Lack of pro-active technology in indoor air quality protection

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L.G.H. Koren, M.C.L. Snijders, C.E.E. Pernot, P. Schmid, J.E.M.H. van Bronswijk, Lack of pro-active technology in indoor air quality protection, Gerontechnology 2005; 3(3):149-158. Indoor air quality (IAQ) influences the health of humans, the young and the old being generally more susceptible. Indoor air, the air that we breathe more than 80% of the time, is increasingly pre-treated or arriving through filters and ducts. Any technological solution for ventilation should pro-actively protect IAQ, by improving or not deteriorating the quality of outdoor air coming in, and alarming when IAQ levels are declining. In this study we examined how human IAQ needs are met, in design or in practice, by domestic ventilation systems, including natural ventilation, balanced ventilation, and adaptive systems. **Methods** Three population groups with different sensitivity towards air quality were recognized: healthy adults (between 20 and 49 years of age), healthy younger and older persons, and chronic lung sufferers. Risk aspects of ventilation systems were identified from literature: pollution accumulation, draught, and maintenance. Current indoor air quality in Dutch dwellings was evaluated from continuously measuring 4 indoor air quality indicators (CO_2, humidity class, ventilation rate, and fine particles) in 37 dwellings for a whole week in winter each. Ventilation was by windows and grids, or grids and exhaust fans. Actual IAQ levels in dwellings were linked to complaint percentages in different air qualities derived from literature. **Results** The size of the groups with moderate (young, old) and high (lung sufferers) sensitivity is large and increasing, both in relative and absolute figures. An acceptable IAQ for the most susceptible group was not present in any of the dwellings, whilst only one dwelling met the standards for the group of young and older persons. Most common cause was inadequate ventilation. Newer systems with balanced ventilation have intrinsic risks with regard to maintenance (filters) and cleaning (ducts). Intelligent adaptive systems with mechanical exhaust only are in theory the best choice to protect IAQ. **Discussion** A healthy design of a ventilation system should include flexibility in supplied airflow (both a secure base level around the clock, and a high on-demand level) and an excellent removal of accumulated dirt on the surfaces of the ventilation system at the inlet side. Newer systems with adaptive features should be checked further in practice. Pro-actively protecting IAQ in dwellings through adaptive sensor-controlled ventilation systems may be a way to avoid health risks from indoor air for the elderly and other susceptible populations.

Keywords: IAQ, ageing, health, ventilation, building

Sixty percent of the dwellings in the Netherlands have natural ventilation only and 40% have exhaust fans, usually in bathroom, toilet, and kitchen[1]. In 2000, these exhaust fans were present in approximately 2 million dwellings. Newer systems including balanced ventilation, demand-adaptable ventilation, and others had less than 1 percent market penetration in 2004, but up to 11% of newly built dwellings (maximum 60,000 a year in total) have been provided with balanced ventilation systems[2]. Demand-controlled ventilation systems are rare.

Differences in indoor air quality (IAQ) arise from differences in supply and exhaust characteristics of these ventilation systems. Complaints of dwellers indicate that the prevailing ventilation systems are unable to supply adequate ventilation. Do upcoming systems contain the features needed for a healthy indoor environment? Indoor air quality influences the health of humans, especially of susceptible persons[3]. In the last decades, ventilation strategies have changed due to the advent of environmental consciousness, and so has the amount of outdoor air that is brought in. In reaction, classifications of indoor air were aimed at limits to specific parameters: concentration of volatile organic compounds (VOCs), carbon monoxide (CO) or carbon dioxide (CO_2)[4]. Other approaches aim at a limit of complaining persons: indoor air quality satisfying 70-85% of all inhabitants, allowing up to 30% to be dissatisfied[5,6].

The population in western countries is aging; a quarter of the population will be over 65 in the next few decades[25]. Furthermore, the incidence of airways-related diseases is increasing. IAQ levels should be set according to the actual needs of the individual persons concerned.

In this first study domestic ventilation systems are evaluated for health implications, with regard to the needs of groups of the Dutch population with different demands for indoor air quality. Performance of current systems is assessed by measuring actually supplied IAQ in 37 dwellings, and risk characteristics of current and upcoming ventilation systems are compared to evaluate the role of these systems in future health aspects of the indoor environment.

MATERIALS & METHODS

Dutch population statistics[25,26] were used to determine the population size suffering from the most relevant indoor-air related diseases and to establish age groups at risk. Health complaints were taken as limits to determine levels of indoor air suitable to satisfy different risk groups. The most susceptible group was defined as the upper 10% of complainers of the population at a specific exposure, while the least susceptible group was linked to 15% or 20% complainers, depending on the usual amplitude in complaining from the specific exposure. The 20% limit is often used for the sick building syndrome. A complaint level of 5% is the limit of detection[18]. To establish the impact of IAQ on human diseases, data were obtained by literature study, including Medline and Science Citation Index (1965-2001). The external determinants of the indoor air related disease were obtained from Dutch handbooks on health status and from prospective studies[7,8].

The most common ventilation systems in Dutch dwellings are type A (natural ventilation) or type C (mechanical exhaust, with natural inlet grids or windows); a third type, D, has become popular among builders because of energy-saving possibilities. Type B is almost never used in dwellings. For the purpose of this study we created 3 or 4 subdivisions per category to identify specific positive or negative health-related properties (*Table 1*). Those characteristics of each system were selected that influence IAQ and bear therefore health risks.

Table 1. Typology of ventilation systems

Main system	Subsystems			
Type A Naturally ventilated	**A1** Grids or windows	**A2** Grids or windows, vertical ducts (chimneys)	**A3** Supply-controlled grids	
Type C Mechanical ventilation, exhaust only	**C1** Grids or windows exhaust fans in bathroom, toilet, kitchen	**C2** Demand-controlled exhaust ducts, supply through grids	**C3** Demand-controlled and natural exhaust, supply through grids (hybrid)	
Type D Mechanical ventilation, supply and exhaust	**D1** Constant supply and exhaust	**D2** Demand-controlled supply and exhaust of air	**D3** Demand-controlled supply and exhaust of air, with heat-recovery	**D4** Demand-controlled and natural supply and exhaust of air (hybrid)

Actual frequency of occurrence of the levels of indoor air quality was established during the winter period (December-March) in 37 dwellings from 2 cities, 3 villages, and rural areas in the western and southern part of the Netherlands. The dwelling sample was assembled from three other studies on respectively COPD, asthma, and mould problems, and contained all popular Dutch dwelling types; the ventilation systems were of type A1 (in 8 dwellings), A2 (in 9), and C1 (in 20). In nine of the dwellings lived a person with COPD, in eight of these together with a wife or family. In at least three of the other 28 dwellings asthmatic persons were present, but these dwellings were not specifically selected for the presence of persons with a disease. The dwelling population had a larger quantum of elderly and a smaller quantum of young children than in the general Dutch population. The building characteristics of these dwellings mimic the Dutch situation to a large degree[3], although the size of the sample is too small to be a valid sample for the Dutch dwellings. Among the differences is an under-representation of apartments in favour of family homes. No balanced or demand-controlled ventilation systems (Type D) were present.

The following parameters were measured: CO_2 concentration as a measure of the presence of irritants of biological nature and of cooking and heating gasses; temperature and relative humidity from which humidity class was established; the humidity class is a measure that has a strong relationship with allergen levels originating from mites and fungi[9]; and the number of fine dust particles ($\geq$ 0.3 micron) indicating both organic and inorganic irritants. In each dwelling, measurements were performed continuously during a week in the living room.

Measuring equipment included a data logger (Almemo type 2290-8, Ahlborn, Holzkirchen, Germany); a CO_2 sensor, being a diffusion-based non-dispersive infrared (NDIR) spectrometer (Valtronics 2045, Envico, Zoeterwoude NL); a combined temperature and humidity sensor, respectively a NTC-element type N and a capacitive sheet sensor (Almemo FH A 646, Ahlborn, Holzkirchen, Germany). Ambient air pressure was obtained from a weather station of the Royal Dutch Meteorologic Institute (KNMI, De Bilt, The Netherlands), closest to the sampled dwelling. Sensor data of kitchen and bedroom were available for a limited number of dwellings and therefore not used.

From daily recordings by the dwellers of their presence and activities, and by CO_2 measurements, ventilation rate was assessed as follows: we assumed that (a) sedentary occupants were the only source of pollution, (b) the outdoor CO_2 concentration was excellent (below 500 ppm) and (c) both ventilating air and pollutants were uniformly distributed throughout the ventilated space. Children and employed adults were assumed to spend on average 7 hours per day in the living room, elderly persons on average 10 hours[10,11]. The 80th percentile (P_{80}) of 24 hours CO_2 monitoring refers to the 4.8 hours with the highest pollution, and may serve as the approximate median concentration in the living room during occupation. Based on these assumptions, the following first order differential equation describing CO_2 generation (G) and ventilation (V) has been adopted for a given volume L:

$$L \cdot dc = G \cdot dt + V \cdot (C_a - C) \cdot dt$$

which may be solved as:

$$V = \frac{G}{(C_t - C_a)} \cdot \left(1 - e^{\frac{V \cdot t}{L}}\right)$$

where V = room ventilation rate per person [$m^3 \cdot h^{-1}$ per person]
G = CO_2 generation rate per hour per person [$ppm \cdot h^{-1}$ per person]
C = concentration at any given time
C_a = CO_2 concentration rate in outdoor air [ppm]
C_t = CO_2 concentration rate in indoor air as function of time [ppm]
t = time of occupancy [h]
L = room volume per person [m^3 per person]

This equation was used to calculate the week-average room ventilation rate; V may be calculated by the Newton-Raphson method (iteratively). CO_2 generation rate was set at 20.000 $ppm.h^{-1}$ per person, derived from a breathing volume of 0.5 $m^3.h^{-1}$ and a CO_2 concentration rate in expired air of 4%.

RESULTS

In order to evaluate the health risks of domestic ventilation systems we first identified the pertaining diseases. The most relevant diseases with external determinants that are related to indoor air quality are chronic bronchitis and lung emphysema (together: COPD, chronic obstructive pulmonary diseases), and asthma[8,12]. The prevalence of these diseases in the Dutch population age groups includes at least 460.000 persons in total. On average, 1 to 2 percent of the population is suffering from either of these diseases[26].

Risk groups

We identified three age groups of different prevalence. Two age groups appear more at risk than the general adult population. The group of 20 to 49 years of age is least at risk and will be further referred to as 'healthy adults'. The young, aged below 20, are 50 to 150% more at risk in case of asthma. The group aged 50 and older is especially vulnerable in case of COPD, 10 to 20 times more than any of the younger groups. The main victims in case of COPD are men, mainly due to a larger percentage of smokers among men. COPD percentages of the male population involve a rise from 3% at 65 years of age to 15% or more at 80-plus[25]. Trends are that more women take up smoking and that COPD prevalence of women increases accordingly[8].

Among hyperresponsive COPD and asthma sufferers, complaints from indoor air are already present at low levels of irritants. Typically, a CO_2 concentration of 1000 -1200 ppm induces irritant effects in healthy young adults, whereas in sensitive individuals, effects are established at 30% to 40% lower concentrations[13]. Although fine dust particles are known to cause irritation and induce asthma exacerbation, the levels at which complaints start are not conclusive[14]. This is probably due to the large variation in the origin and nature of these dust particles.

IAQ criteria

Current guidelines are aiming at a no-complaint level of at least 80% of all occupants[5,17]. This 80% refers mostly to healthy adults, and only a small part of the more susceptible groups is satisfactorily served with this level. As an example: acceptable risk levels for CO_2 of 1000 or even 1800 ppm are maintained, whereas levels as low as 700 ppm may induce airway problems in sensitive persons (*Table 3*).

In this study, air quality levels supplied and measured in dwellings are classified to the demand of the selected groups. The least susceptible group, the healthy adults, will be generally satisfied within the 80% level (up to 20% of individuals complaining). Chronic lung disease sufferers are more susceptible to the health effects of air pollution than healthy adults[19,20], and require an indoor air quality that satisfies at least 90% of all occupants[18], or a maximum complaint level of 10%. The other occupant groups are also satisfied at this health level. We assumed that the susceptibility of children and elderly persons lies in-between these two levels, equalling an 85% satisfaction rate (15% complaining maximally). Only a limited time of excess is allowed: short periods of increase of pollutants are known to induce exacerbation of hypersensitive symptoms[12]. We used levels of 15 minutes per day (P_{99}) and 1 hour per day (P_{95}).

Ventilation rates satisfying susceptible groups were assessed from design criteria for the indoor environment[6,19]. Threshold levels for each level were deduced from the added pollution of occupants and indoor materials, assuming a degree of occupancy of 0.05 person per square meter.

The humidity class is a measure of the indoor long-term climate and is established from temperature and humidity measurements through calculation of the difference between indoor (I) and outdoor (O) water vapor pressure (AH_{in-out})[21]. This value, originally a month-average, indicates the prevalence of moulds and mites. Both produce allergenic substances and irritants; moulds may also produce toxins. Indoors, mite and fungal growth depend primarily on humidity[22]. A sharp increase of mite and fungal growth has been related to the boundary between humidity class II and III. This boundary is not a straight line, but a curbed one with sections between 1.5 and 3 g/m^{-3}. Looking at intervals of excess humidity, de Boer[23] found that a period of 3 hours a day or more suffices to sustain mite growth in an otherwise dry environment. This allows an excess P_{90} level (2.4 hours a day) to satisfy the health demands of most groups. As humidity variation in the rooms is not taken into account, a safe excess level of P_{95} is chosen for the most susceptible group.

A hygienic level for dust particles has not been established yet. In this study we use the outdoor air level as a reference and take a tenfold increase in number of particles as a limit. This arbitrary factor 10 originates from the sampling results revealing that in case of a source known to induce complaints (smoking), particle numbers increased at least ten times.

Thus, air quality levels for young and old, chronic asthmatics and COPD sufferers, and healthy adults are deduced (*Table 2*)[24].

*Table 2. Demanded air quality level, based on the requirements of inhabitant groups with different susceptibility, for CO_2 concentration, humidity class, and room air supply rate per square meter floor surface as environmental indicators. P-values denote the time period of a day 24; *CO_2 concentration at standard temperature (20°C) and pressure (1013 mbar)*

Air quality level for	Requirements		
	CO_2^*	Humidity class	Room air supply rate
Chronic lung disease sufferers	$P_{99} \leq 680$ ppm	$P_{95} \leq$ II	$\geq 2.4\ l \cdot s^{-1} \cdot m^{-2}$
Children and elderly persons	$P_{99} \leq 865$ ppm	$P_{90} \leq$ II	$\geq 1.5\ l \cdot s^{-1} \cdot m^{-2}$
Healthy adults	$P_{99} \leq 1085$ ppm	$P_{90} \leq$ II	$\geq 1.05\ l \cdot s^{-1} \cdot m^{-2}$

Supplied IAQ

To examine whether the demanded air quality levels are presently supplied, a group of 37 dwellings was examined. Estimated ventilation rate in the studied dwellings was in the range between 0.3 to

0.5 air changes per hour, and in 34 of 37 dwellings CO_2 levels were over 865 ppm for more than a quarter of an hour each day. From the indoor air measurements we calculated P_{90}, P_{95} and P_{99}-intervals of four indoor quality parameters for each dwelling. Using Table 3, dwellings were counted that satisfied the requirements of each susceptibility group. Dwellings that are apt for chronic lung sufferers also satisfy the other two groups (Table 3). It appears that in only 1 of 37 dwellings measured, recalculated values meet IAQ criteria for elderly; no dwellings are health sustaining for COPD sufferers.

*Table 3. Dwelling fitness for 37 dwellings according to CO_2 level, humidity class, ultra fine particle I/O ratio and assessed room ventilation rate in Dutch living rooms during winter (n=37). Overall classification based on set of indicators (highest class found). Figures indicate for each parameter its fitness to accommodate consecutively chronic lung disease sufferers, young and old persons (under 20 or above 49 years of age), and healthy adults. Dwelling fitness overlaps: dwellings fit for lung sufferers are suitable for the other two groups too, dwellings fit for young and old also suit healthy adults; *CO_2, humidity class, room ventilation rate; **CO_2, humidity class, room ventilation rate, ultra-fine particle I/O ratio*

Susceptibility level	Number of dwellings satisfying requirements according to					
	CO_2	Humidity Class	Room ventilation rate	Ultrafine particle I/O ratio	Set of 3 indicators*	Set of 4 indicators**
Chronic lung sufferers	1	5	0	5	0	0
Young (<20) or elderly (≥50)	3	10	3	5	1	1
Healthy adults	6	36	13	5	4	1
Not satisfying any level	31	0	24	16	32	35
Not classified	0	1	0	16	1	1

Ventilation systems

Those technical aspects of ventilation systems were considered that influence health and are not so much related to specific design but to concept or 'general' design. These aspects are compared for each system (Table 4). First of all the efficiency of removing pollutants is important. Natural ventilation does not guarantee a satisfactory dilution of pollutants. Primarily during the summer period the absence of an indoor-outdoor temperature difference as a driving force causes ventilation to stagnate. The standard three-point exhaust fans (C1) are at the moment set at the minimum of the desirable volume, and are not capable to compensate for pollution peaks. High airflow rates are to be expected from inlet windows. From 1992 onwards, mostly ventilation grids have been installed in the Dutch dwellings[1]. Grids and ventilation windows are generally used irregularly. The windows are positioned above the normal windows and are difficult to open and close; furthermore opening means usually open wide,

*Table 4. Characteristics of ventilation systems with regard to health risks (asthma, COPD); ~ Critical level regarding asthma and COPD; * Variable: removal varies from dwelling to dwelling depending on design and location, may be capable to remove incidentally high concentrations; average: no surplus capacity; high: surplus capacity; # Air flow low: below 0.15 m/s; high: over 0.15 m/s; varies: depends on location; o Small surface size: surface up to 2 times the initial opening or exit to the outdoor air (in cm2); large: surface 10 times or more this opening; † Polluting risk low: maintenance usually once a year, handling easy, delay non-fatal; high: maintenance more often and/or handling difficult and/or delay fatal (total clean-up necessary, with imperfect result)*

Ventilation system	Removal of pollutants from the indoor air*	Air flow (draught)# surface of installation°	Size of air -exposed		Polluting risk of installation†	
			supply	exhaust	supply	exhaust
A1	variable ~	variable	small	small	low	low
A2	variable ~	variable	small	large	low	high
A3	variable ~	low	small	small	low	low
C1	average ~	low - high	small	large	low	high
C2 -C3	high	low	small	large	low	high
D1	average ~	low	large ~	large	high ~	high
D2 -D3 -D4	high	low	large ~	large	high ~	high

resulting in draught. Grids differ in size and shape but many are difficult to open and close (rust or paint between panels) and often not easy to clean[30]. Newer grids have easier handling and may be cleaned e.g. in the dishwasher.

Maintenance of all ventilation parts is important, but especially the air inlets. One of the aspects of the Sick Building syndrome of office buildings is the mechanical supply of air. Only an adequate maintenance prevents the advent of airway symptoms. At the supply side the health risk aspects point at the surface size of the air inlet pipes, and at the filters. The latter should be of sufficient capacity, remain dry (relative humidity < 70%) to avoid germinating of bacteria or moulds, and be changed regularly. The interior of the inlet channels becomes polluted, in a slow process, by the small fraction of particles escaping the filters and by condensation or interacting gasses. When filters are not changed regularly or get moist and fungal ridden, more intensive pollution of the interior takes place. Efficient cleaning of ventilation ducts is not possible at the moment. Attempts to clean the soiled ducts in office buildings by way of mechanical brushing or spraying of chemicals appeared not effective. Spraying with liquid acids (as is practiced by some companies in the Netherlands) may be dangerous to health and harm the duct inside, and should be thoroughly studied and accredited by the government before being used in (Dutch) homes or offices[15].

Exhaust ducts, although much more polluted, are generally less important; redistribution of the trapped material is possible when the system goes off or in case of inversion, a backflow due to temperature or wind pressure. When applying air recycling, maintenance is of increased importance: the indoor air contains in general more particles than the outdoor air. In systems with heat recovery, out-going air is supposed to exchange only heat with fresh air. However, a small percentage (up to 5%) of leakage may be expected[16].

User behaviour mixed with or derived from design and installation flaws are responsible for part of the low IAQ levels. For example, grids and other air inlets are not cleaned because they are too high, too difficult to open or remove, or do not fit into the dishwasher. Exhaust fans are turned off because of increased noise[30]. In some of the dwellings adequate ventilation was difficult despite a properly functioning ventilation system, because of the dwelling design: air inlet was only possible through low-placed windows that were draughty and unsafe, or traffic noise prohibited the use of air inlets.

No well-documented evidence exists whether newly installed balanced ventilation systems (D) or adaptive hybrid systems (C2-C3) function in practice better or worse than simple exhaust fans and grids. Case evidence from personal experience seems to indicate that less known technology results in bigger flaws both in installation and in use. In one case, a switched inlet and outlet pair was discovered months after installation. In another case adequate ventilation depended on the proper use of a summer/winter button for heating/cooling; of course, the button and its use was forgotten by some of the occupants of that apartment building.

DISCUSSION

For the Dutch situation and for most of the western countries[27], asthma and COPD are the diseases most influenced by indoor air quality. In asthma especially the young, and in COPD the elderly are involved, although evidence exists of a large underscoring of asthma in the elderly too[28]. Persons already suffering from asthma or COPD are prone to ongoing airway inflammation and demand an even higher quality of air than healthy young or old persons. In our study we combined levels on three IAQ parameters to track and avoid variations in sensitivity in a single parameter.

High CO_2 levels and low ventilation rates indicated that IAQ in almost all of the 37 Dutch dwellings was inappropriate to sustain health for two of the three identified risk groups. In the studied dwellings, ventilation systems of the types A (natural) and C1 (natural plus exhaust fans) were installed. Since 1980, the capacity of the C1 systems is levelled to reach 9.10^{-4} $m^3/(s.m^2)$. Infiltration, that is, ventilation through unintended openings around windows and other building parts, has decreased in the same period from more than 0.3 m^3/s (at 10 Pa pressure difference) to an average of 0.1 m^3/s [29]. New dwellings may have only one tenth of that, and depend much more than before on intended/installed ventilation.

We are aware that the group of dwellings studied has not been randomly chosen. However, the absolute levels of pollution and the high frequency of exceeding acceptable levels indicate that indoor air quality in Dutch dwellings is poor. Other studies have shown that indeed IAQ is not good[30].

While dilution and removal of polluted air are most important in sustaining IAQ, current ventilation systems do not function well in practice, as shown by this and other studies[1,30]. A combination of reasons is the cause of this phenomenon. Grids, windows, and fans are often not well designed, resulting in improper use or malfunctioning; set points of fans are at minimum demands to save energy, not allowing for any fallback of flow capacity in time. Maintenance of ventilation systems is poor, causing extra pollution coming indoors and decreased flow rates. Users are unaware of the importance of ventilation and close grids or keep windows shut permanently. Even when a pollution peek is foreseeable (cooking, a party), the manual fan switch, which should be set to 'high', is often not used.

The presently studied ventilation systems A and C1 are in practice not adequate to sustain a healthy environment for population groups with an increased susceptibility for asthma or COPD. The reasons are both technological and user-derived. The latter is, however, mixed with poor design. Will newer ventilation systems do better? A preliminary study revealed that in 25% of all new dwellings the intended ventilation level is not reached[30]. Balanced ventilation systems with heat-recovery have different risks than traditional systems, and appear up to now not better than mechanical exhaust fans or natural ventilation only.

Ventilation technology that is able to avoid high concentrations of pollutant at any time and keeps IAQ excellent throughout the day could work pro-actively in the prevention or decrease of symptoms of airway diseases. Adequate ventilation prevents acute symptoms from high pollutant concentrations, and may be beneficial on the long term. For the latter effect more proof is necessary, though. This will only be true when this ventilation system can cope with the above reasons for practical malfunctioning.

Pro-active ventilation technology is ventilation that provides an excellent IAQ throughout the day, thus sustaining health. Most of the alternative ventilation systems (C2 - C3, D1 - D4) were at first designed to reduce energy, meanwhile taking care of adequate ventilation. We opt for those systems that are taking care of healthy ventilation in disregard of a bonus energy reduction. The most promising systems are the ones that allow dwellers to increase or decrease the supply rate at any location they want, meanwhile taking care of proper base ventilation. These adaptive sensor-controlled systems must also be easy to handle and to clean. The persons most responsible for proper implementation and use are at first the designer and the installer. The user, of any age, should be only the last, and intentionally least important party to sustain a healthy indoor environment.

We are unaware of any field study that shows that any of the new ventilation systems functions adequately in presence of a variety of dwellers, such as the lung disease sufferers and the group over 50 years of age. From the risk characteristics (Table 2), the systems that may have the demanded qualities are the C2 and C3 systems. A further study into the practical use of these is wanted.

CONCLUSION

In almost all of the dwellings studied, IAQ was less than optimum for any population group, but especially for elderly lung sufferers. Present systems lacked the combination of secure base level ventilation and a high on-demand level that could result in a pro-active protection against health risks for asthma and COPD sufferers and sensitive groups. In newer systems an increased size of air-exposed surface (filters, ducts) of the ventilation system introduces an intrinsic risk. Adaptive, easily maintained and handled systems without ducts for inflowing air are the most promising systems to contribute to a healthy home environment for all.

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