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Socio-economic costs of indoor air pollution: A tentative estimation for some pollutants of health interest in France

Guillaume Boulanger[a,*], Thomas Bayeux[a], Corinne Mandin[b], Séverine Kirchner[b], Benoit Vergriette[a], Valérie Pernelet-Joly[a], Pierre Kopp[c]

[a] French Agency for Food, Environmental and Occupational Health and Safety (ANSES), Maisons-Alfort, France
[b] University of Paris-Est, Scientific and Technical Center for Building (CSTB)/Observatory of Indoor Air Quality, Marne-la-Vallée, France
[c] University of Paris-Sorbonne 1, Paris, France

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ABSTRACT

An evaluation of the socio-economic costs of indoor air pollution can facilitate the development of appropriate public policies. For the first time in France, such an evaluation was conducted for six selected pollutants: benzene, trichloroethylene, radon, carbon monoxide, particles ($PM_{2.5}$ fraction), and environmental tobacco smoke (ETS). The health impacts of indoor exposure were either already available in published works or were calculated. For these calculations, two approaches were followed depending on the available data: the first followed the principles of quantitative health risk assessment, and the second was based on concepts and methods related to the health impact assessment. For both approaches, toxicological data and indoor concentrations related to each target pollutant were used. External costs resulting from mortality, morbidity (life quality loss) and production losses attributable to these health impacts were assessed. In addition, the monetary costs for the public were determined. Indoor pollution associated with the selected pollutants was estimated to have cost approximately €20 billion in France in 2004. Particles contributed the most to the total cost (75%), followed by radon. Premature death and the costs of the quality of life loss accounted for approximately 90% of the total cost. Despite the use of different methods and data, similar evaluations previously conducted in other countries yielded figures within the same order of magnitude.

1. Introduction

An evaluation of the socio-economic costs of indoor air pollution can help reveal pollutants, buildings, sources and situations that should be prioritized, thus facilitating the development of appropriate public policies. Nevertheless, extensive evaluations of indoor air pollution have rarely been conducted to date, likely because of the difficulties associated with assessing burden of disease (BOD) values for a large variety of indoor pollutants and exposure situations. In 2005, the California Air Resource Board (CARB) published an initial evaluation of the costs of indoor air pollution in California, US (CARB, 2005). Carbon monoxide (CO), volatile organic compounds (VOCs), environmental tobacco smoke (ETS), radon, mold and sick building syndrome were considered. Indoor pollution was estimated to cost California's economy more than $45 billion each year, with half of this cost attributable to ETS.

Some studies focused on specific indoor pollutants. The annual cost of dampness and mold exposure in the home was estimated to be $3.5 billion per year in the US (Mudarri and Fisk, 2007). In France, Pichery et al. (2011) estimated the annual cost of cognitive and behavioral deficiencies associated with exposure to lead in the home.

Other studies have provided economic evaluations in the context of cost-benefit analyses. Fisk and Rosenfeld (1997) estimated that the potential financial benefits of improving indoor environments exceeded costs by a factor of 18 to 47. The health and productivity benefits of complying with the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) standards were quantified by Dorgan and Dorgan (2000). Wargocki and Djukanovic (2005) compared the annual benefit from increased productivity due to a better indoor air quality, improved by the increase of the air supply rate, to the annual energy and maintenance costs of the heating, ventilation and air-conditioning system in one office building. Similarly Fisk et al. (2011) performed a cost-benefit analysis in office buildings and showed that improving indoor air quality, e.g., increasing ventilation rates and reducing mold and dampness, cost less than the return in benefits from the resulting reductions in sick building symptoms and absenteeism.

* Corresponding author at: French Agency for Food, Environmental and Occupational Health and Safety (ANSES), 14 rue Pierre et Marie Curie, 94701 Maisons-Alfort Cedex, France.
E-mail address: guillaume.boulanger@anses.fr (G. Boulanger).

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Such changes would lead to a benefit of $20 billion annually in the US. Regarding schools, Wargocki et al. (2014) showed that improving indoor air quality through better ventilation, i.e., increased air supply, in Danish schools that do not meet the Danish Building Code requirements would lead to better learning performance and result in yearly increases of €173 million in the gross domestic product (GDP) and €37 million in public finances. Within the HEALTHVENT project, the efficiency of different strategies to reduce indoor exposure to $PM_{2.5}$, outdoor bioaerosols, VOCs, CO, radon, home dampness, and secondhand smoke in the EU-26 was assessed, and the scenarios were compared (Asikainen et al., 2016). The costs and benefits of filtration use have been assessed by several authors (Fisk et al., 2002; Bekö et al., 2008; Aldred et al., 2015).

Other studies have expressed the impacts of indoor air pollution in terms of disability-adjusted life-years (DALYs; the sum of years of life lost as a result of premature death and the years of life spent living with a disease). The DALY calculation is based on: 1) an attributable fraction of exposure or disease associated with the examined risk factor and 2) the national estimates available for the target exposure or disease. Through the European ENVIE project and its follow-up IAIAQ (Jantunen et al., 2011), the health impacts of indoor air pollution within the EU-26 were calculated. Six diseases (asthma, lung cancer, cardiovascular diseases, chronic obstructive pulmonary disease [COPD], upper and lower respiratory infections and acute intoxication) and six groups of associated indoor pollutants (particles, dampness, bioaerosols, radon, CO and VOCs) were considered. The total BOD of indoor air pollution was found to be 2 million DALYs per year within the EU-26. Two-thirds of this BOD was attributable to particles. Examining the European context from a larger scope, the World Health Organization (WHO) assessed the BOD values associated with inadequate housing (Braubach et al., 2011) (i.e., poor indoor air quality resulting from mold and dampness, radon, ETS, lead, CO, formaldehyde and the use of solid fuels for cooking or heating). Still within Europe but on a larger scale, the health impact of benzene, dioxins, secondhand smoke, formaldehyde, lead, traffic noise, ozone, particulate matter ($PM_{2.5}$), and radon represents approximately 3–7% of the annual burden of disease in Belgium, Finland, France, Germany, Italy, and the Netherlands, according to the Environmental Burden of Disease in European Countries Study (EBoDE) (Hänninen et al., 2014). $PM_{2.5}$ was the main pollutant, accounting for 68% of the estimated environmental burden of disease. Schram-Bijkerk et al. (2013) performed a similar study in the Netherlands at the request of Dutch policy makers. The targeted indoor air pollutants included dampness, CO, radon and thoron, formaldehyde and ETS. In the US, Logue et al. (2012) assessed the chronic health impacts of seventy indoor air pollutants measured in American dwellings and calculated a total of 1100 DALYs per year per 100,000 persons. In these studies, the DALYs were not converted into financial costs.

Considering the absence of any evaluation of the socio-economic impacts of indoor air pollution in France, this work aimed to provide an order of magnitude estimate based on existing indoor exposure data for the French population.

2. Materials and methods

2.1. Selected pollutants

A considerable number of pollutants, including chemical, biological, and physical pollutants, are present in indoor environments (Weschler, 2009; World Health Organization, 2010; Logue et al., 2011, 2012). The list of indoor pollutants to be considered was based on: i) the ranking of > 1000 chemical substances that may be present in indoor environments that was initially established by the national Observatory of Indoor Air Quality (OIAQ) (Kirchner, 2011); ii) an international scientific consensus on associated health effects; iii) existing accessible data on the health impacts on the French population or published dose-response relationships for health impact calculations; and iv) existing data on indoor air concentrations at the national level, e.g., data from the national OIAQ, allowing for health impact calculations to be performed when needed.

2.2. Health impact assessment

When the health impact of a given pollutant, i.e., diseases and deaths attributable to indoor exposure to a pollutant, had not been previously assessed in France, this impact was calculated *ad hoc*. Two approaches were used, depending on the nature of the available data. The first method followed the principles of quantitative health risk assessment based on the US National Research Council method (NRC, 1983) and was used when a toxicological reference value (TRV), i.e., an inhalation unit risk, was available. When no TRV was available but a reliable odds ratio or relative risk (RR) was identified in the literature, a second approach based on concepts and methods relating to the health impact assessment approach used in the Aphekom study (Declercq et al., 2012) was used.

For both these approaches, toxicological data and indoor concentrations related to each target pollutant were used. Toxicological data were retrieved from previous reviews and monographs by the French Agency for Food, Occupational and Environmental Health and Safety (ANSES) and from national and international agencies and institutions, while indoor concentrations were measured in dwellings at the national level by the OIAQ housing survey (Kirchner et al., 2007; Kirchner, 2011). In brief, > 30 pollutants were measured for one week (7 days) during 2003–2005 in 567 dwellings randomly selected among the 24 million main residences in France, excluding oversea residences.

In the absence of similar representative data on other indoor settings, such as schools, offices, and leisure spaces in France, the target pollutant concentrations that the French population has been exposed to indoors were assimilated into the concentrations measured in dwellings. Moreover, for this first-tier evaluation, the median indoor concentration in French dwellings was considered for target compounds. The time spent indoors by the French population was considered to constitute 90% of their lifetime (Kirchner, 2011).

In turn, the annual number of premature deaths attributable to indoor exposure to each examined pollutant was calculated when not already available. Furthermore, when not already available, the morbidity of each studied health effect, i.e., the new cases of a disease, was estimated from the mortality / morbidity ratio for this disease multiplied by the calculated (or available) mortality rate of the French population for the given disease. The mortality/morbidity ratio was obtained using data provided by the National Institute for Cancer (INCa), the French Ministry of Health and the French Institute for Public Health Surveillance (InVS).

For each disease, the difference between the average age of death and the life expectancy of the general population (80 years of age (Pison, 2005)) was needed to determine the number of life-years lost. The average age of death for each studied disease was obtained from the Center for Epidemiology on Medical Causes of Death (CepiDC; www.cepidc.inserm.fr). Similarly, the number of life-years with each studied disease was needed; INCa (2007) and World Health Organization (2004) data provided information on the survival times for each disease examined. Finally, when needed, i.e., when using the quantitative health risk assessment method, the number of people in each age category was obtained from the National Institute of Statistics and Economic Studies (INSEE).

Because exposure data, i.e., indoor air concentrations, were obtained through a survey conducted between 2003 and 2005, the reference year for this evaluation was set at 2004. As much as possible, all other collected data were from 2004. Otherwise, figures for the closest years were retrieved and considered attributable to 2004 by default.