# A Methodology to assess economical impacts of poor IAQ in office buildings from DALY and SBS induced costs

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**Abstract.** Indoor air quality is a major issue that concerns everyone. Indeed, human being spend more than 70% of time in indoor environment. Indoor pollutants are responsible for many chronic diseases such as lung cancer or leukaemia, but it also has short-term outcomes, it can cause headache, coughing, running nose, etc, it affects daily concentration and productivity of office workers. Considering the numerous consequences of indoor pollution, a will to quantify induced costs seems logical. In 2003 a study conducted in US concluded a global 41 billion € cost, in France, total cost of indoor pollution for the whole nation was estimated around 19 billion € in 2014. Nonetheless, for an individual person or a whole building, the point of view is not the same, and therefore, integrated costs will differ from those for a nation. This work aims at proposing a methodology to estimate IAQ costs in office buildings, with a function that accounts for pollutants concentration and number of workers. This proposed methodology permits calculation of costs for Disability Adjusted Life Years (DALY). A distinction is made for each individual pollutant cost, accounting for healthcare costs, life years lost and productivity loss. An original part of this work consists in also integrating Sick Building Syndrome (SBS) costs. Preliminary results show a higher cost for SBS compared to DALY.

**Keywords.** Indoor Air Quality, office buildings, economical cost, DALY, SBS.
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## 1. Introduction

People spend more than 70% of their time in indoor environments [1]. Indoor air is often more polluted than outdoor air. Therefore, its preoccupation is of major concern. Long-term exposure to chemical substances may cause chronic diseases with more or less severity, such as, asthma, bronchitis, pneumonia, lung cancer or leukemia… On a short term perspective, it is also responsible for headaches, eyes or nose irritations… Those acute reversible effects are known as Sick Building Syndrome (SBS) [2]. As indoor Air Quality (IAQ) may lead to a need for medical treatment, incapability to work or even loss of productivity, [3,4], there is a financial consequence. Economic impact of indoor air quality has already been studied in the past, globally [5,6,7], in schools [8,9], in residential buildings [10] . As it is a complex task that has a wide range of impacts, choices have to be made to select the various costs as well as a way to quantify their financial impacts, depending on selected point of view (global costs for a nation, building scale or individual costs). Usually, estimations are made from the point of view of a government by associating costs to a general quantity of Disability Adjusted Life Years (DALY) lost. Identified costs are medical costs, life quality lost, research and measurement studies as well as productivity lost. Some studies include willingness to pay. Depending on the studies, a negative cost (gain) can also be included if people die prematurely due to poor IAQ while living at the expense of society (e.g: savings realized by unpaid pensions, insurances for retired or unemployed person). Those previous studies include a complete range of parameters and set the basis of IAQ socioeconomical assessment. Nevertheless, in order to identify specific financial losses for an individual person, a building or a company, methodologies proposed require to be modified. This paper aims at proposing a new complementary approach designed to fulfill these needs in office buildings, applicable both at building or individual scale. Although, the proposed formula can afterward be readapted to the purpose of other building types (schools, dwellings, retirement houses…), this investigation focuses only on office buildings. Indeed, working environment represents a strategic point as well from the time spent inside as for the financial income it is associated to.

In average, people work 1744h per year, which represents 19.9% of their total annual time. This

percentage of time spent in working environment differs lightly from one industrialized country to another, it ranges from 15.5% (Germany) to 25.5% (Mexico), in Belgium, people work 1574h per year(18%) [11]. Any disturbance in working environment could possibly have a significant negative economic impact Those costs impact both workers, companies that employ them and insurances.
This work is part of the project flux50 Smart Ventilation that aims at qualifying ventilation in mid-sized buildings.
In this study, we will start discussing methodologies proposed in the past (available in french or english litterature) as well as a few results published. Then we will explain our new approach based on DALYs lost, and an original aspect that consists in implementing a Sick Building Syndrome (SBS) cost. A set of first results from a dwelling measurement campaign is finally presented before concluding with perspectives and limitations of this actual work.

# 2. Basics of IAQ economics previously established

Unfortunately, the literature rather poor and dated when it comes to assess and quantify costs induced by indoor air quality. This evaluation process is a complex task that requires to make assumptions and proposals. Nevertheless, the work of ANSES [5] propose a complete analysis and identified several costs (medical, research studies and measurements, productivity, …) . They concluded a total cost of 19 billion € per year for the whole French nation.

The methodology used was to quantify all the DALYs lost due to poor indoor air quality by analysing global burden disease (GBD) data and medical costs for various diseases associated to it. Authors also determined a life year cost and a yearly productivity. As they adopt the point of view of a government, all financial fluctuations (positive or negative) are included. For each DALY lost, an annual sum of money is calculated, corresponding to a combination of resources produced by work and pensions paid by government (unemployed or retired, refunding of medical costs by insurances…). If applied consecutively to different types of populations, such chosen parameters may lead to unusual situations. For example, employees having a sickness is considered as a much larger loss to the nation , than people living at its expanses and then dying prematurely, as soon as the sickness decreases worker's productivity. Indeed, second category fluctuations also induce a gain because savings are realized on pensions that should be paid. Even if it remains an objective observation of money incomes and outcomes designed for the purpose of a government it raises ethical questions and is not applicable as it is, to the scale of a building or a person.

A second major contribution in this field is the work of Sherman et al. [6]. In this review study they suggest monetization of DALYs or Health Adjusted Life Years (HALY) as a suitable solution. Including only the cost of a life year, they estimate the value of 150,000US$ per DALY in developed country. In 2005, CalEPA estimated to 41 billion € total IAQ cost in California [12] based on willingness to pay.

DALY calculation is possible as a function of pollutant concentration, therefore it is possible to adapt previous works to evaluate costs induced locally, at building scale.

In the next section, we will explain our method based on DALY cost calculation associated to a SBS cost.

# 3. Calculating indoor quality impacts in office buildings from DALY and SBS induced costs

In this section, we shall propose a way to estimate IAQ cost with a concentration response function in office buildings. Two combined approaches will be used, DALY and Sick Building Syndrome (SBS) costs calculations.

### *3.1 Health impact assessment with DALY approach*

A bad environment can sometimes cause sickness or severe diseases. It is therefore necessary to assess the costs related to health issues. In order to do so, it is first needed to estimate health impact.
An existing approach consists in counting Disability Adjusted Life Years (DALY) lost due to exposure to chemical substance. The unit for this metric is the number of healthy years lost. In the initial formulation [13], two methodologies (depending on available information) are proposed to calculate a dose response function for a large range of chemical species.
The first one is the Intake Incidence Daly (IND) approach (equations (1) &(2)), based on human epidemiologic data.

$$\boldsymbol{DALYs = DALY\ f\ X\ disease\ inc} \quad (1)$$

$$\boldsymbol{disease\ inc = pop\ X\ y0\ X\ (1 - e^{-\beta Cexp})} \quad (2)$$

Where $DALY\ f$ is DALYs lost per incidence, $disease\ inc$ is the disease incidence, y0 is the baseline prevalence of illness per year, β is the coefficient of the concentration change, $Cexp$ is the exposure-related concentration, and pop is the number of persons exposed.
The second approach is the Intake Daly (ID) method that is based on animal toxicological data (equations (3)(4) &(5)) .

$$\boldsymbol{DALYs = \frac{\partial DALY}{\partial intake} X\ intake} \quad (3)$$

$$\frac{\partial DALY}{\partial intake} = \frac{\partial DALY}{\partial intake} c\ X\ AF + \frac{\partial DALY}{\partial intake} nc \quad (4)$$

$$intake = C\ X\ time\ X\ air\ intake\ X\ day \quad (5)$$

Where ∂DALY/∂intake are the cancer *(c)* and noncancer *(nc)* mass intake-based DALY factors, C is the indoor concentration, time is the percentage of time spent in the environment per day, air intake is the volume of air inhaled per day, day is the considered number of day , and AF is the age-dependent adjustment factor for cancer exposure.

### 3.2 DALY cost calculation

To associate DALY to a cost, a cost per DALY has to be determined for each pollutant. In literature, 5 main categories were identified:

- Mortality and life cost
- Medical costs
- Productivity cost
- Research, prevention and regulation costs
- Willingness to pay

In the Flux50 project, we are aiming to define a cost that can be applied at the scale of an individual person or a building, so that each ventilation strategy can be studied independently.

Cost related to willingness to pay, research, prevention and regulation should not be accounted in office buildings.

In a previous socio-economical study, life year (LY) cost was estimated around 115 000€ per year per person [13].

Average national productivity ($P_{cost}$) is estimated around 145 000 € per year per person [5], this value corresponds to average French productivity. When applied individually to a specific building, $P_{cost}$ should be recalculated, based on average employees productivity inside building.

Medical costs vary from one pollutant to another as the diseases induced are also different.

Concerning the productivity cost due to DALY, we consider that the proportion of productivity loss is equal to the life quality loss (e.g, a person suffering a disease that induces a 20% life quality lost, would have a 20% productivity loss). We are conscient that this may induce a bias because some diseases may have a low quality life lost and yet induce a working stop.

Average medical cost per DALY is proposed for studied pollutants [14] in Table **Tab. 1**. For pollutants whose medical cost could not be found, authors arbitrarily selected a cost of 40,000€ (Average + 10,000€ marge).

**Tab. 1** - Medical cost induced by pollutants (€)

| Pollutant | Medical cost (€) |
|---|---|
| Benzene | 46 000 |
| Trichloroethylene | 70 971 |
| Radon | 25 526 |
| PM | 10 402 |
| CO | 1 085 |

Finally DALY cost of a pollutant *i* is the sum of concerned medical cost ($\boldsymbol{H\ cost_i}$), productivity loss ($\boldsymbol{P_{cost}}$) as well as life cost (**$\boldsymbol{LY\ cost}$**), as detailed in equation *(6)*

$$\boldsymbol{Daly\ cost_i = LY\ cost + P_{cost} + H\ cost_i} \quad (6)$$

### 3.3 Calculation of global productivity loss by SBS

Although there is already a productivity loss integrated in the DALY calculation, it is important to also integrate a global productivity loss. Productivity loss associated to DALY cost is due to severe chronic diseases (that will obviously impact working productivity). Nevertheless, a bad environment can cause concentration disturbance and productivity loss without leading to severe diseases. For one person that may suffer severe disease, there may a proportion of other employees who feel uncomfortable and are therefore less efficient at work due to temporary acute effects.

An original part of this study consists in proposing a calculation of SBS cost. Nevertheless, influence of SBS is difficult to assess  numerically since it is an information that mainly comes from questioner. When having an in situ inquiry it is possible to ask the Percentage of Occupants Presenting at least 1 (SBS) Symptom in a persistant way (from 1 to 3 days a week) during the last 4 weeks (POPS) or at least 2 symptoms (POPS2). A correlation was proposed [16] between POPS and IAPI [17] index as well as another one between POPS2 and IEI [18].

$$\boldsymbol{Mean\ IAPI = 0.25 \times Mean\ POPS - 14.3} \quad (7)$$

$$\boldsymbol{Mean\ IEI = 0.30 \times Mean\ POPS2 - 14.6} \quad (8)$$

Productivity loss for POPS is assumed to be twice lower than productivity loss for POPS2. Therefore, cost due to SBS can be estimated as follows.

$$\boldsymbol{SBS_{cost} = P_{cost} \times \left[ (P_{loss} \times POPS2) + \left( \frac{P_{loss}}{2} \times (POPS - POPS2) \right) \right]} \quad (9)$$

By reusing equations *(7)* and *(8)*, we can write:

$$SBS_{cost} = P_{cost} \times P_{loss}\left(\frac{IEI + 14.6}{0.60} + \frac{IAPI + 14.3}{0.5}\right) \times \frac{2}{5} \quad (10)$$

As POPS and POSPS2 describes persisting symptoms as occurring from 1 to 3 times a week, a coefficient of $\frac{2}{5}$ was added to ponderate Productivity loss and consider it occurs 2 days in working week of 5 days. As IEI is dependant of IAPI (equation (11) ),

$$IEI = \frac{IAPI + IDI}{2} \quad (11)$$

*SBS cost* is finally calculated as described in equation *(12)*.

$$SBS_{cost} = P_{cost} \times P_{loss}(0.83 + 2.83IAPI + 0.83IDI) \times \frac{2}{5} \quad (12)$$

Productivity decrease due to SBS in office buildings is assumed to be 6% for POPS2 and 3% for POPS, which is relevant with findings of Wargocky et al. [3]

### 3.4 Global cost

Finally, to assess global cost due to IAQ in office buildings, we sum DALY and SBS as described in equation *(13)*

$$IAQ_{Cost} = \sum_{i}^{p} Daly_i \times Daly\ cost_i + SBS_{cost} \quad (13)$$

This solution proposes a cost per year per employee with a dose-response function. In order to estimate costs in an entire building, simply multiply per number of employees in the building.

## 4. Results and discussion

As authors did not have access to office measurement campaign, the proposed methodology was applied to values of dwelling measurement campaign conducted from 2003 to 2005 in France [19]. For lack of better, assumption is made that concentration levels have same order of magnitude in dwellings and offices. Estimated costs per year and per person for each pollutants studied, total DALYs cost, SBS cost and total cost are presented in Fig. **1**.

Concerning pollutants, we notice that Acetaldehyde, Benzene, Styrene, Tetrachloroethylene, Toluene, Trichloroethylene and Xylenes have a maximum value lower than 5€/year/person which is relatively low compared to Formaldehyde, Acrolein and PMs. As expected, cost induced by PMs is major when measured (91% of total DALY). Total DALY cost ranges from 0.07 to 3,200€/year/person because PMs are not measured in every situation. Costs related to DALYs are relevant with literature although PMs importance is higher than results obtained by ANSES[5]. This can be explained by the fact that their study include a negative cost of 136.5 billion euros for this pollutant because of unpaid pensions (65,3% of total gains), which considerably lowers the impact of PMs.

SBS cost ranges from 1,300 to 2,900€/year/person. Average (2,300€) value is higher than for any other category. This first value tends to prove the importance of considering SBS in future works.

Total costs ranges from 1,842 to 6,300€/year/person in office buildings. Even if the data originates from a dwelling measurement campaign, costs assessed in this study are relevant enough to be applied to office purpose (SBS function is limited by 2 extremities). Total cost is impacted mainly by daily productivity decrease reported from SBS (50,5%), followed by DALY cost of PM (45,5%).

All costs included, and with the selected parameters, one DALY costs 265,250€ in average.

## 5. Discussion, limitations and perspectives

The methodology proposed in this document allows quantification of costs induced by indoor air quality issues in building offices by including medical costs, life year costs and productivity costs associated to DALY lost as well as acute SBS costs. This solution is designed to be used at the scale of an individual person or a whole building.

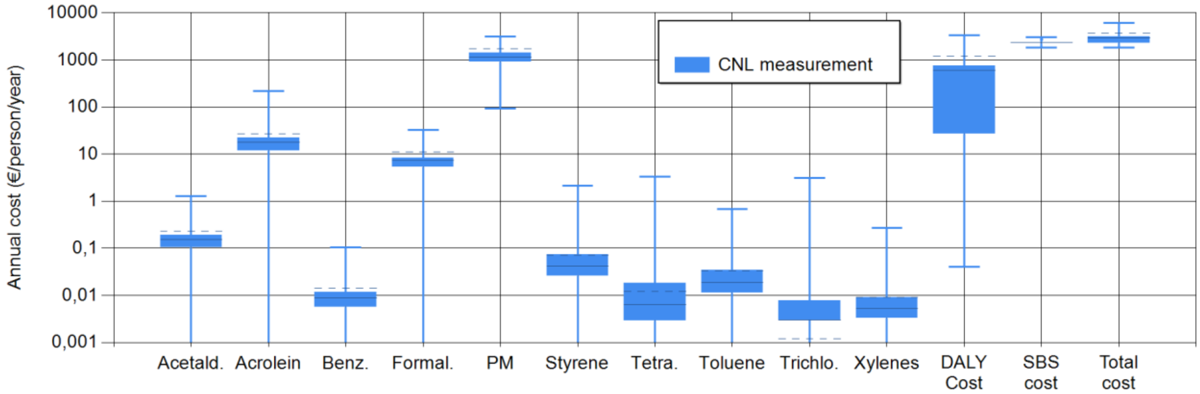


**Fig. 1** - Estimated costs of indoor air quality in France, for major pollutants, DALY and SBS cost.

### *5.1 Discussion*

Assessment of costs obtained in this work show that indoor air quality has a very important economical. Therefore, taking special precautions to improve IAQ is a major issue that could directly profit to everyone. Similar conclusions were found in previous studies [3,20,21]. In worst situations we estimate the possibility to reach 3000€/year/person of benefit.
This methodology can be applied to various cases and most parameters can be adapted to the context of a specific study. With more detailed information (medical insurance cover rate, company insurance rate, salary, company policies…), a further step would be to differentiate resulting costs by the category of population they directly impact. A company will be impacted by SBS cost and maybe a part of DALYs if it has to pay for a part of absent while sick employee salary. A worker will be impacted by a varying part of DALYs (productivity used must be replaced by perceived salary), depending on his/her health insurance covering for medical costs and maybe a part of SBS if revenues are not only a fixed salary, but also productivity related.

### *5.2 Limitations of the study*

Some of the assumptions made induce limitations.
Although results obtained are expressed by €/year/person, if the methodology is applied to a small scale sample, results may highly differ from reality. Indeed, all parameters are estimated from statistical values which means that every costs are pondered by their probability of occurrence and passed on every one. In reality, costs will differ highly from one individual to another, depending on his constitution, resilience, type of work done…
As explained earlier, percentage of productivity decrease related to DALY is assumed to be proportional life quality lost. Nevertheless, in some situations, a disease may result to a work interruption whereas life quality lost remains lower. Therefore DALY cost might be underestimated by this bias.
Data used to produce results is from 17 years old measurement campaign. It may be possible that a more recent measurement campaign would show lower concentration levels.

### *5.3 Perspectives of this work*

The methodology proposed in this study is a further step to assessment of economic impact of indoor air quality, yet, it remains a proposal that can be improved.
With better knowledge, medical costs associated to each pollutant can be refined (diseases and their incidence, up to day costs…), as well as the associated productivity lost.
It could be possible to establish new correlations more accurate between SBS and objective measurements.
More studies conducted about productivity lost at work due to IAQ would refine the productivity decrease parameters used.

### *5.4 Future works*

This study was conducted in the frame of Flux50 Smart ventilation project. The objective of this project is to qualify ventilation in mid-sized buildings accounting for various aspects. Buildings studied are not limited to offices. Therefore, this methodology will be readapted to fit purposes of residential buildings, retirement houses and schools.
A simulation based on a coupling between CONTAM and TRNSYS softwares is currently being developed, accordingly to procedure described in work form Cony [22], to produce transient concentration files for all types of buildings.
As IAQ is not the only included field in this project, members of the project are actually collaborating to extend this methodology and adapt it to all concerned categories (acoustic comfort, sleep quality, hygrothermal comfort and user satisfaction, resilience, installation and maintenance costs as well as energy consumption).

## 6. Conclusion

This work proposes a new complementary approach to estimate IAQ costs in office for individual person or building scale. An original aspect of this study is to include SBS costs corresponding to the global population suffering reversible acute effects that lightly (but daily) impact work productivity.
Result obtained for DALY cost are relevant with results found in literature. Importance of PMs (1,150€/year/person in average) remains major as they account for a majority of DALYs (around 90%). Economic impact induced by SBS (2,300€/year/person in average) appears to be even higher than health impact. All costs included, authors estimate that one DALY costs 265,250€ in average. Higher preoccupation of IAQ issues in building conception and refurbishment is once again confirmed to be of major importance.

## 7. Acknowledgement

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