimiques, il faut une communication claire au sujet de l'efficacité des diverses mesures de réparation.

Une harmonisation s'impose dans **l'évaluation des concentrations recherchées** pour les polluants intérieurs chimiques et microbiologiques préoccupants. Pour les concentrations de moisissures dans l'air ou les spores de moisissure, des valeurs seuils font défaut.

Au moment d'évaluer les expositions intérieures aux produits chimiques, il faut en outre envisager une gamme plus large de composés émis, qui aille au-delà des émissions des produits de construction et qui dépasse le champ de compétences de l'OMS. Par ailleurs, une liste complète et harmonisée des valeurs de référence sanitaires, notamment les nouveaux polluants, permettra une évaluation plus précise de l'impact de la QAI sur la santé. Actuellement, ce travail consiste en un « patchwork » de VR avec divers facteurs d'évaluation.

V. REFERENCES

Chemical indoor air priority pollutants in Belgium

AFSETT - Agence française de sécurité sanitaire de l'environnement et du travail. Procédure de qualification des émissions de composés organiques volatils par les matériaux de construction et produits de décoration. Rapport d'expertise collective, France: French Agency for Environmental and Occupational Health Safety 2009.

AgBB - Ausschuss zur gesundeheitlichen Bewertung von Bauprodukten. Evaluation procedure for VOC emissions from building products. Part 3: LCI values, Germany: Committee for Health-related Evaluation of Building Products 2012.

Air fresheners 2006-2008 Influence on IAQ (report 2006/MIM/R/032), Exposure and risk assessment (report 2008/IMS/R/222), Recommendation for the regulation of sustainable air fresheners (2008/MIM/R/063).

Ambient air quality. Standard gravimetric measurement method for the determination of the PM2,5 mass fraction of suspended particulate matter. 2005.

ATSDR - Agency for Toxic Substances and Disease Registry Atlanta US. Toxicological profile for methyl tert-butyl ether. ATSDR, Department of Health and Human Services, Public Health Service 1996.

ATSDR - Agency for Toxic Substances and Disease Registry Atlanta US. Toxicological profile for 1,4-dichlorobenzene. ATSDR, Department of Health and Human Services, Public Health Service 2006.

ATSDR - Agency for Toxic Substances and Disease Registry Atlanta US. Toxicological profile for ethylbenzene. ATSDR, Department of Health and Human Services, Public Health Service 2010a.

ATSDR - Agency for Toxic Substances and Disease Registry Atlanta US. Toxicological profile for styrene. ATSDR, Department of Health and Human Services, Public Health Service 2010b.

ATSDR – Agency for Toxic Substances and Disease Registry Atlanta US. Toxicological profile for benzene, ATSDR, Department of Health and Human Services, Public Health Service 2007a.

ATSDR – Agency for Toxic Substances and Disease Registry Atlanta US. Toxicological profile for xylene. ATSDR, Department of Health and Human Services, Public Health Service 2007b.

Belgian strategic plan Air 2009-2012. Belgian strategic product plan 2009-2012. Available from: URL:<http://www.health.belgium.be/internet2Prd/groups/public/@public/@mixednews/documents/ie2law/19059047.pdf>

BIBA - Binnenlucht in Basisscholen – Indoor air in Primary schools. The indoor air quality in school environments, an assessment of the influences of ambient air, ventilation and interior design. BIBA, 2009. Available from: URL:<http://wwwb.vito.be/flies>

Billionneta C, Gay E, Kirchner S, Leynaert B, Annesi-Maesano I. Quantitative assessments of indoor air pollution and respiratory health in a population-based sample of French dwellings. Environmental Research 2011;111:425-34.

Bladt S, Lenelle Y, Bouland C, Chasseur C. Index of Indoor Air Chemical Pollution in Brussels Habitat. Forum geographic 2010;9:93-6.

Bluyssen P, De Richemont S, Crump D, Maupetit F, Witterseh T, Gajdo P. Actions to reduce the impact of construction products on indoor air : outcomes of the European project Healthy Air. Indoor Built Environ 2010;19:327-39.

Bluyssen P. Indoor sources and health effects. 2010. Available from: URL:<http://www.health.eutrio.be>

Bruxelles Environnement. Polluants Intérieurs. Comments les limiter ? Available from: URL:<http://www.health.belgium.be/internet2Prd/groups/public/@public/@dg5/documents/ie2divers/18076922.pd >

BS – Belgisch Staatsblad. Besluit van de Vlaamse Regering houdende maatregelen tot bestrijding van de gezondheidsrisico's door verontreiniging van het binnenmilieu. BS van 19 oktober 2004, blz. 72552-60.

Buekers J, Torfs R, Deutsch F, Lefebvre W, Bossuyt M. Inschatting ziektelast en externe kosten veroorzaakt door verschillende milieufactoren in Vlaanderen, studie uitgevoerd in opdracht van de Vlaamse Milieumaatschappij 2012.

Carlstedt F, Jönsson B, Bornehag C. PVC flooring is related to human uptake of phthalates in infants. Indoor Air 2013;23:32-9.

CEN - European Committee for Standardization. Construction products: Assessment of release of dangerous substances. Available from: URL:<http://www.nen.nl/Normontwikkeling/Doe-mee/Normcommissiesennieuwetrajecten/Normcommissies-Bouw/CENTC-351.htm>

Clean Air, Low Energy – Schone Lucht, Lage Energie. Exploratory research on the quality of the indoor environment in energy efficient buildings: the influence of outdoor environment and ventilation. 2012.

Crump DR, Dengel A, Swainson M. Indoor air quality in highly energy efficient homes - a review, United Kingdom, NHBC Foundation 2009.

Dahlgren G, Whitehead M. Policies and strategies to promote social equity in health. Stockholm, Sweden, Institute for Future Studies 1991.

Danish Society of Indoor Climate. Standard Test Method for the Determination of Particle Emission from Building Products, 1997.

Daümling C. Product evaluation for the control of chemical emissions to indoor air – 10 years of experience with the AgBB scheme in Germany. Clean-Soil, Air, Water 2012;40:779-89.

De Brouwere K, Cornelis C, Arvanitis A, Brown T, Crump D, Harrison P et al. Application of the maximum cumulative ratio (MCR) as a screening tool for the evaluation of mixtures in residential indoor air. Science of the Total Environment 2014;1:;479-80.

De Brouwere K, Goelen E, Spruyt M, Torfs R. Ranking indoor air health problems using health impact assessment. 2007.

de Hollander AE, Melse JM, Lebret E, Kramers PG. An Aggregate Public Health Indicator to Represent the Impact of Multiple Environmental Exposures. Epidemiology 1999;10:606-17.

EC – European Commission. The index Project. Final Report, 2005.

ECA – European Collaborative Action. Harmonisation framework for health based evaluation of building products indoor emissions in Europe. ECA Urban air, indoor environment and human exposure. Report n° 29, 2013.

ECA – European Collaborative Action. Harmonisation framework for indoor products labelling schemes in the EU. Urban Air, Indoor environment an Human Exposure. Report n° 27, 2012.

ECA – European Collaborative Action. Impact of Ozone-initiated Terpene Chemistry on Indoor Air Quality and Human Health. Urban Air, Indoor environment an Human Exposure. Report n° 26, 2007.

ECA – European Collaborative Action. Total Volatile Organic Compounds (TVOC) in Indoor Air Quality Investigations. Indoor Air Quality and its impact on Man. Report n° 19, 1997.

EnVIE – Co-ordination Action on Indoor Air Quality and Health Effects. Publishable final activity report. 2009.

EPHECT - Emissions, Exposure Patterns and Health Effects of Consumer Products in the EU. Available from : URL:<https://esites.vito.be/sites/ephect/Pages/home.aspx>

European Centre for Environment and Health Event. The Products policy and Indoor Air Quality. 2010.

Federale Openbare Dienst Sociale Zaken, Volksgezondheid en Leefmilieu. Wet van 21 december 1998. Wet betreffende de productnormen ter bevordering van duurzame productie- en consumptiepatronen en ter bescherming van het leefmilieu en de volksgezondheid.

FLIES - Flanders Indoor Exposure Survey. The influence of contaminants in ambient air on the indoor air quality and children's exposure. Available from: http://www.vito.be/flies

Floor coverings. Bepalen van criteria inzake kamerbrede vloerbedekkingsproducten in kinderdagverblijven op basis van risico analyse mbt gezondheidsimpact op kinderen. Report 2010.

FOD Leefmilieu – Federale Openbare Dienst Leefmilieu. Lente van het Leefmilieu. 2009.
Geiss O, Giannopoulos G, Tirendi S, Barrero-Moreno J, Larsen B, Kotzias, D. The AIRMEX study - VOC measurements in public buildings and schools/kindergartens in eleven European cities: Statistical analysis of the data. Atmospheric Environment 2001;45:3676-84.

Glorieux, I, Coppens K, Koelet S, Moens M, Vandeweyer,J. Vlaanderen in uren en minuten. De tijdsbesteding van de Vlamingen in 480 tabellen. VUB Press, Brussel, 2002.

Goelen E, Geuzens P, Maes F, Provoost J, Torfs R, Verschaeve L et al. Uitwerken van een Vlaams beleid rond binnenhuismilieu, eindrapport. 2003.

Goelen E, Geuzens P, Maes F, Provoost J, Torfs R, Verschaeve L. Uitwerken van een Vlaams beleid rond binnenhuismilieu Eindrapport. 2003 Available from: URL:<http://wwwb.vito.be/flies

Greenguard Certification Program for Chemical and Particle Emissions for Electronic Equipment. 2013.

Gustafsson, H. Building materials identified as major emission sources for indoor air pollutants. A critical review of case studies. Swedish Council for Building research, 1992.

Hanninen O, Knol A. European Perspectives on Environmental Burden of Disease Estimates for Nine Stressors in Six European Countries. National Institute for Health and Welfare. Final Report 2011.

Harrison P, Crump D, Kephalopoulos S, Yu C, Däumling C, Rousselle C. Harmonised Regulation and Labelling of Product Emissions - A New Initiative by the European Commission. Indoor and Built Environment 2011;20:581-3.

Health based evaluation of indoor products emissions in EU. DG Sanco Experts Group on Indoor Air Quality meeting. 2011.

HealthyAir. State-of-the-art draft. 2007.

HEMICPD - Horizontal evaluation method for the implementation of the construction products directive in Belgium. Final report 2010. Available from: URL:<http://www.wtcb.be/go/hemicpd>

HESE project - Health Effects of Schools Environments. 2002-2005.

Horizontal evaluation method for the implementation of the Construction Products Directive (HEMICPD).
Available from: URL:<http://www.belspo.be/belspo/fedra/proj.asp?l=en&COD=P2/05>

INDEX report. Critical Appraisal of the Setting and Implementation of Indoor Exposure Limits in the EU. WHO guidelines for indoor air quality selected pollutants. 2005.

Indoor Air Monit. Harmonised criteria for monitoring requirements in EU related to the INDEX high priority list of chemicals.

Indoor Air Quality and its Effects on Health: A Presentation of the guidelines for Health-Based Ventilation in Europe. HealtVent Project. 2013.

INFLAME project. Indoor Contamination with Flame Retardant Chemicals: Causes and Impacts. Available from: URL:< http://www.birmingham.ac.uk/research/activity/inflame/index.aspx>

Investing for a greener future. EU green week 2016. Available from: URL:<http://ec.europa.eu/environment/greenweek/>

ISO - International Organization for Standardization. Indoor air – Part 35: Measurement of polybrominated diphenylether, hexabromocyclododecane and hexabromobenzene. 2013.

ISO - International Organization for Standardization. Indoor air -- Part 26: Sampling strategy for carbon dioxide (CO2). 2012.

ISO - International Organization for Standardization. Indoor air -- Part 1: General aspects of sampling strategy. 2004.

ISO - International Organization for Standardization. Indoor air -- Part 15: Sampling strategy for nitrogen dioxide (NO2). 2008.

ISO - International Organization for Standardization. Indoor air -- Part 2: Sampling strategy for formaldehyde. 2001.

ISO - International Organization for Standardization. Indoor air -- Part 4: Determination of formaldehyde -- Diffusive sampling method. 2004.

ISO - International Organization for Standardization. Indoor air -- Part 5: Sampling strategy for volatile organic compounds (VOCs). 2007.

Jantunen M, Oliveira F, Carrer P, Kephalopoulos S. Promoting actions for healthy indoor air (IAIAQ). European Commission Directorate General for Health and Consumers. 2011.

Jantunen M, Oliveira Fernandes E, Carrer P, Kephalopoulos S. IAIAQ - Indoor air risks and impacts of alternative policy interventions in the EU countries. The IAIAQ study. Indoor air 2010.

Järnström H, Saarela K, Kalliokoski P, Pasanen A. The impact of emissions from structures on indoor air concentrations in newly finished buildings – predicted and on-site measured levels - Indoor and Built Environment 2008;17:313-23.

Jungsoo K, De Dear R, Cândido C, Zhang H, Arens E. Gender differences in office occupant perception of indoor environmental quality (IEQ). Building and Environnement 2013;70:245-56.

Kephalopoulos S, Kotzias D. Status of harmonisation of indoor air monitoring and the health based evaluation of indoor products emissions in EU. DG Sanco Experts Group on Indoor Air Quality meeting. 14 June 2011. Luxemburg.

Kingdom of Belgium. Royal Decree establishing threshold levels for the emissions to the indoor environment from construction products for certain intended uses. Available from: URL:<http://ec.europa.eu/enterprise/tris/pisa/app/search/index.cfm?fuseaction=pisa_notif_overview&iYear=2012&inum=568&lang=EN&sNLang=EN&CFID=4782229&CFTOKEN=ff208a525964ec3-FAB7924D-AFC0-00F7-5FC1E4618287C26A>

Kousa A, Oglesby L, Koistinen K, Künzli N, Jantunen M. Exposure chain of urban air PM2.5—associations between ambient fixed site, residential outdoor, indoor, workplace and personal exposures in four European cities in the EXPOLIS-study. Atmospheric Environment 2002;36:3031-39.

Kuske M. Presentation of a local indoor air service in Belgium – few cases and results of interventions. Indoor air 2008.

Lai HK, Jantunen MJ, Künzli N, Kulinskaya E, Colvile R, Nieuwenhuijsen MJ. Determinants of indoor benzene in Europe. Atmospheric Environment 2007;41:9128-35.

Lazarov B, Swinnen R, Spruyt M, Goelen E, Stranger M, Desmet G. Optimisation steps of an innovative air sampling method for semi volatile organic compounds. Atmos Environ 2013;79:780-6.

Levin H. National Programs to Assess IEQ Effects of Building Materials and Products, prepared for US EPA. 2010.

Levin H. The big indoor emissions threat–secondary emissions.World Sustainable Buildings Conference. 2008.

Limits in the EU. 2005.

Lor M, Graindorge F, Piens M, Wolfs L, Remontet P. Highlights of the changing legislation and developments in the field of IAQ and construction material emissions and its VOC challenges for (architectural) coatings. Conference Emission and odours from materials, Brussels. 2012.

Lor M, Vause K, Dinne K, Goelen E, Maes F, Romain AC et al. Horizontal Evaluation Method for the Implementation of the Construction Products Directive. State of art report. 2010.

Maes F, Wolkoff P, Norgaard A, Barrero-Moreno J. Report on the chemical characterization of health relevant secondary reaction products incl. SOAs. 2014.

Meek ME, Boobis AR, Crofton KM, Heinemeyer G, Van Raaij M, Vickers C. Risk assessment of combined exposure to multiple substances: a WHO/IPCS framework, Regul Toxicol Pharm 2011;60:S1-S14.

Mendell MJ, Cozen M, Lei-Gomez Q, Brightman HS, Erdmann CA, Girman JR et al. Indicators of moisture and ventilation system contamination in U.S. office buildings as risk factors for respiratory and mucous membrane symptoms: analyses of the EPA BASE data. J Occup Environ Hyg 2006;3:225-33.

Mendell MJ, Mirer A, Cheung K, Tong M, Douwes J. Respiratory and allergic health effects of dampness, mold, and dampness-related agents: a review of the epidemiologic evidence. Environ Health Perspect 2011;119:748-56.

Method for measuring chemical emissions from various sources using dynamic environmental chambers. Greenguard 2008.

Method for the evaluation of chemical emissions from flooring using environmental chambers, Greenguard 2007.

Mølhave L. Organic compounds as indicators of air pollution. Indoor Air 2003;13:12-9.

Murray CJ, Lopez AD. On the comparable quantification of health risks: lessons from the global burden of disease study. Epidemiology 1990;10:594-605.

Murray CJ, Lopez AD. The global burden of disease: a comprehensive assessment of mortality and disability from diseases, injuries and risk factors in 1990 and projected to 2020.

Nicolas M, Ramalho O, Maupetit F. Reactions between ozone and building products: Impact on primary and secondary emissions, Atmospheric Environment 2007;41:3128-38.

OEHHA – Office of Environmental Health Hazard Assessment. Appendix D.3: Chronic RELs and toxicity summaries using the previous version of the Hot Spots Risk Assessment Guidelines. 1999.

OEHHA – Office of Environmental Health Hazard Assessment. Chronic RELs and toxicity summaries using the previous version of the Hot Spots Risk Assessment guidelines. 1999.

Ongoing VIS traject “DO-IT Houtbouw”. 2012-2016. Available from: URL:<http://www.do-ithoutbouw.be/>

Ontario Air Standards For Trimethylbenzenes: 1,2,3-Trimethylbenzene 1,2,4-Trimethylbenzene 1,3,5-Trimethylbenzene. Ontario Ministry of the Environment 2007.

Ontwikkeling van een referentiekader voor duurzame woningen. Available from: URL:<http://www.wtcb.be/homepage/index.cfm?cat=bbri&sub=rd&pag=projects&art=sustainable_housing&niv01=intro>

Outcome of the EU Workshop on: Harmonisation of the health based evaluation of emissions from building products in the EU using the LCI-concept. 2010. Available from: URL:< http://ihcp.jrc.ec.europa.eu/our_activities/public-health/outcome-workshop-emissions-building-materials

Prüss-Ustün A, Corvalán C. 2006. Preventing disease through healthy environments –Towards an estimate of the environmental burden of disease. World Health Organization, Geneva. 2006. Available from: URL:<http://www.who.int/entity/quantifying_ehimpacts/publications/preventingdisease.pdf>

Rationale, principles and implications. Brussels 2013.

Saarela K, Tirkkonen T, Laine-Ylijoki J, Jurvelin J, Nieuwenhuijsen MJ, Jantunen M. Exposure of population and micro-environmental distributions of volatile organic compound concentrations in the EXPOLIS study. Atmospheric Environment 2003;37:39-40.

Salthammer T, Uhde E. Organic Indoor Air Pollutants; occurrence, measurement, evaluation. Wiley-Vch 2011.

Sarigiannis D, Karakitsios S, Gotti AD, Liakos I, Katsoyiannis A. Exposure to major volative organic compounds and carbonyls in European indoor environments and associated health risks. Environmental International 2011;37:743-65.

Schram-Bijkerk D, van Kempen E, Knol A. The burden of disease related to indoor air in the Netherlands: do different methods lead to different results? Occup Environ Med 2013;70:126-32.

Stranger M, Potgieter-Vermaak SS, Van Grieken R. Characterization of indoor air quality in primary schools in Antwerp. Indoor Air 2008;18:454–63.

Stranger M, Potgieter-Vermaak SS, Van Grieken R. Comparative overview of indoor air quality in Antwerp.Environment International 2007;33:789-97.

Stranger M, Potgieter-Vermaak SS, Van Grieken R. Particulate matter and gaseous pollutants in residences in Antwerp. Science of The Total Environment 2009;407;1182-92.

Swaans M, Spruyt R, Bormans L, Verbeke D, Poelmans E, Goelen F et al. Onderzoek naar de gezondheidskwaliteit van Vlaamse woningen. Eindverslag. Studie uitgevoerd in opdracht van Toezicht Volksgezondheid. 2008.

Swaans W. Investigation on the health quality of homes in Flanders. 2011.

Tham K. Priorities for ISIAQ in addressing climate change and sustainability challenges. Editorial Indoor Air 2013;23:1-3.

The European environment and health action plan 2004-2010. COM 2004;1:729.

The INDEX project. Critical Appraisal of the Setting and Implementation of Indoor Exposure.

Torfs. Exposure and risk assessment of air fresheners. 2008.

Uhde E, Salthammer T. Impact of reaction products from building materials and furnishings on indoor air quality – a review of recent advances in indoor chemistry. Atmospheric Environment 2007;41:3111-28.

US-EPA - United States Environmental Protection Agency. Integrated Risk Information System (IRIS) summary acetaldehyde. US-EPA, Washington DC. 1991.
US-EPA - United States Environmental Protection Agency. Toxicological Review naphthalene - in support of Summary Information on the Integrated Risk Information System (IRIS), Washington DC. 1998.

US-EPA - United States Environmental Protection Agency. Toxicological Review cyclohexane - in support of Summary Information on the Integrated Risk Information System (IRIS), Washington DC. 2003a.

US-EPA - United States Environmental Protection Agency. Toxicological Review xylenes - in support of Summary Information on the Integrated Risk Information System (IRIS), Washington DC. 2003b.

US-EPA - United States Environmental Protection Agency. Toxicological Review n-hexane - in support of Summary Information on the Integrated Risk Information System (IRIS), Washington DC. 2005a.

US-EPA - United States Environmental Protection Agency. Toxicological Review toluene- in support of Summary Information on the Integrated Risk Information System (IRIS), Washington DC.2005b.

US-EPA - United States Environmental Protection Agency. Toxicological Review trichloroethylene - in support of Summary Information on the Integrated Risk Information System (IRIS), Washington DC. 2011.

US-EPA - United States Environmental Protection Agency. Toxicological Review tetrachloroethylene (perchloroethylene) - in support of Summary Information on the Integrated Risk Information System (IRIS), Washington DC.2012.

Ventilation and indoor air quality in new homes. California Environmental Protection Agency – Air Resources Board. 2009.

VITO – Vlaamse Instelling voor Technologisch Onderzoek. Q-INTAIR: modellering van binnenluchtkwaliteit op basis van bouwmaterialen- emissies, gebouwluchtdichtheid en ventilatie van woningen. VITO study 2009.

Weschler CJ. Chemical reactions among indoor pollutants: what we've learned in the new millennium. Indoor air 2004;14:184-94.

WHO – World Health Organization. Air quality guidelines for Europe. WHO. Regional Office for Europe Copenhagen. 2000.

WHO – World Health Organization. Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update; 2005.

WHO – World Health Organization. Guidelines for indoor air quality – selected substances. WHO; 2010.

Wolkoff P, Nielsen GD. Organic compounds in indoor air - their relevance for perceived indoor air quality? Atmospheric Environment 2001;35:4407-17.

Wolkoff P. Wilkins C, Clausen PA, Nielsen GD. Organic compounds in office environments – sensory irritation, odor, measurements and the role of reactive chemistry. Indoor Air 2006;16:7-19.

Yu CW, Kim JT. Building environmental assessment schemes for rating of IAQ in sustainable buildings. Indoor and Built Environment 2011;20:5-15.

Administration de l'Aménagement du Territoire et du Logement. Normes de qualité des logements. Direction du Logement, 2013.

Ahlbom A, Backman A, Bakke J, Foucard T, Halken S, Kjellman NI et al. NORDPET. Pets indoors - A risk factor for or protection against sensitisation/allergy. A Nordic interdisciplinary review of the scientific literature concerning the relationship between the exposure to pets at home, sensitization and the development of allergy. Indoor Air 1998, 8:219-35.

Air Allergy – Belgian Aerobiological Surveillance Network. Available from: URL:<http://www.airallergy.be>

Albrecht A, Fisher G, Brunnemann-Stubbe G, Jäckel U, Kämpfer P. Recommendations for study design and sampling strategies for airborne microorganisms, MVOC and odours in the surrounding of composting facilities. Int J Hyg Environ Health 2008;211: 121-31.

Alvarez AJ, Buttner MP, Stetzenbach LD. PCR for bioaerosol monitoring: sensitivity and environmental interference. Appl Environ Microbiol 1995;61:3639-44.

American Lung Association. Bacteria and Viruses. Healthy Air. Available from: URL:<http://www.lung.org/healthy-air/home/resources/bacteria-and-viruses.html>

Analysis of Fungal Flora in Indoor Dust by Ribosomal DNA Sequence Analysis, Quantitative PCR, and Culture. Environmental Microbiology 2008;74:233–44.

Andersson M, Downs S, Mitakatis T, Leuppi J, Marks G. Natural exposure to Alternaria spores induces allergic rhinitis symptoms in sensitized children. Pediatr Allergy Immunol 2003;14:100-05.

APW – Association des Provinces Wallonnes. Les Services provinciaux d'analyse des milieux intérieurs. URL:< http://www.apw.be/index.php?page=sante-environnementale>

Arrêté du Gouvernement de la Région de Bruxelles. Capitale déterminant les exigences élémentaires en matière de sécurité, de salubrité et d'équipement des logements. Capitale du 04 septembre 2003.

Arshad SH. Does exposure to indoor allergens contribute to the development of asthma and allergy? Curr Allergy Asthma Rep 2010;10:49-55.

Axelsson IG, Johansson SG, Zetterstrom O. Occupational allergy to weeping fig in plant keepers. Allergy 1987;42:161-7.

Beffa T, Blanc M, Lyon PF, Vogt G, Marchiani M, Fischer JL et al. Isolation of Thermus strains from hot compost (60 to 80°C). Applied and Environmental Microbiology 1996: 1723-27.

Beguin H, Nolard N. Mould biodiversity in homes I. Air and surface analysis of 130 dwellings. Aerobiologia 1994;10:157-66.

Besluit van de Vlaamse Regering houdende maatregelen tot bestrijden van de gezondheidsrisico's door verontreiniging van het binnenmilieu. Ministerie van de Vlaamse Gemeenschap, 11 juni 2004.

Bircher AJ, Langauer S, Levy F, Wahl R. The allergen of Ficus benjamina in house dust. Clin Exp Allergy 1995;25:228-33.

Black PN, Udy AA, Brodie SM. Sensitivity to fungal allergens is a risk factor for life-threatening asthma. Allergy 2000;55:501-04.

Blomme K, Tomassen P, Lapeere H, Huvenne W, Bonny M, Acke F et al. Sensitisation to airborne moulds and severity of asthma: cross sectional study from European Community respiratory health survey. Int Arch Allergy Immunol 2013;160:200–07.

Bornehag CG, Sundell J, Sigsgaard T. Dampness in buildings and health: Report from an ongoing epidemiological investigation on the association between indoor environmental factors and health effects among children in Sweden. Indoor Air 2004;14: 59–66.

Bouillard L, Michel O, Dramaix M, Devleeschouwer M. Bacterial Contamination of Indoor Air, Surfaces, and Settled Dust, and Related Endotoxin Concentrations in Healthy Office Buildings. Ann Agric Environ Med 2005;12:187–92.

Brasel TL, Campbell AW, Demers RE, Ferguson BS, Fink J, Vojdani A et al., Detection of trichothecene mycotoxins in sera from individuals exposed to Stachybotrys chartarum in indoor environments. Arch Environ Health 2004;59:317-23.

Brasel TL, Martin JM, Carriker CG, Wilson SC, Straus DC. Detection of Airborne Stachybotrys chartarum Macrocyclic Trichothecene Mycotoxins in the Indoor Environment. Applied and Environmental Microbiology 2005;71:7376–88.

Brewer JH, Thrasher JD, DavStraus DC, Madison RA, Hooper D. Detection of Mycotoxins in Patients with Chronic Fatigue Syndrome. Toxins 2013;5:605-17.

Brooks S.M. Irritant Induces Airway Disorders. 2005. Available from: URL:<http://www.stuartbrooksmd.com/papers/irritant-induced-airways-disorders.pdf>

Brussee JE, Smit HA, van Strien RT, Corver K, Kerkhof M, Wijga AH et al. Allergen exposure in infancy and the development of sensitization, wheeze, and asthma at 4 years. J Allergy Clin Immunol 2005;115:946-52.

Cartieaux E, Rzepka MA, Cuny D. Indoor air quality in schools. Arch Pediatr 2011;18:789-96.

Chasseur C, Gofflot S, Nolard N. Microbial Indoor air quality in office buildings with central air conditioning installation in Belgium. An easy tool for a bacterial quality evaluation. 5th International Conference on Bioaerosols, Fungi, Bacteria, Mycotoxins and Human Health. Saratoga Springs, New York;2003:210.

Chasseur C, Verhaegen AM, Gofflot S, Nolard N. Microbiological controls in air conditioning systems: a standard preliminary approach. Proceeding of Healthy Buiding Espoo, Finland 2000;3:555-9.

Chasseur C. Bladt S., Wanlin M. Indoor environmental germs and health: WIV-ISP involvement in the Belgian habitat over the last 20 years. WIV-ISP annual report. 2014.

Chasseur C, Bladt S, Wanlin M. Index of Indoor Airborne Fungal Spores Pollution in Brussels Habitat. Healthy Buildings 2015.

Chen CM, Rzehak P, Zutavern A, Fahlbusch B, Bischof W, Herbarth Oet et al. Longitudinal study on cat allergen exposure and the development of allergy in young children. J Allergy Clin Immunol. 2007;119:1148-55.

Chen YC, Tsai CH, Lee YL. Early-life indoor environmeental exposures increase the risk of childhood asthma. Int J Hyg Environ Health 2011;215:19-25.

Code Bruxellois du Logement. Ordonnance portant le Code bruxellois du Logement du 17 juillet 2003. MB du 09 septembre 2003.

Code Wallon du Logement – Arrêté du Gouvernement wallon déterminant les critères minimaux de salubrité, les critères de surpeuplement et portant les définitions visées à l'article 1er,19° à 22°bis. MB du 30 octobre 2007. p. 55871.

Cohn RD, Arbes SJ, Jaramillo R, Reid LH, Zeldin DC. National Prevalence and Exposure Risk for Cockroach Allergen in U.S. Households. Environmental Health Perspectives 2006;114:522-26.

Cole Johnson C, Ownby DR, Havstad SL, Peterson EL. Family history, dust mite exposure in early childhood, and risk for pediatric atopy and asthma. J Allergy Clin Immunol 2004;114:105-10.

COST - Coordination European Scientific and Technique. Biological Particles in Indoor Environments. Brussels, Report n° EUR14988EN 1993,613/2.

CPSC - Consumer Product Safety Commission. Indoor Air Pollution: Introduction for Health Professionals. American Medical Association. Available from: URL:<http://www.cpsc.gov/cpscpub/pubs/455.html>

CRIOC - Centre de Recherche et d'Information des Organisations de Consommateurs. Pets 2010. Available from: URL:< http://www.oivo-crioc.org/files/fr/4926fr.pdf>

Crocker DD, Kinyota S, Dumitru G, Ligon CB, Herman EJ, Ferdinands JM et al. Effectiveness of home-based, multi-trigger, multicomponent interventions with an environmental focus for reducing astham morbidity: a community guide systematic review. Am J Prev Med 2011;41:S5-32.

Custovic A, Woodcock A. Exposure and sensitization in infants and children.Curr Opin Allergy Clin Immunol 2001;1:133-8.

Custovic A. Fletcher A, Pickering CA, Francis HC, Green R, Smith A et al. Domestic allergens in public places III - house dust mite, cat, dog and cockroach allergens in British hospitals. Clinical and Experimental Allergy 1998;28:53-9.

Dewolf MC, Charlet F., Roger M., Kuske, Bladt S., Chasseur C. et al. Nursery project: Development of an autoassessment tool and analysis of the indoor environment. HENVI Health Aspects of Indoor and Outdoor Air Pollution. Luxembourg, 2008.

Education santé. 2014;188. Available from: URL:< http://www.educationsante.be/es/article.php?id=125>

Eggleston PA and Arruda LK. Ecology and elimination of cockroaches and allergens in the home. Journal of Allergy and Clinical Immunology 2001;107:422-9.

Engelhart S, Loock A, Skutlarek D, Sagunski H, Lommel A, Farber H et al. Occurrence of Toxigenic Aspergillus versicolor Isolates and Sterigmatocystin in Carpet Dust from Damp. Environmental Microbiology 2002;68:3886–90./

EPA - United States Environmental Protection Agency. An Introduction to Indoor Air Quality 2012. Available from: URL:< on http://www.epa.gov/iaq/biologic.html>

EPA – United States Environmental Protection Agency. Indoor Air Pollution: An Introduction for Health Professionals 2012. Available from: URL:< http://www.epa.gov/iaq/pubs/hpguide.html>

FARES – Fonds des Affections Respiratoires. Asthme – Théorie 2014. Available from : URL:<http://www.fares.be/content/view/100/109/>

Fisk WJ, Eliseeva E, Mendell MJ. Association of residential dampness and mold with respiratory tract infections and bronchitis: a meta-analysis. Environmental Health 2010; 9:72.

Fisk WJ, Lei-Gomez Q, Mendell MJ. Meta-analyses of the associations of respiratory health effects with dampness and mold in homes. Indoor Air 2007;17:284-96.

Gołofit-Szymczak M, Górny RL. Bacterial and Fungal Aerosols in Air-Conditioned Office Buildings in Warsaw. Poland-The Winter Season. International Journal of Occupational Safety and Ergonomics 2010;4:465–76.

Gomez C, Freihaut J, Bahnfleth W. Resuspension of allergen-containing particle under mechanical and aerodynamic disturbance from human walking. Atmos Environ 2007;41: 5257-70.

Gorny RL, Dutkiewicz J, Krysinska-Traczyk E. Size distribution of bacterial and fungal bioaérosols in indoor air. Ann Agric Environ Med 1999;6:105–13.

Gorny RL, Dutkiewicz J. Bacterial and fungal aerosols in indoor environment in central and eastern European countries, 2002.

Greenfacts – Facts on Health and the Environment. Damp housing with mould growth, mite infestation, cockroaches and toxins 2014. Available from: URL:< http://www.greenfacts.org/en/respiratory-diseases/l-3/05-indoor-air-pollution.htm#2p2>

Haverinen U, Husman T, Vahteristo M, Koskinen O, Moschandreas D, Nevalainen A et al. Comparison of Two-Level and Three-Level Classifications of Moisture-Damaged Dwellings in Relation to Health. Effects.Indoor Air 2001;11:192–9.

Health Canada. Env Health Directorate Health Canada. Ottawa, Ontario 1995.

Heer CE, Nieden A, Jankofsky M, Stilianakis NI, Boedeker RH, Eikman TF. Effect of bioaerosol polluted outdoor air on airways of residents: a cross sectional study. Occup Environ Med 2003;60:336-42.

Heinemann S, Beguin H, Nolard N. Biocontamination in air-conditioning. Health implications of fungi in indoor environments. Elsevier 1994;2:179-86.

HGR - Hoge Gezondheidsraad. Aanbevelingen ter voorkoming van Legionella-infecties in verzorgingsinrichtingen. Brussel: HGR; 2002. Advies nr. 7509.

Horner WE, Worthan AG, Morey PR. Air and dustborne mycoflora in houses free of water damage and fungal growth. Environmental microbiology 2004:6394-400.

Hossain MA, Ahmed MS, Ghannoum MA. Attributes of Stachybotrys chartarum and its association with human disease. J Allergy Clin Immunol 2004;113:200-9.

HSE – Health and Safety Executive. What is Legionnaires' disease? 2013. Available from: URL:< http://www.hse.gov.uk/legionnaires/what-is.htm>

Hsu NY, Wang JY, Su HJ. A dose-dependent relationship between the severity of visible mold growth and IgE levels of pre-school-aged resident children in Taiwan. Indoor Air 2010;20:392-98.

HUD – US Department of Housing and Urban Development. Healthy Homes Issues: Asthma 2006. p.9.

INSPQ - Institut National de Santé Publique du Québec. Les risques à la santé associés à la présence de moisissures en milieu intérieur. Direction des Risques Biologiques, Environnementaux et Occupationnels et Laboratoire de Santé Publique du Québec 2002:15-49.

ISP – Institut Scientifique de Santé Publique. Information sur la légionellose. Available from: URL:< https://www.wiv-isp.be/EPIDEMIO/EPIFR/plabfr/leg.htm

Jarvis BB, Sorenson WG, Hintikka EL, Nikulin M, Zhou Y, Jiang J et al. Study of toxin production by isolates of Stachybotrys chartarum and Memnoniella echinata isolated during a study of pulmonary hemosiderosis in infants. Appl Environ Microbiol 1998; 64:3620–5.

Karimian-Techerani D, Hentges F. Allergy to Ficus benjamina. Bull Soc Sci Med Grand Duche Luxemb 2002;2:107-13.

Kelley WN. Textbook of Internal Medicine.1989;1874-75.

Kelly LA, Erwin EA, Platts-Mills TA. The indoor air and asthma: the role of cat allergens. Curr Opin Pulm Med. 2012;18:29-34.

Kim JL, Elfman L, Wieslander G, Smedje G, Norbäck D. Indoor molds, bacteria, microbial volatile organic compounds and plasticizers in schools-associations with asthma and respiratory symptoms in pupils. Indoor Air 2007;17:153-63.

Litonjua AA, Carey VJ, Burge HA, Weiss ST, Gold DR. Exposure to cockroach allergen in the home is associated with incident doctor-diagnosed asthma and recurrent wheezing. J Allergy Clin Immunol 2001;107:41-7.

Nederlandse Gezondheidsraad. Advies inzake het binnenhuisklimaat, in het bijzonder het ventilatieminimum in Nederlandse woningen. 1984.

Macher JM, Tsai FC, Burton LE, Liu KS. Concentrations of cat and dust-mite allergens in dust samples from 92 large US office buildings from the BASE Study. Indoor Air 2005; 15:82–8.

Malchaire J, Chasseur C, Nolard N. Sick Building Syndrome - Analyse et prévention. Nationaal onderzoeksinstituut voor arbeidsomstandigheden 1999:148.

Matysik S, Herbarth O, Mueller A. Determination of volatile metabolites originating from mould growth on wall paper and synthetic media. Journal of Microbiological Methods 2008:182–87.

MC - Mutualité Chrétienne. Eczéma. Available from: URL:<http://www.mc.be/maladies-traitements/eczema/index.jsp>

Mehrer A, Lorentz W, Gareis M, Trautmann C, Kroppenstedt, Stackebrandt Z. Cytotoxicity of different actinomyces isolated from building materials. In Bioaérosols, Fungi, Bacteria, Mycotoxinx and human health, editors. Eckardt Johanning, Albany: USA, 2005:60-5.

Mendell MJ, Mirer AG, Cheung K, Tong M, Douwes J. Respiratory and allergic healy-th effects of dampness, mold, and dampness-relatied agents : a review of the epidemiologic evidence. Envir Health Prespect 2011;119:748-56.

Michel O, Bakkioui H, Hankard D, Chawaf J, Higuet S, Rosseuw C et al. Prevalence of non-diagnosed asthma in schoolchildren of low socio-economic status in Brussels. Am J Respir Crit Care Med 1999;159:A145.

MMK - Medische Milieu Kundige. Available from: URL:<http://www.mmk.be>

Moularat S, Robine E, Ramalho O, Oturan MA. Detection of fungal development in closed spaces through the determination of specific chemical targets. Chemosphere 2008:224–32.

Murray CS, Woodcock A, Custovic A. The role of indoor allergen exposure in the development of sensitization and asthma. Curr Opin Allergy Clin Immunol 2001;1:407-12.

Nevalainen A, Seuri M. Of microbes and men. Indoor Air 2005;15:58–64.

O'Driscoll BR, Hopkinson LC, Denning DW. Mold sensitization is common amongst patients with severe asthma requiring multiple hospital admissions. BMC Pulm Med 2005;5:4.

O'Hollaren MT, Yunginger JW, Offord KP, Somers MJ, O'Connell EJ, Ballard DJ et al. Exposure to an aeroallergen as a possible precipitating factor in respiratory arrest in young patients with asthma. N Engl JMed 1991;324:359-63.

Päivi MS, Arbes SJ, Sever M, Jaramillo R, Cohn RD, London SJ et al. Exposure to Alternaria alternata in US homes is associated with asthma symptoms. J Allergy Clin Immunol 2006;4:892-98.

Park JH, Cox-Ganser JM. Mold exposure and respiratory health in damp environments. Frontiers in Bioscience 2011;3:757-71.

Pasanen AL. A Review: Fungal Exposure Assessment in Indoor Environments. Indoor Air 2001;11:87-98.

Pitkäranta M, Meklin T, Hyvärinen A, Paulin L, Auvinen P, Nevalainen A et al. Analysis of fungal flora in indoor dust by ribosomal DNA sequence analysis, quantitative PCR and culture. Applied and Environmental Microbiology 2008;74(1):233-244.

Platts-Mills TA, Vervloet D, Thomas WR, Aalberse RC, Chapman MD. Indoor allergens and asthma: Report of the Third International Workshop. Journal of Allergy and Clinical Immunology 1997;6:1-24.

Raja YXu, Ferro AR, Jaques PA, Hopke PK. Resuspension of indoor aeroallergens and relationship to lung inflammation in asthmatic children. Environment International 2010; 36:8-14.

Reboux G, Bellanger AP, Roussel S, Grenouillet F, Sornin S, Piarroux R et al. Indoor mold concentration in Eastern France. Indoor Air 2009;19:446–53.

Reboux G. Mycotoxins: health effects and relationship to other organic compounds. Revue française d'allergologie et d'immunologie clinique 2006;46:208-12.

Reynolds KA, Wattb P, Boonea SA, Gerbaa CP. Occurrence of bacteria and biochemical markers on public surfaces. International Journal of Environmental Health Research 2007;3:225-34.

Rintala H, Pitkäranta M, Toivola M, Paulin L, Nevalainen A. Diversity and seasonal dynamics of bacterial community in indoor environment. BMC Microbiology 2008;8:56.

Royal Decree of August 4 1996. Concerning the protection of workers from risks related to exposure to biological agents at work. Belgian Official Journal of 01.10.1996 - p. 25285.

Salo PM, Zeldin DC. Does exposure to cats and dogs decrease the risk of developing allergic sensitization and disease? Journal of Allergy and Clinical Immunology 2009;124:751-52.

Sami-Lux. Qualité de l'environnement intérieur dans les écoles fondamentales de la province de Luxembourg – Rapport final, 2010.

Schenkelberger V, Freitag M, Altmeyer P. Ficus benjamina – the hidden allergen in the house. Hautarzt 1998;49:2-5.

Straus DC. Molds, mycotoxins, and sick building Syndrome. Toxicology and Industrial Health 2009;25:617–35.

Strom PF. Identification of thermophilic Bacteria in solid-waste composting. Environmental Microbiology 1985:906-13.

Stryjakowska-Sekulska M, Piotraszewska-Pająk A, Szyszka A, Nowicki M, Filipiak M. Microbiological Quality of Indoor Air in University Rooms. Polish J of Environ Stud 2007;16:623-32.

Taubel M, Sulyok M, Vishwabath V, Bloom E, Turunen M, Jarvi K et al. Co-occurrence of toxic bacterial and fungal secondary metabolites in moisture-damaged indoor environments. Indoor Air 2011;21:368–75.

Technische Verslag voor woningen. 2013. Available from: URL:<https://www.wonenvlaanderen.be/ondersteuning_voor_professionelen/woningkwaliteit_voor_professionelen/technische_verslagen_over_woningkwaliteit?f03f25ee475a65ab2bbbec6bae9205efa65a581e=d7lup8s4932jf31psmm0jl82f2>

The Health Council of the Netherlands. Endotoxins - Health-based recommended occupational exposure limit. The Hague; Health Council of the Netherlands 2010.

Tischer Ch, Chen Ch, Heinrich J. Association between Domestic Mould and Mould Components,and Asthma and Allergy in Children: A Systematic Review. ERJ Express 2011.

Tsai FC, Macher JM, Hung Y-Y. Concentrations of Airborne Bacteria in 100 United States Office Buildings. Proceedings of Indoor Air 2002,353-58.

Van Emon JM, Reed AW, Yike I, Vesper SJ. ELISA measurement of stachylysin in serum to quantify human exposures to the indoor mold Stachybotrys chartarum. J Occup Environ Med 2003;45:582-91.

Van Lynden-Van Nes AM, Koren LG, Snijders MC, Van Bronswijk EM. Medical Impact of Arthropod Allergens. Proceedings of the 2nd International Conference of Insect Pests in the Urban Environment. Ed. Wildey KB. - Exeter: Wheatons 1996.

Vojta PJ, Friedman W, Marker DA, Clickner R, Rogers JW, Viet SM et al. First National Survey of Lead and Allergens in Housing: Survey Design and Methods for the Allergen and Endotoxin Components. Environmental Health Perspectives 2002;110:527–32.

WHO - World Health Organization. Dampness and Mould. WHO Guidelines for Indoor Air Quality. 2009 p. 228.

Wood RA, Kim BS, Mudd E, Peyton MD, Eggleston A. The distribution of cat and dust mite allergens on wall surfaces. Journal of Allergy and Clinical Immunology 1992;1:126-30.

Zureik M, Neukirch C, Leynaert B, Liard R, Bousquet J, Neukirch F. Sensitisation to airborne moulds and severity of asthma: cross sectional study from European Community respiratory health survey. BJM 2002;325.

Radon in indoor air in Belgium

90/143/EURATOM. Commission Recommendation on the protection of the public against indoor exposure to radon. Official Journal of the European Communities 1990; 80:26-28.

96/29/EURATOM. Council Directive of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation. Official Journal of the European Communities 1996;L314.

2001/928/EURATOM. Commission Recommendation of 20 December 2001 on the protection of the public against exposure to radon in drinking water supplies. Official Journal of the European Communities 2001;L344.

2013/59/EURATOM Council Directive of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom. Official Journal of the European Union 2014; L13.

Baysson H, Tirmarche M, Tymen G, Gouva S, Caillaud D, Artus J-C et al. Indoor radon and lung cancer in France. Epidemiology 2004;15:709-16.

BEIR IV – Committee on Health Risks of Exposure to Radon. Health risks of radon and other initially deposited alpha-emitters. US National Research Council Report 1988; National Academy Press, Washington DC.

Belgian cancer registry. Statistics, tables on yearly basis. Available from: URL:<http://www.kankerregister.org/>

B-NORM. Kennisverspreiding over de problematiek van natuurlijk voorkomende radioactiviteit in bouwmaterialen. NuTec Publication 2013;1-118.

Darby S, Hill D, Auvinen J, Barros-Dios JM, Baysson H, Bochicchio et al. Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies. Br Med J 2005;330:1-223.

FANC – Federaal Agentschap voor Nucleaire Controle. Besluit houdende de vaststelling van radon risicozones op Belgisch grondgebied van 10 augustus 2011. BS. van 15 september 2011.

IARC – International Agency for Research on Cancer. Monographs on the Evaluation of Carcinogenic Risks to Humans Man-made Mineral Fibres and Radon. IARC Press, Lyon 1988;43.

ICRP – International Commission on Radiological Protection. Lung cancer risks from indoor exposures to radon daughters. ICRP 1987;17:1.

ICRP – International Commission on Radiological Protection. Recommendations of the International Commission on Radiological Protection. IRCP Publication 60, Pergamon Press, Oxford 1991.

ICRP - International Commission on Radiological Protection. Protection Against Radon 222 at Home and at Work. ICRP Publication 65, Pergamon Press, Oxford 1993.

ICRP - International Commission on Radiological Protection. Recommendations of the International Commission on Radiological Protection. Protection of the public in situations of prolonged radiation exposure. IRCP Publication 82, Pergamon Press, Oxford 2000.

ICRP – International Commission on Radiological Protection. The 2007 Recommendations of the International Commission on Radiological Protection. IRCP Publication 103, Pergamon Press, Oxford 2007.

ICRP – International Commission on Radiological Protection. Lung cancer risk from radon and progeny and statement on radon. IRCP Publication 115, Pergamon Press, Oxford 2010.

Krewski D, Lubin JH, Zielinski JM, Alavanja M, Catalan, VS, Field RW et al. Residential radon and risk of lung cancer: a combined analysis of 7 North American case-control studies. Epidemiology 2005;16:137-45.

Lubin JH, Wang ZY, Boice JD, Xu ZY, Blot WJ, Wang LD et al. Risk of lung cancer and residential radon in China: pooled results of two studies. Int J Cancer 2004;109:132-37.

Poffijn A, Vanmarcke H. The Indoor Radon Problem in Belgium. In: Indoor Air Quality and Ventilation 1990;Selper Ltd:339-45.

Radiation Protection 88. Recommendations for the implementation of Title VII of the European Basic Safety Standard Directive (BSS) concerning significant increase in exposure due to natural radiation sources. Luxemburg 1997.

UNSCEAR - United Nations Scientific Committee on the Effects of Atomic Radiation. Rapport to the General Assembly. United Nations 2000.

UNSCEAR - United Nations Scientific Committee on the Effects of Atomic Radiation. Sources-to-effects assessment for radon in homes and workplaces. United Nations sales publication 2009; Volume II: E.09.IX.5.

Vanmarcke H, Poffijn A, Raes F, Eggermont G, Uyttenhove J, Berkvens P et al. Radon in het leefmilieu. Annals of the Belgian Association for radiation protection 1988;13:33-56.

WHO - World Health Organization. Handbook on indoor radon: a public health perspective. WHO; Geneva 2009.

Zhu HC, Charlet JM, Tondeur F. Geological Controls to the Indoor Radon Distribution in Southern Belgium. The Science of the Total Environment 1998;220:195-214.

Zhu HC. La cartographie des zones à risque en radon dans les habitations. Rapport final de la convention cartographie-radon du 1-1-2001 au 31-3-2001. Faculté Polytechnique de Mons 2001;1-107.

VI. APPENDICES

Annex 1. References table 9

A review of the emission of VOCs from polymeric materials used in buildings. Building and Environment 1998;33:357-74.

Adhesives. Short term method for measuring the emission properties of low-solvent or solvent-free adhesives after application - Part 4: determination of volatile diisocyanates. 2003. NBN ENV 13999-4.

AFSSE - Agence Francaise de Sécurité Sanitaire Environnementale. Caractérisation des émissions de COV et de formaldéhyde par six produits de construction. 2005.

AgBB - Ausschuss zur gesundheitlichen Bewertung von Bauprodukten. Health-related Evaluation of Emissions of Volatile Organic Compounds (VVOC, VOC and SVOC) from Building Products. 2012.

AGÖF - Arbeitsgemeinschaft Ökologischer Forschungsinstitute. Guidance Values for Volatile Organic Compounds in Indoor Air. 2008.
Available from: agoef.de/agoef/oewerte/orientierungswerte_englisch.html.

ANSI/BIFMA – American National Standards Institute / Business + Institutional Furniture Manufacturers Association. Standard test method for determining VOC emissions from office furniture systems, components and seating. M 7.1. 2011.

Bepalen van criteria inzake kamerbrede vloerbedekkingsproducten in kinderdagverblijven en crèches op basis van risico-analyse met betrekking tot de gezondheidsimpact op kinderen. Study ordered by the Federal Public Service of Health, Food Chain Safety and Environment. VITO & BBRI.

Blondel A, Plaisance H. Screening of formaldehyde indoor sources and quantification of their emission using a passive sampler. Building and Environment 2011;46:1284-91.

Boor B, Järnström H, Xu Y, Novoselac A. Identification of VOCs, Phthalates, and Isocyanates in Crib Mattresses. Healthy Buildings 2012;2:1579-80.

Building material emissions study. Integrated Waste Management Board. 2003.

BUMA – Building Materials. Prioritizitation of BUilding MAterials as indoor pollution sources. Available from: URL:<http://www.uowm.gr/bumaproject/>.

Burdack-Freitag A, Mayer F, Breuer K. Identification of odor-active organic sulfur compounds in gypsum products. Clean 2009;37:459-65.

Construction products - Assessment of release of dangerous substances - Determination of emissions into indoor air 2013. CEN/TS 16516.

COST E49. Processes and Performance of Wood-Based Panels. 2007.

Däumling C. Product evaluation for the control of chemical emissions to indoor air - 10 years of experience with the AgBB scheme in Germany. Clean - Soil, Air, Water 2012;40:779-89.

Destaillats H, Maddalena R, Singer B, Hodgson A, McKone T. Indoor pollutants emitted by office equipment: A review of reported data and information needs. Atmospheric Environment 2008;42:1371-88.

Determination of VOC emissions from French wood products. 4th European Wood-Based Panel Symposium. Hanover; Germany 2004.

Dong Hwa K, Dong Hee C, Doyun W, Wenping Y, Schleibinger H, Jacinthe D. Household materials as emission sources of naphthalene in Canadian homes and their contribution to indoor air. Atmospheric Environment 2012;9:79.

Ehrnsperger R, Misch W. Implementation of health and environmental criteria in technical specifications for construction products. UBA 2005.

EOTA – European Organisation for Technical Assessment. TR34 - General ER 3 Checklist for ETAGs/CUPAs/ETAs-Content and/or release of dangerous substances in products/kits.2012. Available from: URL:< http://www.eota.eu/en-GB/content/technical-reports/11/>.

EPHECT database BUMAC.

FCBA - Institut Technologique Forêt Cellulose Bois-construction Ameublement. Détermination de l' émission de composés volatils à partir de produits de construction. 2006.

Greenguard methods GGTM P040, P057, P058, P066, P072. Available from: URL:<http://www.greenguard.org/en/CertificationPrograms/CertificationPrograms_certificationProcess/CertificationPrograms_testingProcedures.aspx>.

Gunnarsen L, Kolarik B. PCB in sealant, concrete, paint and lacquer 40 years after use of sealant with PCB - Calculation of total remaining mass in a contaminated dwelling. Healthy Buildings 2012;2.

Hague J, Mann R, Reilly M, Ryan G, Young S. A review of the potential impact of VOC emissions on the future market share for engineered wood products. Forest and Wood Products Australia 2009.

Horn W, Jann O, Kasche J, Bitter F, Müller D, Müller B. Environmental and health provisions for building products – Identification and evaluation of VOC emissions and odour exposure. UBA 2007.

IFA - Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung. Liste der kreberzeugenden, mutagenen und reproduktions-toxischen Stoffe (KMR-Liste).

Indoor Environment - Airborne particles and settled dust. Wiley online Library, 2003.

Influence of Air Fresheners on the Indoor Air Quality. Study ordered by the Federal Public Service of Health, Food Chain Safety and Environment 2006.

Jann O, Rockstroh J, Wilke O, Noske R, Brödner D, Schneider U, Horn W. Development of a Test Method for an Investigation into Limiting the Emissions from Printers and Copiers within the Framework of Assigning the Environmental Label. UBA 2004.

Järnström H, Saarela K, Kalliokoski P, Pasanen A. Reference values for indoor air pollutant concentrations in new, residential buildings in Finland. Atmospheric Environment 2006;40:7178-191.

Järnström H, Saarela K, Kalliokoski P, Pasanen A. Reference values for structure emissions measured on site in new residential buildings in Finland. Atmospheric Environment 2007;41:2290-302.

Järnström H, Saarela K, Kalliokoski P, Pasanen A. Comparison of VOC and ammonia emissions from individual PVC materials, adhesives and from complete structures. Environment International 2008;34:420-27.

Järnström H, Saarela K, Kalliokoski P, Pasanen A. The impact of emissions from structures on indoor air concentrations in newly finished buildings: predicted and on-site measured levels. Indoor and Built Environment 2008;17:313-23.

Jensen AA. Hexabromocyclododecane (HBCDD) - A Flame Retardant Used in Polystyrene Insulation Products - Emissions, Exposures and Impacts. Healthy Buildings 2012.

JRC – Joint Research Center. Harmonisation framework for indoor products labelling schemes in the EU. ECA report 27. 2012.

Katsoyiannis A, Leva P, Kotzias D. VOC and carbonyl emissions from carpets: a comparative study using four types of environmental chambers. Journal of Hazardous materials 2008;152:669-76.

Key international chemical emissions, labeling and IAQ programs for building materials & products. Air Quality Sciences 2012. Availlable from: URL:<http://www.aqs.com/docs/campaigns/click-here-to-download-international-product-emissions-report.pdf>.

Kim S, Kim JA, An JY, Kim HJ, Kim SD, Park JC. TVOC and formaldehyde emission behaviors from flooring materials bonded with environmental-friendly MF/PVAc hybrid resins. Indoor Air 2007;17:404-15.

Kirkeskov L, Witterseh T, Funch LW, Kristiansen E, Mølhave L, Hansen MK et al. Health evaluation of volatile organic compound (VOC) emission from exotic wood products. Indoor Air 2009;19:45-57.

Knudsen H, Clausen P, Wilkins C, Wolkoff P. Sensory and chemical evaluation of odorous emissions from building products with and without linseed oil. Building and Environment 2007;42:4059-67.

Kolarik B, Frederiksen M, Gunnarsen L, Meyer H. The correlation between PCB concentrations in indoor air, sealants and building characteristics in contaminated Danish apartments. Healthy Buildings 2012;6.

Koninkrijk België. Koninklijk besluit van 8 mei 2014 tot vaststelling van de drempelniveaus voor de emissies naar het binnenmilieu van bouwproducten voor bepaalde beoogde gebruiken. BS 18/08/2014.

Lor M, Graindorge F, Piens M, Wolfs L, Remontet P. Highlights of the changing legislation and developments in the field of IAQ and construction material emissions and its VOC challenges for (architectural) coatings. Conference Emissions and odour from materials 2012.

Lor M. HEMICPD state of the art report. 2010. Available from: URL:<http://www.belspo.be/belspo/fedra/proj.asp?l=en&COD=P2/05>.

Meeting the challenge of reducing VOC product emissions: a 20 year review. Indoor Air 2011.

Kemmlein S, Hahn O, Jann O. Emission of flame retardants from consumer products and building materials. BAM 2003.

Nazaroff W, Weschler C. Cleaning products and air fresheners: exposure to primary and secondary air pollutants. Atmospheric Environment 2004;38:2841-65.

Nederlandse Gezondheidsraad. Advies inzake Het Binnenhuisklimaat, in het bijzonder het ventilatieminimum, in Nederlandse woningen. Den Haag Gezondheidsraad 1984; 1984/01

NRC - National Research Council Canada. Investigation of building materials as VOC sources in indoor air. Workshop on Construction Technologies 2004:173-80.

Organic Indoor Air pollutants, Second completely revised edition. Wiley online Library 2007.

Paints and Varnishes - Assessment of emissions of substances from coatings into indoor air - Sampling, conditioning and testing 2013. EN 16402.

Poulhet G, Dusanter S, Crunaire S, Locoge N, Gaudion V, Merlen C et al. Investigation of formaldehyde sources in French schools. Healthy Buildings 2012.

Resilient, textile and laminate floor coverings — Test method for volatile organic compound (VOC) emissions. 2010. ISO 10580.

Rheinberger U, Bunke D. Safe construction products for health and the environment: how much testing is necessary to implement the EC Construction Products Directive. UBA 2007.

Roffael E. Volatile organic compounds and formaldehyde in nature, wood and wood based panels. Holz als Roh- und Werkstoff 2006;64:144-9.

Salthammer T, Mentese S, Marutzky R. Formaldehyde in the indoor environment. Chemical Reviews 2010;110:2536–72.

Salthammer T, Schwarz A, Furhmann F. Emissions of reactive compounds and secondary products from wood-based furniture coatings. Atmospheric Environment 1999;33:75-84.

Scherer C, Mair S, Mayer F, Breuer K. Mineral Mortars, Plasters, and Screeds – A Survey of VOC Emission Behaviour. Healthy Buildings 2012.

Spruyt M, Kuske M, Goelen E, Nicolas J. Product policy in the context of the indoor environment quality. Final report 2006.

Triclosan. Canada Gazette 2012:146.

VOC emissions from building components. International Rosenheim Window & Façade Conference. 2010.

Wensing M, Uhde E, Salthammer T. Plastics additives in the indoor environment - flame retardants and plasticizers. Sci Total Environ 2005;339:19-40.

Weschler C. Changes in indoor pollutants since the 1950s. Atmospheric Environment 2009;43:153-269.

Wilke O, Jann O, Brödner D. Untersuchung und Ermittlung emissionsarmer Klebstoffe und Bodenbeläge. UBA 2003.

Wilke O, Jann O, Brödner D. VOC- and SVOC- emissions from adhesives, floor coverings and complete floor structures. Indoor Air 2004;14:96-105.

Wilke O, Horn W, Wiegner K, Jann O, Bremser W, Brödner D, Kalus S, Juritsch R, Till C. Investigations for the improvement of the measurement of volatile organic compounds from floor coverings within the health-related evaluation of construction products. BAM 2009.

Wilke O, Wiegner K, Jann O, Brödner D, Scheffer H. Emission behaviour of wood and materials produced from wood. BAM 2012.

Willem H, Singer B. Chemical Emissions of Residential Materials and Products: Review of Available Information. Ernest Orlando Lawrence Berkely National Laboratory 2010.

Witterseh T. Emissions of chemical substances from products made of exotic wood. Danish Technological Institute 2004;49.

Wolkoff P, Nielsen GD. Organic compounds in indoor air - their relevance for perceived indoor air quality? Atmospheric Environment 2001;35:4407-17.

Annex 2.

In Fungal contamination in public buildings: a guide to recognition and management, Ontario, 1995

p. 59/60: **Indoor Air Quality in Office Buildings: A Technical Guide, Health Canada, 1993**

5.2.8.4 Interpretation of Results.

Since 1989, the ACGIH Bioaerosols Committee has recommended rank order assessment as a means of interpreting air sampling data. This interpretation has been part of the practice in Government of Canada investigations since 1986.

The presence of one or more species of fungi indoors, but not outdoors, suggests the presence of an amplifier in the building. Species identification is critical to the analysis. Because of the problems noted above, numerical guidelines cannot be used as the primary determinant of whether there is a problem. However, numerical data are useful under defined circumstances. Information from a large data set obtained by experienced individuals using the same instrument has practical value. Investigations of more than 50 federal government buildings over several years has resulted in the creation of such a data set. Fungal data from about 600 samples taken between 1986 and 1991 with a Reuter centrifugal sampler with a 4-minute sampling time have been used to prepare the interpretation notes shown below. Data acquired with other samplers require similar analysis. However, if a 4-minute sampling time is used, the numerical data from any proprietary sampler will probably be comparable.

1. Significant numbers of certain pathogenic fungi should not be present in indoor air (e.g., *Aspergillus fumigatus*, *Histoplasma*, and *Cryptococcus*). Bird or bat droppings in air intakes, ducts or rooms should be assumed to contain these pathogens. Action should be taken accordingly. Some of these species cannot be measured by air sampling techniques.
2. The persistent presence of significant numbers of toxigenic fungi (e.g., *Stachybotrys atra*, toxigenic *Aspergillus*, *Penicillium*, and *Fusarium* species) indicates that further investigation and action should be taken accordingly.
3. The confirmed presence of one or more fungal species occurring as a significant percentage of a sample in indoor air samples and not similarly present in concurrent outdoor samples is evidence of a fungal amplifier.
4. The “normal” air mycoflora is qualitatively similar and quantitatively lower than that of outdoor air. In federal government buildings, the 3-year average has been approximately 40 CFU/m³ for *Cladosporium*, *Alternaria*, and non-sporulating basidiomycetes.
5. More than 50 CFU/m³ may be reason for concern if there is only one species other than *Cladosporium* or *Alternaria* present. Further investigation is necessary.
6. Up to 150 CFU/m³ is acceptable if there is a mixture of species reflective of the outdoor air spores. Higher counts suggest dirty air filters or other problems.
7. Up to 500 CFU/m³ is acceptable in summer if the species present are primarily *Cladosporium* or other tree and leaf fungi. Values higher than this may indicate failure of the filters or contamination in the building.
8. The significant presence of fungi in humidifiers and diffuser ducts and on mouldy ceiling tiles and other surfaces requires investigation and remedial action regardless of the airborne spore load.
9. There are certain kinds of fungal contamination not readily detectable by the methods discussed in this report. If unexplained SBS (sick building syndrome) symptoms persist, consideration should be given to collecting dust samples with a vacuum cleaner and having them analysed for fungal species.

VII. COMPOSITION OF THE WORKING GROUP

The composition of the Committee and that of the Board as well as the list of experts appointed by Royal Decree are available on the following website: composition and mode of operation.

All experts joined the working group ***in a private capacity***. Their general declarations of interests as well as those of the members of the Committee and the Board can be viewed on the SHC website (site: conflicts of interest).

The following experts were involved in drawing up and endorsing this advisory report. The working group was chaired by **Eddy GOELEN**; the scientific secretary was Marleen VAN DEN BRANDE.

BLADT Sandrine	Microbial pollutants	IBGE/BIM
BOULAND Catherine	Microbial pollutants	ULB
CASIMIR Georges	Microbial pollutants	HUDERF
CHASSEUR Camille	Microbial pollutants	WIV-ISP
CHARLIER Corinne	Chemical pollutants	ULg
DE BROUWERE Katleen	Chemical pollutants	VITO
DEHANDSCHUTTER Boris	Radon	FANC
DEWOLF Marie-Christine	Microbial pollutants	Hygiène Publique en Hainaut
DINNE Karla	Microbial pollutants	WTCB
GOELEN Eddy	Chemical pollutants	VITO
KUSKE Martyna	Microbial pollutants	Observatoire de la Santé de la Province du Luxembourg
LOR Marc	Chemical pollutants	VITO
MICHEL Olivier	Microbial pollutants	ULB
POFFIJN André	Radon	FANC
ROGER Marc	Microbial pollutants	Hainaut Vigilance Sanitaire
ROMAIN Anne-Claude	Chemical pollutants	ULg
STRANGER Marianne	Chemical pollutants	VITO
STEURBAUT Walter	Chemical pollutants	UGent
VANMARCKE Hans	Radon	SCK

The standing working group Chemical Agents has endorsed the advisory report. The standing working group was chaired by **Luc HENS**; the scientific secretary was Marleen VAN DEN BRANDE.

ADANG Dirk	Health and environment	UCL
HEILIER Jean-François	Ecotoxicology	SPW
HENS Luc	Human ecology	VITO
HOLSBEEK Ludo	Risk assessment, pesticides	LNE
PASSCHIER Wim	Environmental health risk assessment	Maastricht University
SCHIFFERS Bruno	Biocides and pesticides	ULg
STEURBAUT Walter	Human exposure	UGent
VAN LAREBEKE Nicolas	Toxicoloy, cancer	UGent
VANHOOREN Hadewijch	Health and environment, occupational and environmental toxicology	KULeuven
VERSTEGEN Geert	Toxicology	Belgian Poison Centre

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Au sujet du Conseil Supérieur de la Santé (CSS)

Le Conseil Supérieur de la Santé est un organe d'avis fédéral dont le secrétariat est assuré par le Service Fédéral Santé publique, Sécurité de la Chaîne alimentaire et Environnement. Il a été fondé en 1849 et rend des avis scientifiques relatifs à la santé publique aux ministres de la Santé publique et de l'Environnement, à leurs administrations et à quelques agences. Ces avis sont émis sur demande ou d'initiative. Le CSS s'efforce d'indiquer aux décideurs politiques la voie à suivre en matière de santé publique sur base des connaissances scientifiques les plus récentes.

Outre son secrétariat interne composé d'environ 25 collaborateurs, le Conseil fait appel à un large réseau de plus de 500 experts (professeurs d'université, collaborateurs d'institutions scientifiques, acteurs de terrain, etc.), parmi lesquels 300 sont nommés par arrêté royal au titre d'expert du Conseil. Les experts se réunissent au sein de groupes de travail pluridisciplinaires afin d'élaborer les avis.

En tant qu'organe officiel, le Conseil Supérieur de la Santé estime fondamental de garantir la neutralité et l'impartialité des avis scientifiques qu'il délivre. A cette fin, il s'est doté d'une structure, de règles et de procédures permettant de répondre efficacement à ces besoins et ce, à chaque étape du cheminement des avis. Les étapes clé dans cette matière sont l'analyse préalable de la demande, la désignation des experts au sein des groupes de travail, l'application d'un système de gestion des conflits d'intérêts potentiels (reposant sur des déclarations d'intérêt, un examen des conflits possibles, et une Commission de Déontologie) et la validation finale des avis par le Collège (organe décisionnel du CSS, constitué de 30 membres issus du pool des experts nommés). Cet ensemble cohérent doit permettre la délivrance d'avis basés sur l'expertise scientifique la plus pointue disponible et ce, dans la plus grande impartialité possible.

Après validation par le Collège, les avis sont transmis au requérant et au ministre de la Santé publique et sont rendus publics sur le site internet (www.hgr-css.be). Un certain nombre d'entre eux sont en outre communiqués à la presse et aux groupes cibles concernés (professionnels du secteur des soins de santé, universités, monde politique, associations de consommateurs, etc.).

Si vous souhaitez rester informé des activités et publications du CSS, vous pouvez envoyer un mail à l'adresse suivante : info.hgr-css@health.belgium.be.

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