VENTILATION AND HEALTH – A REVIEW

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ABSTRACT

People in industrialised countries spend about 90% of their time indoors. Hence, a good indoor climate is essential for health and well-being. Ventilation of buildings plays an important role concerning health aspects of the occupants and inadequate ventilation may cause health costs that may have been avoidable if ventilation would have been adequate. Additionally, good or bad ventilation has impacts on the quality of the building, e.g. in very tight buildings, the risk of mould and dampness is higher if air change is insufficient. This paper focuses on the influence of different types of ventilation systems and ventilation rate on occupant's health in homes and schools. A literature search has been conducted to review the influence of ventilation on different health outcomes.

Most of the studies were found for the influence of natural vs. any type of mechanical ventilation on different health indicators. But the results of the different studies are not consistent. The reason for this may lie in the sometimes slightly but often considerably different ventilation variables that are evaluated. Studies report e.g. on the one hand that in naturally ventilated day care centres, the prevalence of asthma symptoms and rhinitis decreased whereas in another studies mechanical ventilation systems reduce eye and nasal irritation symptoms as well as tiredness. There are also studies that report no differences between the usage of natural vs. mechanical ventilation systems. One main weak point of many studies is that variables that may bias the results are not indicated, e.g. the state of the filters used. Two studies were designed as intervention study and they investigated the influence of heat recovery ventilators on asthma and respiratory disorders. Wheeze and rhinitis were found considerably lower in homes with heat recovery ventilators.

Low ventilation rates promote the development of allergies and respiratory diseases like wheeze or cough (OR between 1.3 and 2.39). In schools, ventilation rates are often below the recommended values (e.g. about 0.9 to 3 l/s instead of 8 l/s per person) and may therefore ease illness of pupils and teachers.

The following conclusions may be drawn from this work: First, a higher ventilation rate promotes health and attention should be drawn on the achievement of sufficient ventilation rates, especially in schools. Focused

research should give a more detailed insight into this relationship. Second, the influence of the type of ventilation system is ambiguous with respect to the outcome. No clear recommendation for natural or mechanical ventilation could be derived from the available studies. More consistent data is needed with better documentation of confounding variables to consider causal relationships.

KEYWORDS

Ventilation rate, ventilation system, health, illness, review

1 INTRODUCTION

Buildings should protect people from harsh climatic conditions outside, e.g. very cold winters or very hot summers or rainfalls. Based on the materials used for construction and furnishing and the way how the rooms are used, a certain indoor climate occurs in the building. A very important part, how good or bad the indoor climate is, is the ventilation of the building. This includes as well the ventilation system itself, i.e. whether natural or mechanical ventilation or a combination of both is used, and additionally the ventilation rate, that is the amount of fresh air that is delivered inside the room. The indoor climate has a fundamental impact on the health of the occupants. It is known that the occurrence of visible mould spots or dampness may promote the development of asthma and allergies especially when exposure begins at a very young age (Quansah, 2012; Mendell, 2011).

While the research about mould in buildings is very popular, the influence of ventilation in all its different aspects (amount of fresh air, ventilation system) has reached much less attention, especially in residential buildings, schools and day care centres. Much work has been done for offices (e.g. Mendell, 1993, Seppänen & Fisk, 2002, Seppänen et al., 2006), here with an additional focus on performance, but the mere health aspects are seldom considered in a systematic way. The objective of this work is therefore to summarize the available knowledge and to identify future research needs.

2 METHOD AND RESULTS

A literature search was conducted to find the relevant scientific studies that focus on the influence of ventilation on health. The focus was set on homes and schools. To do this, databases, conference proceedings and journal articles were searched. Additionally, references from identified studies and reviews (Seppänen et al., 1999, Wargocki et al., 2002, Daisey et al., 2003, Seppänen & Fisk, 2004, Sundell et al., 2011) were searched by hand for further data. In total, 28 studies could be identified and were analysed in the next sections.

Based on the analysed studies, the following differentiation has been done. Some studies focus on the influence of different ventilation systems on different health outcomes whereas other research looks at the influence of the ventilation rate on health independent of the ventilation system. Other studies (e.g. intervention studies) could not be integrated in this scheme, therefore they are analysed separately.

2.1 The influence of the ventilation system on health

In this part, 13 studies were identified. Mainly, they focus on the influence of natural ventilation (NV) vs. mechanical exhaust ventilation (ME) vs. balanced ventilation (BV), i.e. mechanical supply and exhaust systems. The main characteristics of the studies are listed in Table 1. Inclusion and interpretation criteria were that data for ventilation system and health

outcomes are analysed against each other and conclusions about the type of ventilation system and health outcome are drawn.

Table 1: Overview about the studies with focus on the ventilation system and health in homes and schools

Study	Ventilation system	Outcome	Results
Bogers et al., 2011 (H)	ME vs. BV	Perception of IAQ, subjective health	Perception of IAQ better with ME, no differences on subjective health
Bornehag et al., 2005a (H)	NV vs. ME vs. BV	Asthma, wheeze, cough, rhinitis, eczema	Eczema and rhinitis sig. higher with ME and BV compared to NV
Clausen et al., 2011 (H)	NV vs. ME, NV vs. BV	Child absenteeism in day care centres	No influence of ventilation system
Ebbehoj et al., 2005 (S)	Mechanical ventilation vs. not	General, mucous membrane and skin symptoms	Male teachers tended to have more throat irritation symptoms in mechanically ventilated schools
Emenius et al., 2004 (H)	NV vs. ME, NV vs. BV	Wheeze	No effect when OR are adjusted with different confounders
Engvall et al., 2003 (H)	NV vs. ME vs. BV vs. mixed system	Irritation symptoms, headache, tiredness	Irritation symptoms lower with ME and BV, headache and tiredness not clear
Engvall et al., 2005 (H)	Constant vs. season-ally adapted mecha-nical ventilation	Irritation symptoms, headache, tiredness	No difference between the two ventilation systems
Norbäck et al., 1995 (H)	NV vs. ME vs. BV	Asthma	No influence of ventilation system
Øie et al., 1999 (H)	NV vs. ME vs. BV	Bronchial obstruction	No influence of ventilation system
Ruotsalainen et al., 1991 (H)	NV vs. ME vs. BV	Irritation symptoms, cough, headache…	Lethargy, weakness, nausea sig. more often reported in NV houses
Smedje et al., 2011 (S)	Mixing vs. displace-ment ventilation	Perceived IAQ, clini-cal health parameters	No differences in perceived IAQ and clinical parameters, more eye symptoms with displacement system
Wålinder et al., 1998 (S)	NV vs. ME vs. BV vs. supply only vs. displacement	Nasal symptoms , biomarkers	Nasal symptoms lower with NV, nasal obstruction sig. higher with BV compared to any other type
Zuraimi et al., 2007	NV vs. air-conditioned vs. air-conditioned +BV vs. hybrid	Asthma, allergies, respiratory symptoms	Lower prevalence for most asthma, allergy and respiratory symptoms in NV day care centres, AC has higher prevalences of phlegm and cough

H=homes; S=schools

As it is noticeable from Table 1, the number of studies that examine this relationship in a clearly controlled and documented way is rather small. Further, the health outcomes are quite different and range from irritation symptoms and more general symptoms like tiredness to severe diseases like asthma or bronchial obstruction.

Unfortunately, the results do not point in the same direction. Five studies report no differences between the different types of ventilation systems, thereunder those with focus on the illnesses asthma and bronchial obstruction. Rhinitis and eczema seem to be less prevalent in completely naturally ventilated buildings, whereas irritation symptoms seem to be lower with a mechanical exhaust or balanced ventilation system. If differences are found, they include only one study. Probably, there are some confounders that may bias the results, like the unknown state of filters of mechanical systems or the ventilation rate that has been delivered in the rooms.

The study of Zuraimi et al. reported that in day care centres with mechanical ventilation or air-conditioning the ventilation rates were very low and lower as in naturally-ventilated centres. Children had a higher risk for respiratory symptom when they attended a mechanically or hybrid ventilated day care centre.

Supposed that in the aforementioned studies, the filters were adequately maintained and were no source for additional pollution, the conclusion might be that not the ventilation system itself is crucial but the amount of fresh air that is supplied in the room, i.e. ventilation or air exchange rate is much more important than the system itself.

2.2 The influence of the ventilation or air exchange rate on health

The research question in this part is whether an increased ventilation rate could contribute to a better health of the building occupants. Measurements have shown that concentrations of pollutants may be increased when ventilation or air exchange rate is too low (Wålinder et al., 1997a).

The literature search identified in total 10 studies with different physical measurements, thereunder the air change rate (ACH), i.e. how often per hour the air of the room is completely exchanged, the ventilation rate (VR), normally indicated by the amount of l/s-person of air supplied in the room or CO_2 concentrations, where a higher level stands for an inadequate ventilation and air exchange. The main characteristics of the studies are displayed in Table 2.

Table 2: Overview about the studies with focus on the ventilation rate and health in homes and schools

Study	Type of physical measurement	Outcome	Result
Bornehag et al., 2005b (H)	Mean ACH of cases and controls	Asthma, rhinitis, eczema	ACH in houses of children with diagnosed disease are lower
Hägerhed-Engman et al., 2009 (H)	VR above or below median	Asthma, rhinitis, eczema	ORs for all three health outcomes at low ventilation rate are higher, but did not reach significance
Mendell et al., 2013 (S)	Stepwise increase of VR about 1 l/s-person	Illness absence rate	Illness absence rate decreased significantly when ventilation rate is elevated
Muscatiello et al., 2014 (S)	CO_2 concentration above or below median	Teacher symptoms: mucosal membrane, lower respiratory, neuro-physiologic	Very broad and insignificant OR for all health outcomes, no differences
Myhrvold et al., 1996 (S)	CO_2 concentrations 0-999, 1000-1499 and above 1500 ppm	Headache, tiredness, irritation of airways	Headache, and tiredness increased sig. with higher CO2 concentration, airway symptoms increased as well, but showed a weaker correlation
Shendell et al., 2004 (S)	dCO_2 concentration (indoor –outdoor difference)	Absence rates	Absence rate increases about 10-20% with every increase of dCO_2 about 1000 ppm
Sun et al., 2011 (H)	ACH above or below median in winter	Wheeze, dry cough, rhinitis, eczema	Wheeze and dry cough sig higher when ACH below median
Turunen et al., 2014 (S)	VR in l/s-person	Illness absence, fatigue, headache, rhinitis, cough	Correlations between VR and health outcomes did not reach significance
Wålinder et al., 1997a, b (S)	High vs. low ACH	Mucosal swelling	Low ACH increased swelling of nasal mucosa and affect the airways.

H=homes; S=schools

As in the previous section, the measured health outcomes are very different. Taking a look on the influence of ventilation on absence rates, two studies showed that they could be influenced by the amount of ventilation that is available in classrooms. Airway infections like wheeze or cough are higher at a low air change rate, but this is significant in only one study.

In two other studies, airway diseases are not significantly influenced by the ventilation or air change rate.

Higher levels of CO_2 seem to promote headache and fatigue of teachers, but this reached significance as well in only one study. Airway symptoms were not influenced by CO_2 concentration and the calculated OR were very broad in one study (Muscatiello et al., 2014, e.g. the confidence interval of the OR for mucosal membrane symptoms and CO_2 concentration above median ranges from 0.20 to 11.87).

2.3 Further studies on ventilation and health

Some studies focus on the influence of ventilation in a broader sense on different health outcomes other have a different methodology and could not be compared with the aforementioned studies. The literature search identified in total 5 studies, the main characteristics are displayed in Table 3.

Table 3: Overview about the studies with focus on the ventilation in general and with different methodology

Study	Ventilation parameter	Outcome	Result
Dong et al., 2008 (H)	Use of ventilation device (exhaust fan, chimney, fume hood)	Cough, phlegm, asthma, wheeze, allergic rhinitis	No significant difference when ventilation device is used for all health outcomes
Kishi et al., 2009 (H)	Mechnical ventilation by duct or fan, existence in all rooms, regular operation	Sick house syndrome symptoms	No significant influence of the ventilation parameters.
Kovesi et al., 2009 (H)	Installation of home heat recovery ventilators (HRV)	Respiratory disorders of Inuit children	Reported rhinitis and wheeze were in part significantly reduced with HRV, hospitalizations did not change
Simons et al., 2010 (S)	Different ventilation problems	Absenteeism	Air intake near garbage storage, fresh air intake blockage, dirt in ductwork, damper malfunction, inadequate outside air or bad IAQ rating increase absence significantly.
Smedje et al., 2000 (S)	Installation of a new ventilation system	Allergies, asthma, asthmatic symptoms	Allergies or asthma incidences did not differ in rooms with or without new ventilation system, asthmatic symptoms were reduced

H=homes; S=schools

Two of these studies (Kovesi et al., 2009, Smedje et al., 2000) are intervention studies that aim at showing potential ameliorations of health status when a ventilation system is installed that increases air change rate. The results of both studies support the benefit of a newly installed ventilation system: at least some of the included health indicators showed reduced incidences. Nevertheless, the population of the first study is a very special one (Inuit children).

The three other studies used different classifications of ventilation parameters, two of them (Dong et al., 2008, Kishi et al., 2009) focus on the influence of partial ventilation like a fan or fume hood in the kitchen, no differences could be shown here. The third study (Simons et al., 2010) was a cross-sectional study that links reported ventilation problems with health outcomes. Health was impaired when any part of the ventilation system does not work properly, i.e. dirt in ductwork or wrong position of air intakes (near garbage storage). The

conclusion of the last study is therefore, that health impairments emerge relatively clearly when the ventilation system does not work properly.

3 CONCLUSIONS

This literature search analysed in total 28 studies with different methodologies and measurements. The studies investigated homes and schools. One important conclusion is that more systematic research with detailed documentation about all possible confounding variables is necessary. The type of ventilation system seems to be less important compared to the ventilation rate itself and the amount of fresh air that is supplied in the room. Frequently, no differences are found between naturally ventilated and mechanically ventilated buildings. Sometimes, the mechanical ventilation system seems to promote prevalence of respiratory illnesses, sometimes people feel better in mechanically ventilated buildings. The state of the ventilation system plays an important role here to make conclusions so this must be documented better in future studies.

Low ventilation rates seem to interact with the prevalence of asthma and other respiratory diseases, but do not reach significance in all cases. Additionally, they promote absenteeism from school, as has been shown in two studies.

Nevertheless, all statements made above are derived from only one or two studies because the health outcomes are very different and not really comparable and therefore more studies on the same health outcome with different parameters of ventilation are needed to get a more clearer picture about the influence and to derive a health-optimal and energy efficient ventilation concept.

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