Productivity and Indoor Air Quality

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ABSTRACT

People spend in industrialized countries more than 90 % of there lives in an artificial indoor environment (home, transportation, work). In typical office buildings the cost of people is a factor 100 higher than energy costs, which make the performance of people at their work significantly more important than energy costs. Studies on people sick leaves show a very high loss of work time and performance, which have significant economical consequences for companies.

Recent studies in offices and schools show that comfortable room temperatures, increased ventilation above normal recommendation, reduction of indoor pollution sources and more effective ventilation increases the performance of people. The results indicate increase of productivity of 5-10 %.

KEYWORDS: health, comfort, productivity, indoor environment. Air quality

INTRODUCTION

Ambient (outdoor) air quality in cities in industrialized countries has improved greatly in recent decades. During this same period, indoor air quality has declined because of energy conservation, decreased ventilation and the introduction of many new materials and sources of indoor pollution. These developments and the fact that people in industrialized countries spend 90% of their lives indoors on average makes the quality of indoor air an important environmental issue with far-reaching implications for human health. The following three estimates are based on large worldwide field studies.

In many industrialized countries, up to 50% of schoolchildren suffer from asthma and allergy, and this figure has doubled over the past 20 years. A new study by the Technical University of Denmark documents for the first time associations with phthalates from plastic materials and with poor ventilation in homes.

In offices, typically 20–60% of occupants suffer from symptoms associated with sick-building syndrome, which include headache, fatigue and irritation of mucous membranes. The Technical University of Denmark has shown that poor indoor air quality causes sick-building syndrome and that it reduces the productivity of office workers.

In developing countries, 5000 people die daily from polluted indoor air according to the World Health Organization. The cause is indoor pollution from cooking without vents, using wood or manure as fuel.

When discussing problems with the indoor environment the focus is often on the requirements for ventilation. Increasing demand for lower energy consumption of buildings has resulted in decreasing heat losses due to transmission and tighter buildings. This may often result in too low ventilation rates. This fact and the introduction of many new building materials may often lead to un-acceptable indoor air quality and building damage like mould.

The present paper presents results on the influence of the indoor environment on health, comfort and performance of the occupants.

Health

Based on the statement in the WHO constitution [1], health may be defined as a "state of complete physical, mental and social well-being and not merely the absence of disease or infirmity". Likewise, healthy indoor air may be defined as the air that does not provide any risk of disease and that ensures comfort and well being for all occupants [2]. Although the right to health was recognized as early as in 1946 more than a half-century needed to acknowledge that every human being has the right to breathe healthy indoor air [3, 4]. In order to meet this requirement it is the duty of building engineers and designers to adopt adequate techniques, which ensure the excellence of indoor air quality and minimize the occurrence of any possibly harmful compounds in the inhaled air in concentration and for duration that may cause unwanted health or comfort effects.

Exposures in indoor environments and health effects due to such exposures vary between regions of the world. In developing regions limited number of studies has been conducted regarding IAQ and health. The studies have dealt mainly with associations between indoor air pollution, due to un-vented burning of biomass, and health effects such as acute respiratory infections, chronic obstructive pulmonary disease and lung cancer. WHO has calculated that burning of solid fuel for cooking and heating in developing countries might be responsible for nearly 4% of the global burden of disease, i.e. approaching 2 million premature deaths per year [5]. This is one of the main environmental health issues of the world but so far little recognized.

Studies on exposures in indoor environments and health effects in developed countries have mainly been conducted in Europe and North America. The evidence is strong regarding an association between IAQ and lung cancer, allergies, other health and comfort effects including Building Related Illnesses (BRI), Sick Building Syndrome (SBS) and Multiple Chemical Sensitivity (MCS) [6,7].

Health in residential buildings

Allergic and asthmatic diseases have doubled in industrialized countries during the past two decades. They comprise one of the greatest current problems for public health, with enormous costs for medicine, treatment and absenteeism. In many industrialized countries, half the schoolchildren suffer from these allergic diseases, which are the main reason for absenteeism in schools.

The rapid increase of the incidence in allergy/asthma and other health effects (Figure 1, left) over the past few decades implies that it is due to changes in environmental exposures rather then genetic changes.

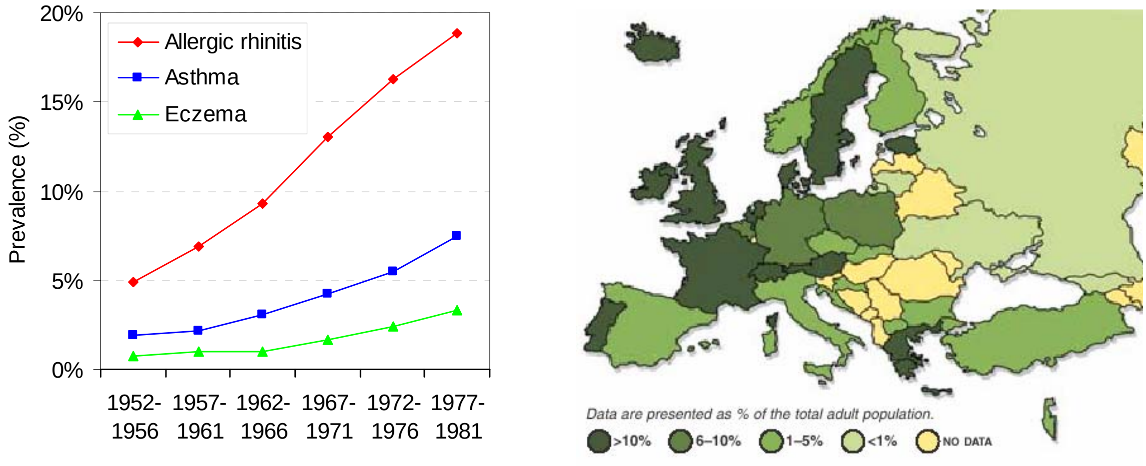

Figure 1. Left: Trends for allergic rhinitis, asthma and eczema among male conscripts (17-20 years age) in Sweden [8]. Right: Current data on prevalence of asthma in adults in Europe [9].

Surprisingly, very few people had asthma in the former communist countries in Eastern Europe before 1989 (Figure 1, right) despite high ambient air pollution in many cities. User charges for energy were often zero or very low, and the ventilation in leaky dwellings was typically much higher than in Western Europe.

Indoor air quality has declined partly because of comprehensive energy conservation campaigns and partly because high energy prices have motivated people to tighten their dwellings and reduce the rate of ventilation, so that the air change in many homes is at a historically low level. Other factors contributing to poor indoor air quality are the many new materials, especially polymers, and the numerous electronic devices that have been introduced indoors in recent decades, especially in children's rooms

The world's largest study [10,11,12,13] on the relationship between poor indoor air quality and asthma comprises 11,000 children, and detailed chemical, physical, biological and medical measurements have been performed in 200 homes with asthmatic children and 200 homes with healthy children. These homes were situated in areas with excellent outdoor air quality. The results show that low ventilation increases the risk of allergic symptoms significantly (Figure 2) and that the presence of phthalates emitted from polyvinyl chloride, including plasticizers in children's rooms, increases the risk of asthma dramatically (Figure 3). The global production of plasticizers has increased enormously since the 1950s and now comprises 3.5 million tons per year. These results may radically affect how indoor environments are designed to protect children from asthma and allergies.

Dampness

In a study of several residential buildings [14,15] with natural ventilation the humidity production was measured to 2,7 kg water per Person per Day. To limit the increase in the humidity in the indoor air from people (persons, cooking, etc.) to 4 g water per kg Air in relation to the outside air, a ventilation rate of 7 l/s per person is required (16,17). In typical residential buildings this is equivalent to 0,35 l / s · m². This corresponds to 0.5 air changes per hour

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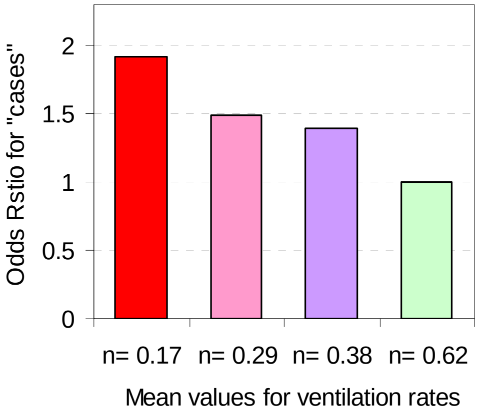

Figure 2. **Odds ratio for being a "case", i.e. children with at least two symptoms of possible three (wheezing, rhinitis, eczema) as function of ventilation rates, in single family houses. [10,11,12]**

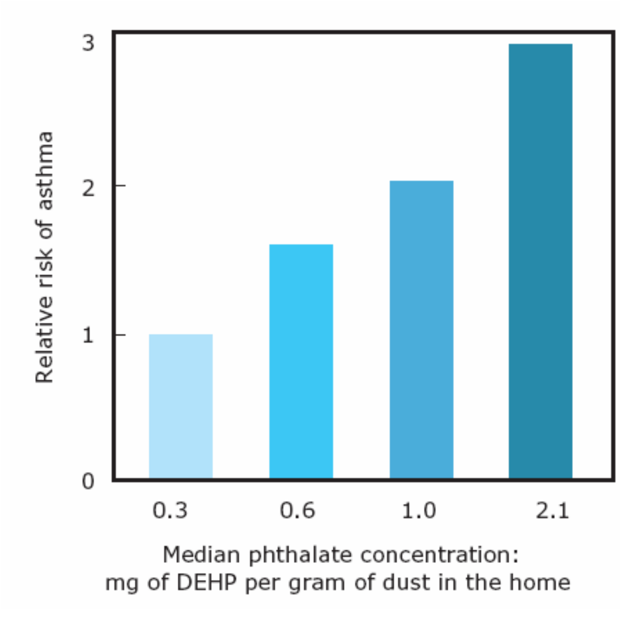

Figure 3: **Plasticizers from polyvinyl chloride in dwellings increase the risk of asthma among children. Each column represents about 90 dwellings. DEHP: di(2-ethylhexyl) phthalate [12,13]**

In a large number of studies (including more than 100000 people) [10,18] an association has been found between living or working in "damp" building and health effects, such as cough, wheeze, allergies and asthma. However, there are indications that also other health effects, such as general symptoms (e.g. tiredness, headache etc.), irritation and airway infections are associated with dampness. It should be noted that it is still not shown which dampness related exposures are responsible for the health effects observed [18,19,20,21]

The criteria used for classifying a building as damp may vary. Identified health-relevant moisture-problems included water damage (visible damp spots or detached/discoloured flooring materials) excess condensation of water on cold surfaces (e.g. on the inside of window panes) and signs of microbial growth (visible mould spots and bad odour). A distinction should however be made between the moisture in the building structure and humidity in indoor air. Moisture in the building construction (originating from outdoor or indoor sources) can degrade building materials, creating favourable conditions for microbial growth and chemical reactions that are often identified as sources of allergens, irritant substances and bad odour. Relative humidity in indoor air may cause condensation on cold interior surfaces or in the construction that also increases the risk of microbial growth and chemical processes. For example, the dew point corresponding to 23 °C with 50% RH of indoor air is 12 °C. Thus any indoor construction with a temperature approaching 12°C for this case is at high risk for condensation and thus ideal place for microbial activities, although the RH in the indoor air is still within acceptable limits. It is also well known that increased water content of indoor air will raise the risk of house dust mite (HDM) infestation (Figure 4, [22]). The infestation of HDM may be considered low (up to 1000 ng/g dust) if indoor absolute humidity remains below 7 g/kg air corresponding to relative humidity of 45% at 20-22°C.

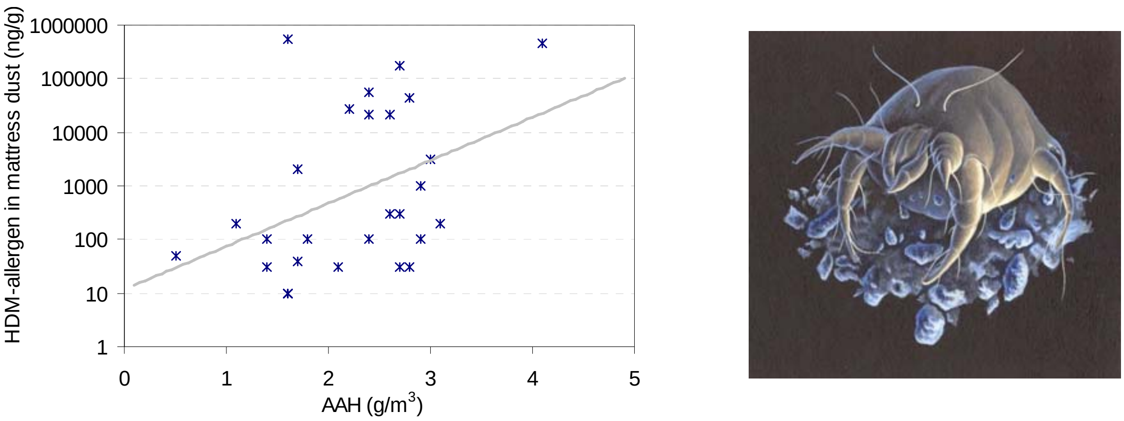

Figure 4. Left: HDM allergen in mattress dust as a function of adjusted additional humidity (AAH) in homes (difference between absolute humidity in air indoors and outdoors) [22]; Right: Close-up of adult dust-mite feeding within household bedding (http://www.jonathanlatimer.com/).

It is often assumed that dry indoor air, i.e. low air humidity could cause a drying out of the mucosa of the upper airways and skin due to increased evaporative power of dry air. A number of laboratory and field studies show that the perception of "dry air" is due more often to the air being polluted or too warm than being physically "dry". Since the sensation of dryness is strongly associated with the prevalence of SBS, it is therefore used as indicator of the health problems in buildings, but not to indicate that the air has low water content [23,24,25]

Ventilation

The scientific evidence, based on a recent European review, indicates that outdoor air supply rates below 25 L/s per person in commercial and institutional buildings are associated with an increased risk of SBS (Figure 5, [20]), increased short-term sick leave and reduced productivity.

Studies on the associations between health effects and ventilation rates and homes are rare. However the literature on “dampness” suggests that inadequate ventilation in homes constitute a major risk factor for health effects (cough, wheeze, asthma and airways infections) (Figure 5). A damp home is also associated with low ventilation rate and low ventilation rate (typically below 0.5 ach) is not only associated with increased house dust mites infestation, but also probably with increased concentration of many indoor-generated air pollutants. It should be noted that homes with higher ventilation rate (typically above 0.5 ach) may also present a risk for increased exposure to airborne pollutants if the bedroom, where people spend a substantial amount of time compared to the other locations of the dwelling, is not well ventilated [20, 26]. A simple indication of low ventilation in bedrooms was shown to be the amount of condensation on windows (Figure 6)

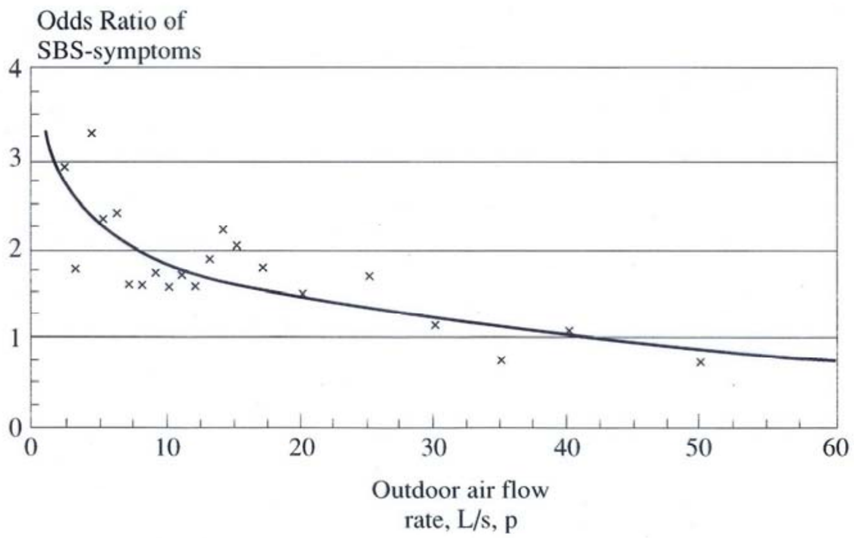

Figure 5. Adjusted odds ratio of SBS for low outdoor air flow rate in commercial buildings [20]

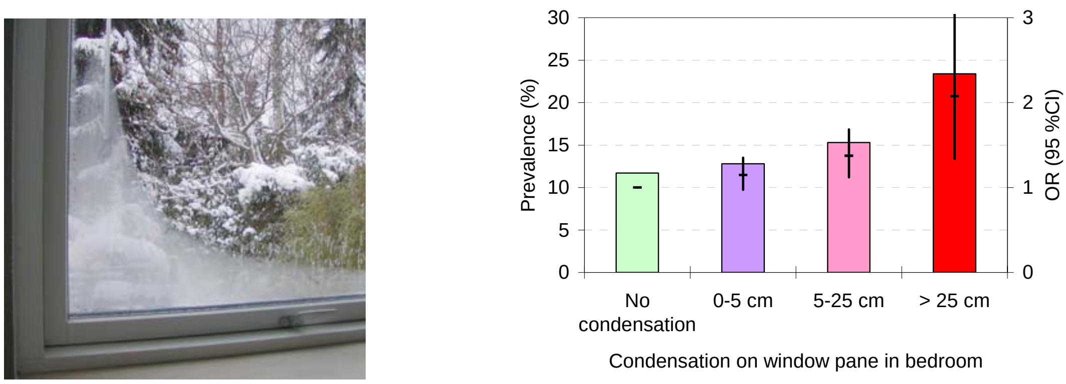

Figure 6: Window water condensation is often sign of poor ventilation in dwellings; Right: Prevalence and odds ratio for rhinitis among children versus condensation on windows pane in bedroom [11]

COMFORT

In most international standards and guidelines the recommended ventilation rates are based on comfort criteria. [27], which is related to the perceived air quality. In a new European standard EN15251 [28] three categories are listed for recommended ventilation rates. This is similar to the existing European Guideline CR1752 [29]. Different parameters like %-Dissatisfied (Figure 7, right), decipol [30,31] or CO_2-Concentration as an indicator of the bio effluents from people (Figure 7, left) and the required ventilation rate (Table 3) are used as an indicator for the indoor air quality. The CO_2 concentration above outdoor level corresponding to the three air quality categories is 460 ppm (category A), 660 ppm (category B) and 1190 ppm (category C).

Earlier most standard and guidelines for the required ventilation rates were given as ventilation per person. Both laboratory and field studies have, however shown that people and their activity (smoking, activity level), building and furnishing (floor covering, paint, furniture, cleaning, electronic equipment, etc.) and ventilation systems (filters, humidifiers, ducts etc.) may also contribute. Even the outside air may be a source to indoor air quality problems. It is, however difficult to compare the different type of sources. One possibility was introduced by using the Olf-Decipol units [30,31].

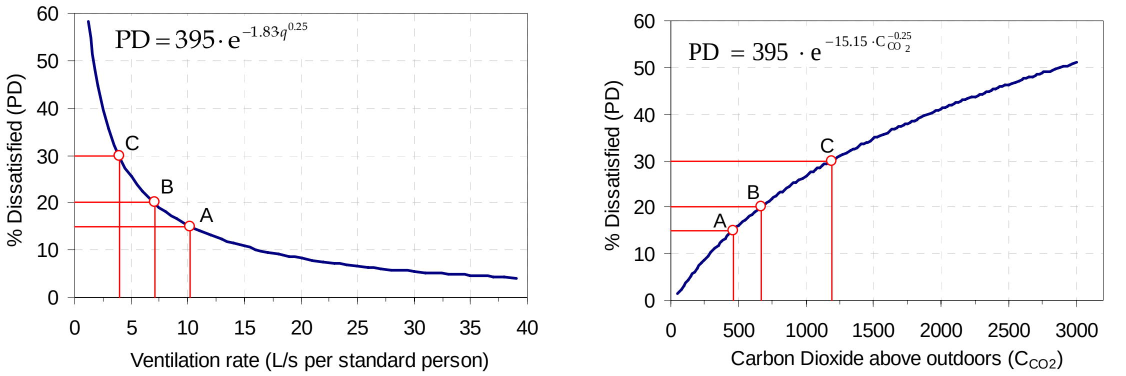

Figure7. Left: Carbon dioxide (CO_2) as indicator of human bio effluents [28,29]; Percentage of dissatisfied visitors as function of the CO_2 concentration above outdoor levels where sedentary occupants are the exclusive pollution sources. Right: Percentage of dissatisfied visitors as function of the ventilation rate per standard person (average sedentary office worker being thermally neutral, [29]). The pollution generated by such a standard person is called "olf"; the required minimum ventilation rate according to the three air quality categories A, B and C are 10 L/s.olf, 7 L/s.olf and 4L/s.olf, respectively.

Table 1 shows the emissions from people and their activity. The CO_2 emission is indicator for the bio effluents from people. The CO emission is used as indicator for smoking.

There is relative little information regarding the contribution of emission from building and furnishing on the perceived indoor air quality [31,32,33]. Some values are shown in Table 2. New studies [34] in non-smoking buildings show values around 0,08 – 0,13 olf/m². These values are in the range of low-polluting buildings (table 3). Even values down to 0,02 olf/m² floor have been measured [35]. Other studies [36] showed that also electronic equipment as PC's can be a significant source (Table 1). A new PC

Table 1 Pollution load caused by occupants.

	Sensory pollution load olf/occupant	Carbon dioxide L/(h x occupant)	Carbon monoxide [a] L/(h x occupant)	Water vapour [b] g/(h x occupant)
Sedentary, 1-1.2 met				
0% smokers	1	19		50
20% smokers [c]	2	19	11×10^{-3}	50
40% smokers [c]	3	19	21×10^{-3}	50
Physical exercise				
low level, 3 met	4	50		200
medium level, 6 met	10	100		430
high level (athletes),10 met	20	170		750
Children, kindergarten				
3-6 years old, 2.7 met	1.2	18		90
school				
14-16 years old, 1-1.2 met	1.3	19		50
Computer				
With CRT-Monitor, new	3			
With Flat screen Monitor	0			

a) From tobacco smoking
b) Applies to persons close to thermal neutrality
c) Average smoking rate 1.2 cigarettes/h per smoker, emission rate 44ml CO/cigarette

Table 2 Pollution load caused by the building, including furnishing, carpets and ventilation system.

	Sensory pollution load olf/(m^2 floor)	
	Mean	Range
Existing buildings[31,32,33]		
Offices [a]	0.3 [d]	0.02-0.95
Offices [b]	0.6 [c]	0-3
Schools, classrooms [a]	0.3	0.12-0.54
Kindergartens [a]	0.4	0.20-0.74
Assembly halls [a]	0.3 [d]	0.13-1.32
New buildings (no tobacco smoking)[34,35]		
Low-polluting	0.1	
Non-low-polluting buildings	0.2	
Extremely low-polluting buildings	0.02	

a) Data based on more than 40 mechanically ventilated buildings in Denmark.
b) Data based on European Audit Project to optimise IAQ and Energy Consumption in Office Buildings, 1992-1995
c) Includes load caused by present and previous tobacco smoking.
d) Includes load caused by previous tobacco smoking.

contributes to the pollution load equivalent to three persons. The monitor mainly causes it.

Like with several other indoor sources from the furnishing (furniture, paint, floor covering etc.) the emissions are highest when the product is new. Therefore a 3 year old monitor has almost no emission.

Both people and building is taken into account in newer standards for the required ventilation rates in buildings. Table 3 show the required ventilation rates from recent standards like EN15251 [28], ASHRAE 62.1 [37], and CR 1752 [29]. There is however quit big differences between the European recommendations and the ones listed by ASHRAE. One major reason is that ASHRAE requirements are minimum code requirements, where the basis for design is adapted people, whereas the European recommendations are based on un-adapted people.

INDOOR ENVIRONMENT AND PRODUCTIVITY

The effects of indoor air quality on productivity became an issue only in the last decade, as a result of extensive research and an understanding of the strong connections between factors such as ventilation, air-conditioning, indoor pollutants and adverse effects on health and comfort. The complexity of a real environment makes it very difficult to evaluate the impact of a single parameter on human performance, mostly because many of them are present at the same time and as a consequence, act together on each individual. In addition, worker motivation affects the relationship between performance and environmental conditions (e.g. highly motivated workers are less likely to have reduced performance in an unfavourable environment; however they may become more tired that may also affect performance).

One way of evaluating the performance is the use of self-reported performance. This was used to study the self evaluation of the influence of environment, job satisfaction and job stress on performance [38]. The study was performed among 170 people in six offices. The self reported performance was made on a nine point scale. Based on the data the following equation for the self reported performance (WEP) could be established:

$$WEP = 6.739 - 0.419E - 0.164JD - 0.048JS \quad (1)$$

Where:
E = Dissatisfaction-Environment
JD = Job satisfaction
JS = Job stress

It is clear that the indoor environment was evaluated to have the biggest influence on performance. Much higher than job satisfaction and job stress.

A common approach, to evaluate the influence of climatic factors on human performance could be to measure the extent to which the SBS symptoms occur, as these symptoms are known to cause distraction from work or even short-term absenteeism. However, this link is not well established yet and must be better understood and recognized. A possible mechanism may be described as follows: (1) inadequate ventilation or superfluous emissions from different sources increase the concentration of pollutants, which negatively affect perceived air quality; (2) reduced air quality negatively affects the central nervous system, increasing SBS symptoms such as headache, difficulty in concentration, tiredness; (3) these symptoms will cause distraction from work and decreased work ability, i.e. productivity loss. Nevertheless, indoor pollution may also exacerbate the sensation of dryness and irritation of eyes. As a consequence, a higher blinking rate and watery eyes will negatively affect visual skills and decrease the performance of visually demanding work.

Table 3 Smoking free spaces in commercial buildings according to ASHRAE 62.1[37], CR 1752 [29], EN15251 [28]

Type of building/ space	Occupancy person/m^2	Cate-gory CEN	Minimum ventilation rate, i.e. for occupants only l/s person		Additional ventilation for building (add only one) l/s·m^2			Total l/s·m^2	
			ASHRAE R_p	CEN	CEN low-polluting building[1)]	CEN *not* low-polluting building	ASHRAE R_a	CEN Low Pol.	ASHRAE
Single office (cellular office)	0,1	A	2,5	10	1,0	2,0	0,3	2	0,55
		B		7	0,7	1,4		1,4	
		C		4	0,4	0,8		0,8	
Land-scaped office	0,07	A	2,5	10	1,0	2,0	0,3	1,7	0,48
		B		7	0,7	1,4		1,2	
		C		4	0,4	0,8		0,7	
Conference room	0,5	A	2,5	10	1,0	2,0	0,3	6	1,55
		B		7	0,7	1,4		4,2	
		C		4	0,4	0,8		2,4	
Auditorium	1,5	A	3,8	10	1,0	2,0	0,3	16	6
		B		7	0,7	1,4		11,2	
		C		4	0,4	0,8		6,4	
Cafeteria/ Restaurant	0,7	A	3,8	10	1,0	2,0	0,9	8	1,17
		B		7	0,7	1,4		5,6	
		C		4	0,4	0,8		3,2	
Classroom	0,5	A	3,8	10	1,0	2,0	0,3	6	2,2
		B		7	0,7	1,4		4,2	
		C		4	0,4	0,8		2,4	
Kinder-garten	0,5	A	5,0	12	1,0	2,0	0,9	7	3,4
		B		8,4	0,7	1,4		4,9	
		C		4,8	0,4	0,8		2,8	
Department store	0,15	A	3,8	14,7	2,0	3,0	0,6	4,1	1,17
		B		10	1,4	2,1		2,9	
		C		6	0,8	1,2		1,7	

There is limited information in the literature showing a direct relationship between SBS symptoms and worker productivity. Analyzing the data of British Office Environment Survey (BOES, [39]) Raw found that people reporting more than two symptoms on the SBS list are likely to have reduced performance ratings, and a linear relationship exists between SBS and self-estimated productivity.

Based on his data, Fisk and Rosenfeld [40] estimated an average decrement in the self-reported productivity of 2%. Raw and his colleagues emphasized that the responses evaluated on a 9-grade subjective scale reflect the responder’s belief, regardless of whether that belief is correct, and the actual productivity was not assessed. Mucous and work-related symptoms were also found to affect self-reported productivity [41], but no further validation on the accuracy of self-reports related to the actual productivity loss were made by other field investigations. Measured data in a field experiment [42] indicate a relationship between SBS symptoms and worker performance. As part of an SBS study of 3 weeks, in which the outdoor air supply was experimentally varied, 47 employees undertook two computerized neurobehavioral tests at their workplace. The workers presenting with more SBS symptoms were found to respond 7% longer in a continuous performance task and to have 30% higher error rate in a symbol-digit substitution test. As correlations were found also with temperature but not for the measured pollutants, it is more likely that the effects observed were not only due to air quality factors.

There is substantial evidence that poorly perceived indoor air quality is likely to have a negative effect on work performance. This effect was demonstrated first by Wargocki et al. [43] when he exposed impartial female subjects in a realistic office environment to the emissions from a carpet. The study showed that by improving perceived air quality, the SBS symptoms were reduced and performance of typical office tasks increased. These findings were later confirmed by several other independent investigations conducted in Denmark using different ventilation rates [44,45] and Sweden [46] using various types of pollution sources and different subjects. Based on these result an overall relation between ventilation rate per person and performance was established (Figure 8). The quantitative relationships were developed based on these results and show that for every 10% increment in % of dissatisfied in the range 15-68%, c.a. 1% decrement in performance of text-typing can be expected [45,47].

The results of recent studies [55,56,57] show that improving IAQ in real buildings has in fact larger effect on the actual performance of office work in the field (up to 9%) than would be predicted from the field laboratory experiments mentioned above.

Indoor environmental quality affects the performance of schoolwork by children

Five independent field intervention experiments were carried out in six identical classrooms in an elementary school in Denmark [58,59]. In three experiments carried out in late summer and in winter, the outdoor air supply rate per child was increased from about 3 L/s to 10 L/s, while in two experiments carried out in late summer the temperature was reduced from about 25 ^{o}C to 20^{o}C. The outdoor air supply rate was increased using the existing mechanical ventilation system while temperature was reduced by either operating or idling split cooling units installed in the classrooms. For each condition, tasks representing up to eight different aspects of schoolwork, from reading to mathematics, were performed by 10 to 12-year-old children. The tasks were selected so that they could have been a natural part of an ordinary school day. The tasks were presented to children by their teachers. Both teachers and pupils were blind to the interventions. No changes to the lesson plan or normal school activities at school were made, so as to ensure that the teaching environment and daily routines remained as normal as possible.

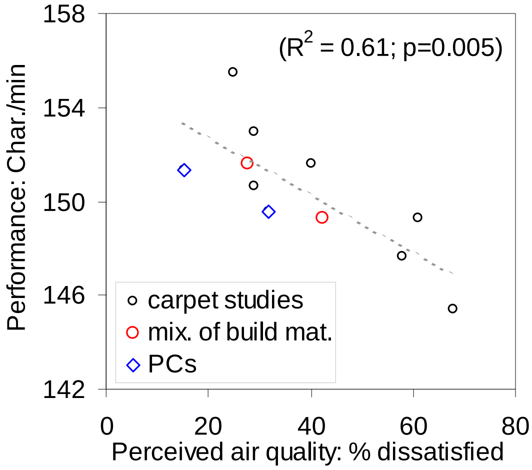

Figure 8. Performance of text-typing as function of PAQ expressed in % dissatisfied, based on the results of laboratory studies, using typical indoor pollution sources such as carpets, linoleum, books and papers on wooden bookshelves, sealant and personal computers [45,47]

The results show that an increased outdoor air supply rate and reduced air temperatures significantly improved the performance of many tasks, mainly in terms of how quickly each pupil worked, but also for some tasks in terms of how many errors were committed: Doubling the outdoor air supply rate improved the performance of schoolwork by about 14.5% (Fig. 9), while reducing classroom air temperature by 1K improved performance by about 3.5%.

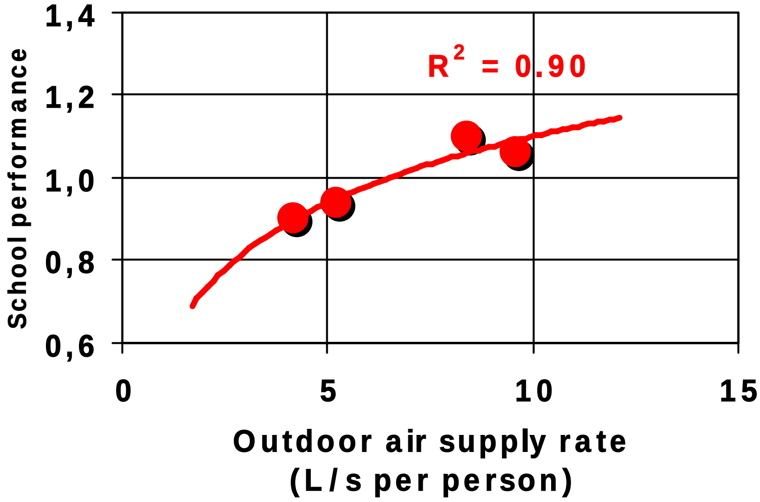

Fig 8 Performance of schoolwork as a function of outdoor air supply rate [58,59]

The studies indicate that improving indoor air quality in classrooms by increasing the outdoor air supply rate, and reducing classroom temperatures, can substantially improve the performance of a wide range of tasks characteristic of schoolwork, from rule-based logical and mathematical tasks requiring concentration and logical thinking to language-based tasks requiring concentration and comprehension. The air quality and temperatures in classrooms are thus very important factors in the learning process and should, together with teaching materials and methods, become an urgent educational priority.

Although Danish pupils were used, the results can be generalized to other countries in Europe and the USA because classroom conditions and the level of education and educational programs in Denmark are quite similar to those in other developed countries.

Economical consequences

It is natural to ask whether such an improvement in the air quality level to obtain only a few percent increment on the productivity side will justify any investment to improve the indoor air quality, especially when there are no obvious complaints, and knowing that thermal conditions even within the thermal comfort zone according to Wyon [48] may reduce performance by 5-15%. Seppanen and Fisk [49] compiled the results from studies relating the indoor thermal temperature to performance (Figure 10).

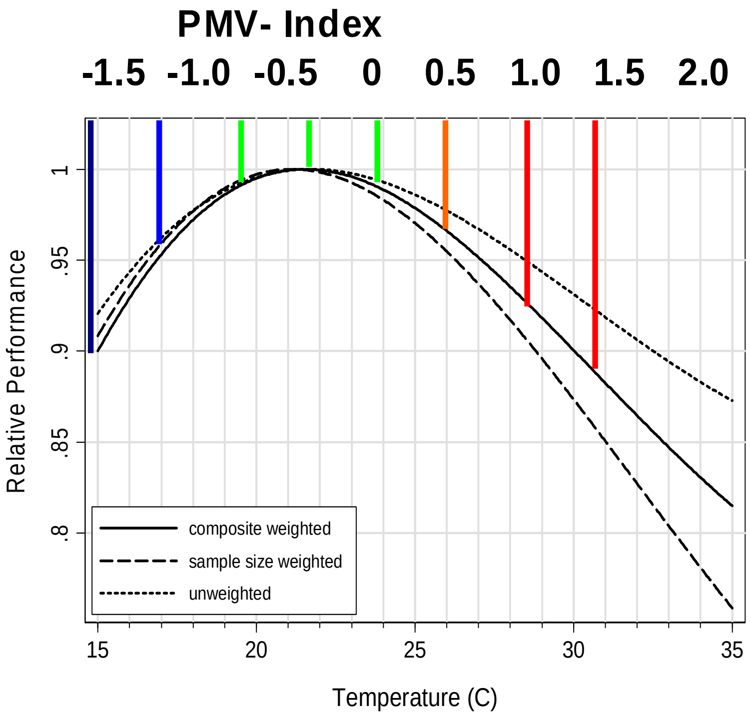

Figure 10. Relation between indoor room temperature and performance from several published studies [49]

Details about clothing and activity were not listed for all studies included in figure 10, so the temperatures cannot easily be related to the corresponding comfort zone. The authors conclude that the nature of this association is that productivity improves as thermal conditions approach a predicted thermal comfort zone.

The salaries of workers in typical office buildings exceed the building energy and maintenance cost by approximately a factor of 100. The same applies for the salaries and annual construction or rental costs [50,51]. Thus, even a 1% increase in productivity should be sufficient to cover any expenses related to doubling of energy or maintenance costs or other large investments involving construction costs or rent.

In view of the fact that a good IAQ also reduces the prevalence of SBS symptoms, Fisk et al. estimated that considerable gains and savings may result in health care costs, involving billions of dollars nation-wide in the US [40,52]. In another study Milton et al. [53] investigated the sick leaves for 3.270 employees in 40 buildings. For the employees in the offices the risk for short sick leaves was a factor 1,53 higher at a ventilation rate of 12 l /s . Person compared to a ventilation rate of 24 l /s . Person.

The effect of improving the indoor environment from Category C to B, or Category B to A was studied by Roelofsen [38]. The results are shown in table 4.

Table 4. Comparison of costs and improved performance by increasing the indoor environment from one category to a higher category [38]

Costs	Category C to B	Category B to A
Additional investments	~80 €/m²	~96 €/m²
Improved performance	~98 €/m² year	~55 €/m² year
Maintenance	~2,8 €/m² year	~1,1 €/m² year
Energy	~0,35 €/m² year	~1,00 €/m² year
Pay-back time	~0,8 year	~1,8 year

The review by Wyon [48] on the published literature showed that the payback time for general upgrading of currently unhealthy office buildings (representing 40% of the building stock) would be as low as 1.6 years if only a 0.5% increase in the overall productivity is achieved. Moreover, the cost-benefit simulation made by Djukanovic et al., [54] showed that the annual increase in productivity was worth at least 10 times as much as the increase in annual energy and maintenance costs, when improving the perceived air quality in office buildings, specifying a pay-back time of no more than 4 months due to the productivity gains achieved.

Based on the current knowledge regarding IAQ and performance of human work it seems that it is worth investing fundamental resources to improve the quality of indoor air, next to other environmental factors in real buildings, that will definitely lead to an improved work performance among the occupants, which is not necessarily measured in terms of characters typed or number of units added.

CONCLUSSIONS

The required ventilation rate in buildings must take into account both comfort and health.

People are not the only sources polluting the air (bio effluents, smoking, and humidity). Also emissions from the building (building materials, paint, furnishing, electronic equipment like PC's and TV's) and HVAC systems must be taken into account.

Studies have shown that even if the ventilation rates meet existing standards there may still be a significant amount of people not finding the environment acceptable and in some cases result in health problems.

An increased ventilation rate will also increase the performance of the occupants. Limiting the pollution sources, improving air quality by air cleaning or increased ventilation rates may increase performance of the occupants by 5 to 10 %.

To reduce energy consumption by decreasing the quality of the indoor environment is a bad investment.

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