Preventing chronic lung disease in an aging society by improved building ventilation: An economic assessment

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F. Franchimon, A.H.J.A. Ament, C.E.E. Pernot, J. Knies, J.E.H.M. van Bronswijk. Preventing chronic lung disease in an aging society by improved building ventilation: An economic assessment. Gerontechnology 2008; 7(4):374-387; doi:10.4017/gt.2008.07.04.025.00. Leading edge ventilation systems in buildings might slow down the degradation of quality of life in a population. We therefore performed an economic assessment to determine the Incremental Cost-Effectiveness Ratio (the amount of money needed to produce one healthy life year) for a full-scale ventilation upgrade of the building stock in the Netherlands, to increase the healthy lifespan of citizens by preventing and diminishing COPD (Chronic Obstructive Lung Disease), lung cancer and asthma. The upgrade includes a capacity increase of ventilation systems in dwellings and schools, as well as demand-driven ventilation control. Current and upgraded ventilation systems are compared for (i) operating costs, (ii) health care costs, and (iii) DALYs (Disability Adjusted Life-Years). This resulted in yearly additional technical operating costs of the upgrade of €13x106 per million inhabitants of the Netherlands. Yearly health benefits per million inhabitants consist of 5,000 DALYs and €23.9x106 of health care expenditure. This leads to an Incremental Cost-Effectiveness Ratio (ICER) for one extra healthy year (DALY) of €18,000, which is an acceptable amount for a healthy life year in the Netherlands. The new ventilation design appears to be cost-effective in preventing and diminishing premature aging of the lungs of Dutch citizens. Future simulation studies are required to increase the accuracy of this assessment.

Keywords: building ventilation, demand-driven, economics, lung disease

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In general, the prevalence of chronic disease is highest at higher ages resulting in increased health care expenditures[1]. However, for asthma, the prevalence appears to be highest in children between 0-14 years old (26%) compared to adults of 60 years and older (15%)[2]. Discounting for multiple diseases, in 2003 700,000 of the 16.5 million Dutch inhabitants had asthma, COPD or lung cancer. About 210,000 of these persons were in the 65-years and older age category[3]. Asthma, as well as COPD (Chronic Obstructive Lung Disease) and lung cancer, is expected to increase by 26% to 47%[4,5] in 2025, mainly due to aging.

One of the characteristics of chronic lung disease is its relationship to the life-long sum of exposures to allergens and ETS (Environmental Tobacco Smoke)[6]. This means that all types of indoor spaces that people visit during their lifetime need to be taken into account to prevent the above-mentioned conditions. A recent Silver Paper[7] asks for such a life course approach for health promotion and preventive actions. In order to be effective these actions should be both technically and economically feasible.

Dedicated ventilation systems may slow down the development of disease and preserve the independence of those affected[8]. For ETS, the efficiency of ventilation plays an essential part in removing tobacco smoke from indoor spaces[9]. The number of allergen producing mites and fungi in buildings is reduced by low indoor relative humidity as managed by a suitable ventilation system[10].

In this article we will assess an upgraded ventilation design for buildings from a macro-economic viewpoint. To evaluate the economic feasibility of this intervention, we include the costs of preventing chronic lung conditions, the reductions in health care expenditure, and the resulting decrease in the individual disease burden in this financial assessment. We calculated the Incremental Cost-Effectiveness Ratio (ICER), i.e., the amount of money needed to produce one extra healthy life-year, of an upgraded ventilation design for the Dutch building stock.

Methodology

Since climatic conditions (for instance, seasonality of temperature and humidity), local building standards (for instance, pre-

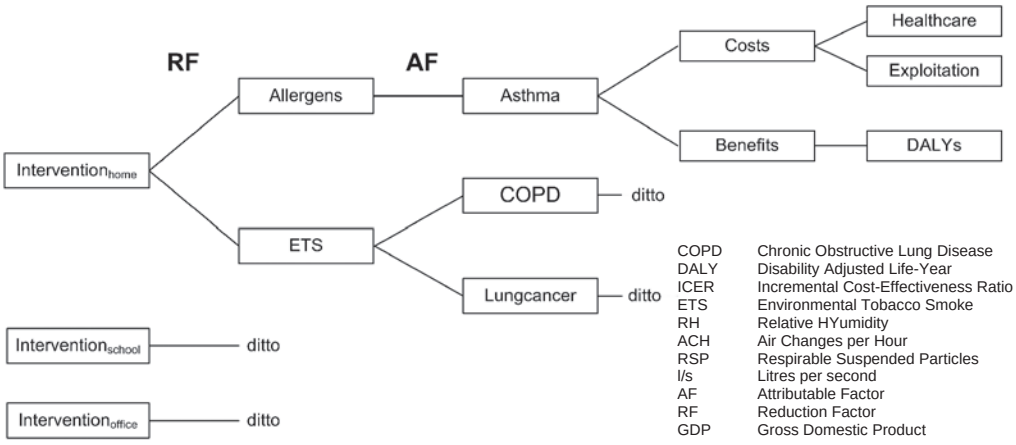

Figure 1. The Reduction Factor (RF) is the estimated reduction in exposure as a result of the upgraded ventilation systems. The Attributable Factor (AF) is the estimated health effect attributable to exposure. The costs and benefits for COPD and lung cancer are identical to those for asthma, in the diagram indicated by ditto. The intervention for schools and offices is identical to the intervention for homes

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scribed minimal ventilation rate) and the quality of the building stock (for instance, insulation, air-tightness of building envelopes, ventilation systems) are all parameters that may vary between regions, we chose to confine this first assessment to a single country: the Netherlands. To determine the ICER, the extra operating costs of the intervention, the reduced health care expenditures and the gained DALYs (Disability Adjusted Life Years) are required. Therefore, the reduced exposure to disease-related pollutants (Reduction Factor) as a result of the intervention, and the health effect of lower exposures to these pollutants (Attributable Factor) were established. Both the Attributable Factor and the Reduction Factor are needed to compute the DALYs gained (benefits) as well as the extra operating costs of the intervention and reduced health care expenditure (costs). This study is limited to asthma, COPD and lung cancer, which are all indoor air associated diseases. The disease-related pollutants are limited to house dust mite allergens (asthma) and ETS (COPD and lung cancer). The calculation model used in this study is presented in Figure 1.

Current building ventilation

The 2003 Dutch building stock consisted of approximately 7 million dwellings[11], 8 thousand schools[12] and 42 million square meters of office floors[13]. Dutch homes are ventilated through natural ventilation (35%), mechanical exhaust (55%) or ventilation with heat recovery (10%)[14]. There are no such data available for schools and offices. On the basis of our own observations, we assumed that 10% of the schools are equipped with natural ventilation and 90% with mechanical exhaust ventilation. For offices, we assumed that 10% are equipped with mechanical exhaust and 90% with heat recovery in the ventilation system.

The efficiency of current systems in removing pollutants (including moisture) appears to be limited as evidenced by the high prevalence of chronic lung diseases mentioned above. Studies showed an average of 0.3 ACH (Air Changes per Hour) for homes and 1.7 ACH for schools[15,16]. For offices ventilation rates are reported mostly above the level required by the Dutch building code (25 l/s per person), only natural ventilation performed below this ventilation requirement[17].

Required ventilation rate

Increased ventilation rates are required to remove indoor pollutants. Therefore, a required amount of ACH has to be set.

Regarding mite allergens, ventilation does not only remove allergenic particles but also keeps the indoor air humidity at lower levels in order to prevent mite growth (<45%)[18]. Low relative humidity (RH) levels can only be achieved in the heating season, (winter) when indoor air is heated. A case-control study performed in Denmark showed that an ACH value of 1.5 reduced mite concentrations in mattresses[19]. The relationship between dampness and growth of house dust mites showed that within 15 months an increase of the ventilation from 1.0 to 1.5 ACH resulted in 80% less medication use. The mite concentration in house dust decreased from 210 mites/g mattress dust to 30–55 mites/g mattress dust, well below the hygienic limit of 100 mites/g dust. This would mean that this intervention is 100% effective for mite concentrations. Fisk[20] reviewed six papers for the association of domestic mechanical ventilation systems with indoor air humidity, dust mite levels, and allergy symptoms. Five of the six reviewed papers did indeed show a significant correlation between increased ventilation and/or lower humidity levels and mite concentrations and/or reduced asthmatic symptoms. The one study that did not show significant results was conducted in a mild and humid climate with less heating in winter. Also Peat et al.[21] reviewed 20 papers for housing characteristics and house dust mite levels

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in homes. Eleven papers stated that indoor humidity as a housing characteristic is associated with house dust mite levels.

In the Netherlands, mattresses are one of the major niches for house dust mites[8]. Another major niche is upholstered furniture. Our study is limited to mattresses since no case-control studies on upholstered furniture and increased number of ACH is available. A Swedish study by Munir et al.[22] found, however, a correlation between relative humidity and mite counts in soft furniture. As the heating season in the Netherlands is shorter than that in Denmark, a higher ACH value is needed to exterminate mites. In the Netherlands there is a 20% higher risk of noxious mite allergen levels compared to Denmark[23]. In order to apply the data from the Danish case-control study to the Dutch climate, an adjustment needs to be made. With a threshold limit of 45% relative humidity during winter, a value of 2 ACH is required[24]. Although the studies of Harving et al.[10,19] showed mite counts 100% below hygienic level after intervention, we took a reduction of 75%.

To establish the ACH for reducing ETS a distinction should be made between cigarette constituents in the vapor phase and those in the Respirable Suspended Particles (RSP) phase. Concerning RSP, Ning et al.[9] showed a decrease in particle concentrations at three different ventilation rates (3.6 ACH, 55 ACH and 79 ACH). The background level of RSP was reached after 30 min at the highest rate and after 90 min at the lowest one. However, high ventilation rates causes more absorption of vapors constituents (such as nicotine) by furnishings and finishing material in indoor spaces, resulting in increased concentrations after desorption. Singer et al.[25] and Nelson et al.[26] showed a rise in nicotine concentrations over time. However, in these experiments, additional fans were present to provide better air circulation, causing more absorption and later desorption of vaporized constituents of ETS on wall surfaces. In real indoor settings, however, there is no perfectly mixed air. Singer et al.[25] also reported on the impact of different ACH values (0.3, 0.6 and 2 ACH) and the presence of finishing material and furniture in a test chamber on the exposure-relevant emission factor of nicotine. They reported a threefold lower exposure-relevant emission factor (effect of adsorption and re-emission over 24 hours) for nicotine in a fully furnished room compared to a wallboard covered room (without furniture).

Sistad and Bronsema[27] developed steady-state models to calculate the air supply rates required to remove nicotine and RSP to an acceptable level (0.5 μg/m^3 and 50 μg/m^3, respectively). Since the model for nicotine ignored the absorption effects of finishing materials and furniture, and several studies described the adverse effect of higher ventilation rates, we did not apply Sistad and Bronsema's nicotine model, but only the model for computing the required ventilation rate for removing RSP:

$$q_v = \frac{p \cdot n \cdot g_{pm} \cdot 10^3}{A \cdot c_{pm} \cdot 3{,}6} \quad (1)$$

where:

p percentage of smokers: 30%[28]

n number of cigarettes smoked per hour: 2 cigarettes per hour

g_{pm} average particle emission in mg/cigarette: 25 mg/cigarette[29]

A floor area per person in living room in m^2: 25 m^2

c_{pm} particulate concentration in μg/m^3: 50 μg/m^3

These input parameters lead to an Air Exchange Rate (in ACH) of 5 to lower the RSP to 50 μg/m^3 (height of living room: 2.5 m). The model is based on continuous smoking, but the hours spent in the home environment do of course also include sleeping and other non-smoking activities. This means that production of ETS in

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the home environment only occurs during the hours of smoking. According to Singer et al.[25], the ACH should be set lower after smoking in order to minimize the absorption and desorption of the vaporized constituents. The concentration of vapor constituents takes many days to drop to background level. Assuming occupants smoke cigarettes on a daily basis, no reduction below acceptable levels is achievable. Since we are only able to lower the particle constituents and not the vapor constituents we established a reduction in noxious exposure of 50%.

Assuming that ETS exposure only takes place in living rooms, the maximum ACH value is based on 5 ACH in a living room (during smoking) and on 2 ACH in other rooms to decrease mite growth only (for instance, the bedroom). It is assumed that occupants only smoke 3 hours a day, resulting in 5 ACH in the living room during 3 hours needed to remove RSP. For the other 21 hours, the ACH value can be set at 2 ACH to exterminate mites in furniture. The average ACH in living rooms in smoking households is therefore 2.4. When the ACH in others spaces is 2, the average in homes occupied by smokers is 2.2. For non-smoking households the ACH in living rooms is 2 and in other spaces also 2, resulting in an average of 2 in homes without smokers. Since our assessment is applied to the Dutch housing stock, the weighted average ACH in Dutch dwellings is 2.1 (30% smoking- and 70% non-smoking households).

In schools, the increased ventilation rate is based on scaling up to the national standard of 1.7 ACH or 7 l/s/person[30]. In this study, we do not recommend an additional increase of ventilation rate beyond the standard level as the amount of house dust mite allergens in schools is below the hygienic level[31] and ETS is not present in schools[32]. Therefore, these exposures are not associated with the development of asthma, COPD or lung cancer.

Offices do not require an increase in ventilation rate as the ventilation rate in offices usually meets hygienic limits[17]. Since this study is limited to house dust mite allergens and ETS, no related adverse health effects are expected from the current systems.

Intervention

To increase ventilation efficiency in buildings we suggest upgrading the existing ventilation systems. For this purpose most of the existing systems can be left intact, including the ventilation principle (natural or mechanical air supply), but the control mechanisms and actuators need to be replaced in order to obtain demand-driven control.

To realize demand-driven control, tobacco smoke detectors are to be installed in living rooms of dwellings and presence or humidity detectors in all rooms to control mites. In schools and offices demand-driven control can be based on presence detection.

In addition, ventilation fans will have to be replaced to supply and/or exhaust more air. Particular attention should therefore be paid to the noise generation of the ventilation upgrade. Currently up to 20% of the occupants of dwellings complain about noise discomfort caused by ventilation systems[33]. Unacceptable noise levels (above 35 dB(A)) may be prevented by fans maintaining air velocities below 4 m/s in ducts, and by placing proper silencers[14].

Attributable factor

Total exposure to house dust mites and ETS not only depends on the concentrations present, but also on the total length of the exposure time.

Since the relevant exposures to pollutants may start early in life, the entire lifespan of the Dutch population in 2003 was taken into consideration. Dutch inhabitants spend 83% of their indoor life at home, 3% at school, and 11% in offices. This is

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based on a population-weighted calculation using data on the living, working and school situations for people over the age of twelve[34,35] as well as on an estimate based on additional data for children under twelve[36,37]. Seen from the perspective of duration of exposure, dwellings are the most crucial locations. Exposure time and intensity both affect human health. It is therefore not only on the basis of exposure time that homes are crucial, but also because the intensity of exposure to allergens and ETS is highest in homes. Mite allergens in schools and offices are in general below the threshold level for allergic disease development of 100 mites per gram[33,38].

The Attributable Factor for asthma as a result of house dust mite allergens was set at 80%. This is mainly based on the medium-term association of asthma and house dust mites found in a 12-month retrospective study by Miraglia del Giudice et al.[39] for 7-12 year old children (Odds Ratio 4.84, 95% CI = 2.42-9.60). The associations for 0-3 year old children and 4-6 year old children were lower, suggesting that the exposure time appears relevant. However, the Attributable Factor is also based on the significant short-term effects that indicate that immediate hypersensitivity can lead to asthma[40] and sensitized children have more daytime asthma attacks[41]. According to a review by Richardson et al.[42], there is sufficient evidence for a causal relationship between house dust mite allergens and the development of asthma, allergen exposure and exacerbations of asthma in individuals already sensitized.

The Attributable Factor for COPD as a result of ETS was set at 60%. This percentage is a conservative estimate based on a study by Robbins et al.[43], who computerized an algorithm through analyzing questionnaires of subjects obtained between 1977-1987 (n=3,918) in order to identify new cases of airway obstructive disease due to passive smoking in both childhood and adulthood (relative risk: 1.72 (95% CI = 1.31-2.23). Although a meta-analysis by Law and Hackshaw[44] mentions a lower risk of ETS for adults with chronic respiratory disease, the estimate for both children and adults appears plausible as Leuenberg et al.[45] found a similarly elevated risk of symptoms of chronic bronchitis for adults exposed to passive smoking.

The Attributable Factor for lung cancer as a result of ETS was set at 25%.This is based on three meta-review studies that pooled the effects of increased risk of lung cancer from second-hand smoking. Although the Dutch Health Council suggests a value of 20%[46], the chosen value of 25% is within the range of the 20 to 30 percent suggested by the US Surgeon General[47] for the increased risk of lung cancer from second-hand smoke exposure associated with living with a smoker. Furthermore, this result fits the 26% (95 % CI = 7%-47%) excess risk stated by Hackshaw et al.[48].

The Attributable Factor for ETS in relation to asthma was not taken into account, although it must be said that the Health Council of the Netherlands concluded that passive smoking can lead to an increased risk of asthma of 20 to 50 percent[46] for children. Averaging the risk stated by the Health Council of the Netherlands led to an Attributable Factor for asthma and ETS of 35%. However, the estimated Attributable Factor for mite allergens in relation to asthma is currently higher than that for ETS.

Operational costs

The investment needed to upgrade existing ventilation systems was estimated at 2 times the cost of current ventilation systems with heat recovery (so called balanced ventilation systems) for dwellings, 2 times the cost for schools and 1.2 times the cost for offices.

The high costs for dwellings are based on both an increased ventilation rate and the

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equipment required for demand-driven control (humidity, presence and ETS detection). An increase in capacity requires more powerful fans and wider distribution systems (for instance, ducts). In schools, only the upgrade to the ACH according to national standards and the equipment for demand control (presence detection) need to be installed. In offices, only additional equipment needs to be integrated into the existing control system.

The depreciation costs ($C_{depreciation}$) were simply calculated by dividing the investment ($C_{investment}$) by the depreciation period. In this calculation the depreciation period was 15 years. Besides depreciation costs, there will also be the costs of interest rate (I). These costs can be calculated on the basis of the average investment (50% of the total investment during this period) and the interest rate. As to the interest rate (I) we used the recent average interest on loans in the Netherlands. The interest costs ($C_{interest}$) were calculated as follows:

$$C_{interest} = \frac{C_{investment}}{2} \cdot I \quad (2)$$

Maintenance costs ($C_{maintenance}$) indicators for HVAC (Heating, Ventilation and Air Conditioning) systems in the Netherlands were also used[49]. We assumed that the maintenance costs for the upgraded ventilation systems equal the maintenance costs for the current balanced ventilation systems. No additional costs were calculated for the ACH upgrade itself.

The Dutch standards for energy performance[50,51] constituted the basis for calculating the additional energy costs (C_{energy}). Upgrading ventilation in dwellings was scaled up to temporary 5 ACH (living rooms) or 2 ACH (other spaces).

For schools, the energy costs were based on 1.7 ACH. Offices remain the same in terms of ACH values. Since all the ventilation systems are demand-driven, an energy reduction in homes, schools and offices of 50%[52], 40%[53] and 22%[53], respectively, is expected.

The operating costs were calculated as follows

$$\Delta C_{exploitation} = \Delta C_{depreciation} + \Delta C_{interest} + \Delta C_{maintenance} + \Delta C_{energy} \quad (3)$$

Health care expenditure

In 2003, health care expenditures for asthma and COPD in the Netherlands amounted to €739x10^6 [54]. Unfortunately, the costs of asthma and COPD care in the Netherlands are grouped under one header. We therefore used the ratio of costs that Hoogendoorn et al.[55] found for asthma and COPD in order to separate the costs of asthma and COPD.

The Attributable (*AF*) and Reduction Factors (*RF*) (see above) were applied to the total costs of the chronic diseases to calculate the reduction in health care expenditure per disease (*d*):

$$\Delta C_{healthcare} = \sum_{i=1}^{n} AF_d \cdot RF_d \cdot C_{d,healthcare} \quad (4)$$

Calculation of DALYs

Health gains were measured in DALYs (Disability Adjusted Life-Years), a health gap measurement for the impact of a specific disease on the quality of life by calculating the years of life lost due to a disease using mortality and weighted morbidity data[56].

$$DALY = YLL + YLD \quad (5)$$

Where:
YLL: Years of Life Lost
YLD: Years Lost to Disability

Years Lost to Disability is the multiplication of the prevalence of the disease and a weighing factor. This weighing factor was established for all diseases by the National

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Institute of Public Health and the Environment[57] and depends on the physical or mental limitations caused by a disease[58].

Incremental Cost Effectiveness Ratio

The annual extra costs (ΔC_{net}) for the intervention were calculated by first determining the extra annual operating costs ($\Delta C_{operating\ costs}$) and subtracting reduced health care ($\Delta C_{healthcare}$)

$$\Delta C_{net} = \Delta C_{exploitation} - \Delta C_{healthcare} \quad (6)$$

The costs of an extra healthy year (DALY) came from a macro-economic calculation with figures normalized for the year 2003. The costs per 1 DALY follows from the Incremental Cost-Effectiveness Ratio (ICER). If the total annual extra costs (ΔC_{net}) of the intervention and the number of gained DALYs ($\Delta DALYs$) are known, the extra costs for 1 DALY gained can be easily calculated as follows:

$$ICER = \frac{\Delta C_{net}}{\Delta N_{DALYs}} \quad (7)$$

The ICER is the amount of money needed to produce 1 DALY, in our study the extra operating costs of upgraded ventilation systems invested for improving building ventilation. Such a result can easily be compared with the ICERs from other societal investments.

Results

Improved human health

Buildings contributed significantly to the disease burden, with Attributable Factors of 80% for asthma, 60% for COPD and 25% for lung cancer. The Attributable Factor and the established Reduction Factor per exposure together constitute the reduced ratio for chronic disease burden related to the upgrade of the ventilation systems. It ranges from 13% for lung cancer to 60% for asthma (*Figure 2*).

Costs

Total investment costs are huge, amounting to €1.4x10^9 with dwellings alone taking up 100% of the reduction in health care expenditures and DALY gains since only house dust mite allergens and ETS are considered. Besides investment costs, the additional operating costs of the upgrading are also dominant factors, such as (i) the depreciation of investment, (ii) interest, (iii) maintenance, and (iv) energy costs of the dwellings. The total additional operating costs are €1.8x10^9 a year (*Table 1*). Calculated per inhabitant, this would amount to €113/year.

Benefits

On the benefit side we see a yearly gain of 81x10^3 DALYs and €383x10^6 for health care expenditure (*Table 2*). This equals approximately five thousand healthy years (DALYs) and €24x10^6 per million inhabitants.

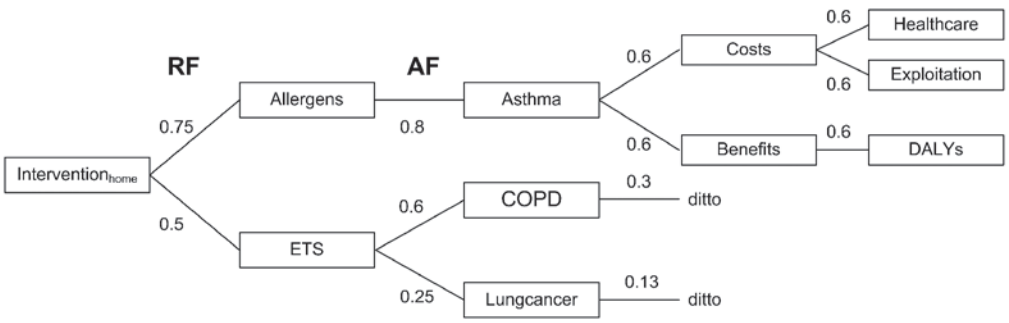

Figure 2. Results for the Reduction Factor (RF) and Attributable Factor (AF) per exposure and disease in the Calculation Model for Homes

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Table 1. Yearly additional operating costs after full penetration of the ventilation upgrade in different types of buildings. (Index year 2003, investment €32.6x10^9, €47x10^6 and €1.2x10^9, for dwellings, schools and offices, respectively)

Cost origin	Changes in operating costs in €10^6			
	Dwellings	Schools	Offices	Total
Depreciation	1,400	3.0	80	1,500
Interest	500	1.0	30	500
Maintenance	300	0.2	13	300
Energy	-400	-21.0	-65	-500
Totals	1,800	-16.8	57	1,800

Since the Attributable Factors are fully based on allergens and ETS, the benefits are gained through the intervention in dwellings only.

Incremental Cost-Effectiveness Ratio

ICER at full penetration of the ventilation upgrade is €18,000.

The ICER determines, after the benefits gained by a reduction of health care expenditure, what society has to pay for one additional healthy life-year. Whereas health care expenditure is of direct value to society, DALY gains contribute to better societal quality of life.

Sensitivity of analysis

Varying the disease-specific Reduction Factor and Attributable Factor gives an indication of the sensitivity of the calculations. If the multiplication of Reduction and Attributable Factors are lowered to two-thirds, from 60, 30 and 12.5% to 40, 20 and 8% for asthma, COPD, and lung cancer, respectively, the ICER for the ventilation upgrade increases to €29,000.

Since the investment determines the depreciation and interest costs, and both of these account for almost 70% of the total exploitation costs, the variance of the investment is a nearly linear function. If the investment to achieve full penetration of the upgrade in dwellings is not 2 times, but 3 times the cost of a standard balanced mechanical system, the ICER is €26,000.

If the penetration of the upgraded ventilation design only takes place in dwellings and not in schools and offices, the ICER remains €18,000. The energy cost reduction in schools and offices through demand control is more or less equal to the financial operating costs and additional maintenance costs.

The energy reduction in dwellings has been set at 50%. If the energy reduction through demand control in dwellings is reduced from 50% to 25%, the ICER is €23,000.

This sensitivity analysis shows the importance of the accuracy of (i) the Attributable and Reduction Factors, (ii) the investment of the upgraded design in dwellings and (iii) the energy reduction through demand-controlled ventilation systems.

Table 2. Benefits for Health Care Expenditure (in €), and healthy years (DALYs) gained for different diseases (index year: 2003)

Cost origin	Expected Disease Reduction Rate [%]	Health Care Expenditure		DALYs	
		Total 2003 x10^6	Expected gains x10^6	Total 2003 x10^3	Expected gains x10^3
Asthma	60	496	297	34	20
COPD	30	212	64	146	44
Lung cancer	13	173	22	135	17
Totals		881	383	315	81

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This analysis also shows the dominance of the full penetration of the intervention in dwellings.

Discussion

This contribution bridges a gap between the building and health domains as it uses both health benefits and ventilation operating costs (including energy costs) in its assessments. Its feasibility depends on the amount of money society is willing to spend on one extra healthy year in a lifespan[59,60]. The WHO suggested a value of one to three times the GDP (Gross Domestic Product) per capita; within this range, an intervention is deemed to be cost-effective[61]. For the Netherlands in 2003, this would amount to €29,000 to €87,000 for 1 DALY[62]. It is interesting in this respect that the ICER of one healthy year of €18,000 is well within the Dutch range, even if the higher value of the sensitivity analysis of €29,000 is taken into account. Macro-economically speaking, the ventilation upgrade we suggest is financially feasible. From a technical point of view, feasibility is also high since only known technologies are to be included in the upgrade.

The fact that the ICER appears to be most sensitive to a proportional change in the reduction ratio of COPD can be explained by the high DALY attributed to COPD, almost all derived from disease year equivalents in the older age categories, and not from premature deaths[3].

Current Dutch Building Code requirements for ventilation systems are primarily geared to the reduction of energy consumption[63], and not to the prevention of chronic disease[30]. However, Fisk and De Almeida[53] showed that improving indoor air quality does not have to lead to higher energy consumption. They concluded that demand-controlled ventilation is an increasingly attractive technology for controlling both indoor air quality and energy consumption. This study confirms the ability of upgraded ventilation systems to improve health without an increment of energy consumption.

The Attributable Factor for COPD and lung cancer was established on the basis of population studies in which no distinction was made between the vaporized and particle constituents of ETS. In our intervention simulation with upgraded ventilation systems, only particulate constituents can be controlled, not the vaporized constituents. ETS contains thousands of gases. This makes it rather complicated to establish the effect of every single component on COPD and lung cancer. This implies a major uncertainty in our assessment. The Attributable Factor for asthma on the other hand in our study was only determined by house dust mite allergens. A house dust mite is a single organism and therefore it is less complicated to establish its effect on asthma.

Our macro-economic assessment did not incorporate productivity gains and diminished sick leave[64], nor the effects of improved school performance[65] on the benefit side, and, on the cost side, the extra health care costs related to the increased number of surviving older adults when indoor conditions have improved[66]. We assume the two amounts are about equal, since Fisk and Rosenfeld[67] found additional productivity gains within the range of $14 to $32.5x10^9$ (indexed for 1993, currently equal to €10 to $24x10^9$). This equals €33 to $80x10^6$ per million inhabitants. Translated to the Dutch population, approximately €0.5 to $1.3x10^9$ can be gained by increased productivity. In the same study the reduction in medical costs was calculated to be $3.7 to $10.7x10^9$, corresponding (currently) with €2.7 to 7.8x109. Adapted for the Netherlands, the medical costs would be €144 to $416x10^9$ (€9 to $16x10^6$ per million inhabitants). In our assessment, the reduction in health care expenditure amounted to $€383x10^6$; which is of the same order of magnitude. Whereas Fisk and Rosenfeld

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included allergy, asthma and respiratory diseases for health care expenditure, we included asthma, COPD and lung cancer. Future research involving long-term simulations may improve the accuracy of our calculations.

Since Dutch citizens spend over 70% of their lifetime in dwellings[35] and as these buildings are more polluted than schools or offices, it appears that upgrading ventilation systems should focus on existing dwellings, in spite of the high operating costs for these buildings. It could be argued that we calculated costs and benefits for the whole population, although diminishing pollutants only benefits persons developing asthma, COPD or lung cancer. However, homes are built for at least 50 years and will have different owners or tenants during their lifespan. Chances are that at least part of the time a tenant will be part of the risk group. Although people spend less than 3% of their lifespan in schools[38], allergies develop mainly in these sensitive early years. So, upgrading ventilation systems in this domain remains crucial. The ventilation rates in offices already meet the hygienic requirements in the Netherlands[17]. Our upgrade will be especially important for a reduction in energy use in offices.

Given the building-related exposure levels of house-dust mites and ETS, exposure at home remains a major health risk. To improve the overall health of the population, it may be wise to start the ventilation upgrade in dwellings.

Outside the Netherlands, the financial and technical feasibility of the new ventilation design may vary, since the socially acceptable value of one DALY depends on economics and local standards. Furthermore, disease prevalence, exposure levels, health care expenditures, the state of the current ventilation systems in relation to outdoor climate, energy costs, etc. are all parameters that may vary from region to region. We recommend that our colleagues in other countries also apply a macro-economic assessment of the interdisciplinary domain of indoor air science and health to their regions as a first step towards improving public health.

Conclusion

The suggested ventilation upgrade will prevent and diminish chronic lung diseases such as COPD, lung cancer and asthma at a monetary cost for an additional healthy year of €18,000. This will especially benefit the older age categories in the population (where COPD and lung cancer is most prevalent), and the youngsters with asthma, and is socially acceptable and technologically feasible in the Netherlands. For other regions, new calculations with local values of the parameters are required.

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