General economic indicator for performance assessment of smart ventilation systems

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SUMMARY

In the frame of the project Flux50 smart ventilation, researchers and industrials aim at qualifying ventilation in mid-sized buildings through multidisciplinary consideration of sleep quality, user satisfaction, acoustic comfort, installation, maintenance, resilience and indoor air quality. As those factors may impact at different levels it is important to select a common metric for evaluation. Assessment of financial costs induced by the various categories will be used in that purpose. The major complexity of this task relies on identification and objective evaluation of each separate cost at building or individual scale. Identified impacts are divided into two categories, hard costs and soft costs. The first one include material, maintenance, operation and installation costs while the second gathers medical costs, productivity lost, learning disturbance and willingness to pay. Authors explain, for each concerned category, a generalization of medical cost calculated by Disability Adjusted Life Years (DALY) approach; and productivity lost function. Costs related to user satisfaction are assessed by a correlation between thermal comfort, energy consumption and productivity. This work is an early stage towards the next step of the project, which is a global optimization of ventilation according to all mentioned aspects. In this purpose, a case study is currently being investigated via a combination of multiple numerical environments of a floor of Antwerpen university.

KEYWORDS

Economic cost, Indoor Environment Quality, Indoor Air Quality, Thermal Comfort, Energy Consumption, Sleep Quality

INDOOR ENVIRONMENT QUALITY AND ITS RELATED COSTS

1 ENERGY CONSUMPTION

costs related to energy consumption are quite simple to obtain. To establish a cost, multiplying energy need for each category (heating, cooling, ventilation…) per KWh cost of the corresponding energy is sufficient.

$$Energy\ consumption\ cost = \sum_{i}^{n} E_{need,i}\ X\ E_{cost,i} \tag{1}$$

Where $E_{need,i}$ is the energy need for energy type i (KWh) and $E_{cost,i}$ is the cost of the corresponding energy (€/KWh).

2 USER SATISFACTION AND HYGROTHERMAL INDUCED COST

Due to thermal discomfort, working productivity may decrease significantly. Therefore a productivity loss is applied as described in equation *(2)*.

$$Hygrothermal\ comfort\ cost\ =\ P_{loss} X\ PPD \quad (2)$$

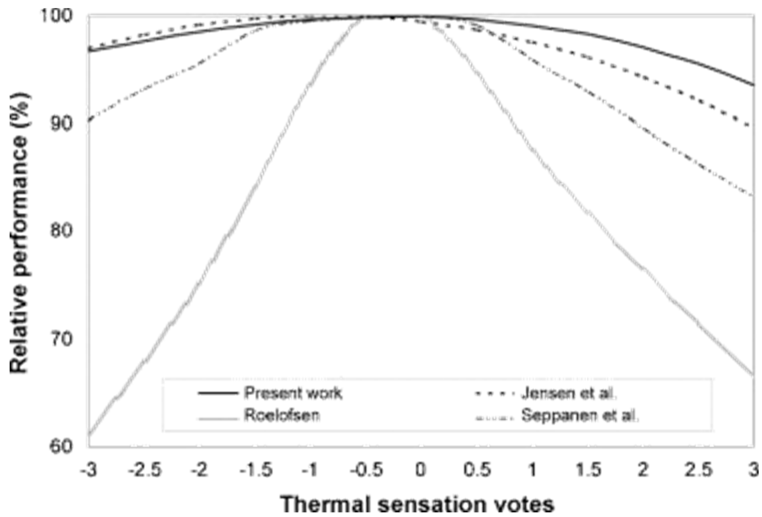

Figure 1 productivity lost as a function of thermal sensation vote. (Lan ,et. al, 2006)

3 INDOOR AIR QUALITY

3.1 Health cost with Disability Adjusted Life Years Lost

The DALY approach allows to quantify Disability Adjusted Life Years lost due to exposure to a chemical substance as explained in Logue et al. (2012). The cost of a DALY depends on which pollutant is responsible for losing it. Indeed, if the life year and productivity cost are independent. As the diseases induced by exposure to a chemical substance, varies from one pollutant to another, health cost will vary as well. The cost for a DALY is detailed in equation *(3)*.

$$Daly\ cost_i = life\ year\ cost + P_{cost} + health\ cost_i \quad (3)$$

All detailed cost per pollutant are referenced in table

Table 1 : Health cost induced by individual pollutant (€)

Benzene	Trichloroethylene	Radon	PMs	CO
46 000	70 971	25 526	10 402	1 085

One life year cost was estimated around 115 000€ by and P_{cost} is roughly estimated by 145 000 € (Pornade, 2014), but can be recalculated for each building, based on the average productivity of the concerned company. This methodology is detailed in work of Cony and Laverge (2022).

3.2 Sick Building Syndrome (SBS) cost calculation

An original part of this work is a proposal of SBS cost calculation as described in equation

$$SBS_{cost} = P_{cost} \times P_{loss}(52.93\% + 2.8325IAPI + 0.8325IDI) \times \frac{2}{5} \quad (4)$$

4 ACOUSTIC

Noise disturbance has two main impacts, over productivity and health. A strong noise disturbance may result to a loss of productivity for people annoyed. Figure presents percentage of people highly annoyed by noise depending on the acoustical level (dB). This percentage is then multiplied by a productivity decrease and a productivity as described in equation . After a long term exposure to a noise, some health issues may occur. To quantify the cost that it represents, we are calculating equivalent DALYs associated to noise (Xiao et. al, 2016).

$$Noise_{Cost} = Daly_{noise} \times Daly\ cost \quad + Productivity\ loss \tag{5}$$

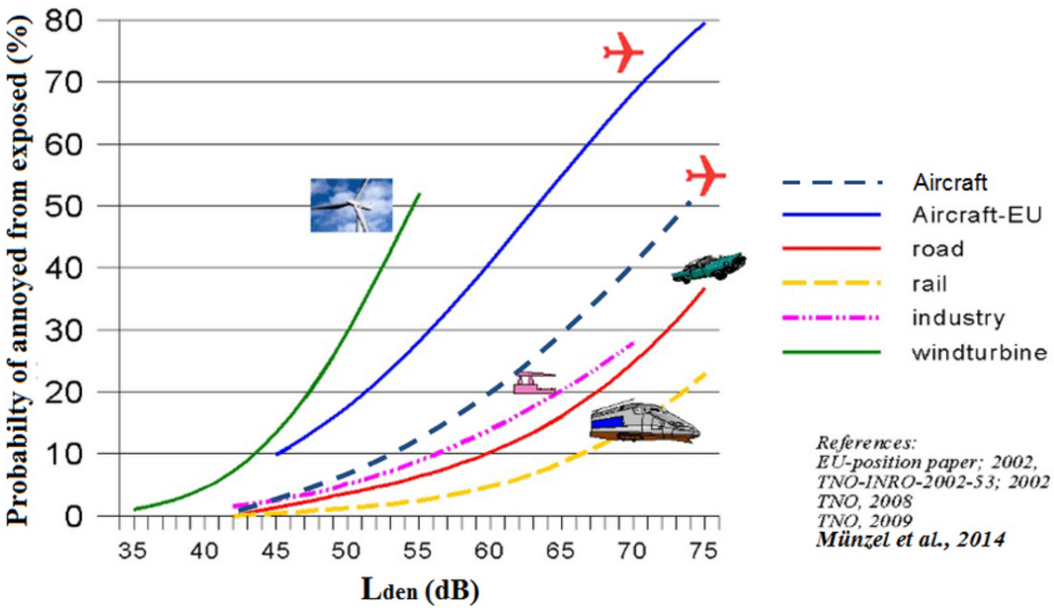

Figure 2 highly annoyed people by various noises as a function of dBs. (Grobarth et. Al, 2019).

5 SLEEP QUALITY

Sleep quality is influenced by many factors. Therefore, sleep quality is hard to quantify, only from environmental parameters. Improving sleep quality from ventilation related parameters is complex, but the detection of bad environments is possible even with a sometimes diverging literature. As a main hypothesis to propose a formula, we consider that probability of sleep disturbance is 1 if all parameters are gathered to influence sleep quality in a negative way.

$$Sleep\ quality = \sum_{1}^{n} \frac{k_i w_i}{n} \tag{6}$$

If $Sq \leq 0$ → good
If $0 < Sq \leq 1$ → probably bad
If $Sq \geq 1$ → bad for sure

Table 2: sleep quality influencing factors (inspired by Chenxi Liao's PhD, 2021)

Column Title	Good (-1)	Neutral (0)	Probably bad (1)	Bad (2n-1)	Coefficient
T (°C)	X	17-28	<17 or >28	X	0.0447
H° (%)	X	40-60	<40 or >60	X	0.0447
CO2 (ppm)	X	750-1150	1150-2600	>2600	0.0351
Noise (dB)	X	X	>35	X	0.0319

In order to obtain a final economical assessment related to sleep quality, researchers are currently investigating DALYs lost due to sleep quality issues as well as their associated costs.

6 ACKNOWLEDGEMENTS

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