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Topic 1. Occupational Health

Can we establish relationship between outdoor air ventilation and health based on the published epidemiological data?

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ABSTRACT Appropriate exposure control is prerogative for reducing the burden of disease (BOD) due to inadequate air quality indoors (IAQ). Ventilation with outdoor air is one of the available exposure control methods and is widespread. It is often assumed that this method will bring tangible effects on health. This paper examines whether the available archival epidemiological evidence provides information on the link between outdoor air ventilation and health that can be used for regulative purposes, when ventilation requirements for non-industrial built environments are set. To achieve this goal, multidisciplinary review was carried out of the scientific literature on health and outdoor air ventilation in non-industrial indoor environments (not covered by previous reviews on this topic) and of major reviews on this topic. The results show, that effects on health were seen for wide range of ventilation rates from 6-7 L/s per person, which were the lowest ventilation rates, at which no effects on some health outcomes were observed in field studies, until 25-40 L/s per person, which were in some studies the highest ventilation rates needed so no effects on health outcomes were seen. The actual contaminant exposures at various levels of ventilation were no characterized. It was observed that available data have many limitations, such as insufficient statistical power, incomplete data on the strength of pollution sources, diversity and variability of ventilation rates, at which effects have been seen, no standardized duration of exposures and diversity of the outcomes, as well as different sensibility of populations exposed. The health-ventilation relationship cannot thus competently be established, also because it must be admitted that outdoor air ventilation is only indirectly related to health by modifying exposures affecting health. It is concluded, that currently available epidemiological data do not provide sound basis for outdoor air ventilation requirements that can be universally applicable in different public and residential buildings to protect against health risks. They show minimum rates at which some health outcomes can be avoided, but these may not be generalized for the entire population of buildings, and thus cannot be used for setting minimum standards and/or regulations. Consequently, ventilation should not be advocated as the only solution to modify exposures, and should be implemented together with, and preferably after, other methods of controlling exposures have been fully exploited.

Keywords: Outdoor air supply rate; non-industrial environments; requirements; health

INTRODUCTION

Ventilation (with outdoor air) is widely recognized as a method for controlling exposures and is thus one of the key methods for preventing health problems related to inadequate indoor air quality (IAQ). Historically, recommended ventilation rates have been as low as 2.5 L/s per person and as high as 30 L/s per person, all depending on which outcome and which approach has been used to set the requirements (Janssen 1999; Addington 2000; Li 2013). Despite numerous experiments and the tradition, experience and evidence accumulated over centuries, the fundamental question on how much ventilation is actually needed indoors is actually still not entirely resolved, specifically as regards the level of ventilation that will eliminate any risks for health.

Ventilation of indoor spaces with outdoor air is expected to play an important role in reducing the burden of disease (BoD) related with exposures indoors. However, existing ventilation standards are based on comfort criteria (e.g., ASHRAE 62.1, 2013; EN 15251, 2007). Thus, the more general question is, whether this approach for setting the requirements will also provide sufficient protection against BoD attributable to inadequate IAQ. To examine this aspect, the results from previous research studies can be used, which by means of laboratory or field experiments investigated the relationship between ventilation rate and different outcomes related to health and/or sensory effects (odour intensity and quality). Majority of these studies were summarized and critically assessed in previously published literature reviews (e.g., Mendell 1993; Godish and Spengler 1996; Seppänen et al. 1999; Wargocki et al. 2002; Sundell et al. 2011).

The reviews show that multiple health outcomes are associated with changes in ventilation rates. They indicate that providing ventilation rates above 0.5 air changes per hour (h^{-1}) in homes can be generally considered to reduce infestation of house dust mites (HDMs) in Nordic countries with moderate to cold climate, and thus are likely to reduce the risk for the allergic reactions related to the presence of HDMs. They show also the range of levels of ventilation that may be effective in reducing other health outcomes, and postulate that in the case of infectious diseases it is not possible to define such level at all (Li et al., 2007). The general consensus in these reviews is, that outdoor air ventilation rates should be above the rate of 10 L/s per person to reduce the prevalence of self-estimated acute health symptoms (Mendell, 1993) called SBS symptoms (WHO, 1982). There are some reviews indicating that increasing ventilation rates above 10 L/s per person up to 15-17 L/s per person is needed to further reduce the prevalence of these symptoms (Seppänen et al. 1999), and some that only above 25 L/s per person there is no further reduction in symptoms to be expected (Wargocki et al. 2002; Sundell et al. 2011). The reviews showed additionally limited evidence on whether increasing ventilation rates up to 10 L/s per person is effective in reducing acute health symptom prevalence. The reviews show also that the maintenance of ventilation systems plays important role in causality, as the systems can become significant sources of pollution.

Present work was launched to supplement previews reviews by critically examining, whether the recently published archival epidemiological data do provide any reliable evidence on the link between outdoor air ventilation and health. A specific focus was on the lessons learnt, and the limitations for using the data reported in these studies, and finally whether these data can be used for regulative purposes, when ventilation requirements for non-industrial built environments based on health are set. Parts of the results of this review are summarized in the following paper, while the more thorough account can be found in Carrer et al. (2015). Present work was the part of the HealthVent project granted by the European Commission aiming in creating health-based ventilation guidelines for Europe that should ensure adequate IAQ, tangible health benefits for the occupants of buildings and a reduction in the BoD in the general population (Wargocki et al., 2013).

METHODOLOGIES

The literature was searched using MEDLINE, Toxnet and Web of Science. It was supplemented by identifying relevant literature in the proceedings of major congresses related to indoor air sciences such as the Indoor Air and Healthy Buildings series. Only papers published between 2000 until mid-2011 were included in the review, in order to avoid duplication of work performed by earlier reviews on health effects and ventilation in non-industrial indoor environments. Few papers published after 2011 were later included as they provided important supplementary information matching the objective of the present work.

One-hundred and sixty-eight articles were identified through the literature search. They were screened by examining their titles and abstracts and only 68 articles that matched the objective of this review were included. The selected 68 articles were assigned to eight reviewers, who assessed their quality and their conclusions and retrieved information relevant for the present work. Two persons were assigned by random to each paper, excluding those for which they were lead or co-authors, so each person reviewed about 25 papers. Reviews were conducted according to a specially developed protocol.

Forty-eight papers were judges as relevant for the objective of the present work and conclusive, i.e. with a strong design and adequate information on ventilation, health effects, data processing, and reporting. These papers were used to form final conclusions. Other papers were not included because they had weak design, or substantial flaws, or showed no relationship between ventilation and health, or were simply irrelevant for the present work. Of these 48 papers, 23 provided information on ventilation rates and health, while in 26 papers there were data on ventilation systems, their maintenance and health.

Based on the results reported in the reviewed papers as well as in the papers identified by the previous reviews, the ranges of ventilation rates were defined at which different endpoints were examined, as well as the ranges and/or single ventilation rates, at which no negative effects had been observed on health.

RESULTS AND DISCUSSION

Present review supplements the results of previous reviews summarizing literature reporting studies that examined effects of ventilation with outdoor air on health; detailed results are shown elsewhere (Carrer et al., 2015). They show that there is a wide range of ventilation rates, at which different health outcomes decline in intensity and/or frequency: The effects were seen from 6-7 L/s per person, which were the lowest ventilation rates, at which no effects on some health outcomes were observed in field studies, until 25-40 L/s per person, which were in some studies the highest ventilation rates needed so no effects on health outcomes were seen. This wide range is most likely, because the level of ventilation depends on exposure, which is directly related to health. Then the level of exposure that affects health depends not only on the ventilation rate, but also on the strength of sources of air pollution, so in some cases the rates need to be high when the sources of pollution are strong, and in some cases low, when the sources are weak.

The results from different studies reviewed were used to determine the lowest ventilation rates, at which the different health outcomes were not affected. These ventilation rates are shown in Figure 1. It shows that the ventilation rates at which no adverse effects were seen for respiratory symptoms, asthma and allergy symptoms, airborne infectious diseases and acute health symptoms were about 6 to 7 L/s per person, however in case of the short term absence rates and performance and learning these rates were from 16 to 24 L/s per person. If the lowest ventilation rates where no adverse effects were seen had been selected based on the building type, then the rates would be 6-7 L/s per person in homes and dorms, 12 L/s per person in schools and 25 L/s per person in offices. In some studies, the health outcomes were observed to change linearly with changing ventilation rates following the exposure-response relationship. Thus to determine ventilation rate at which the outcome can be considered at the acceptable level (with negligible health effects) should be set arbitrarily. This was not done in the present paper to make sure that the conclusions are unequivocal.

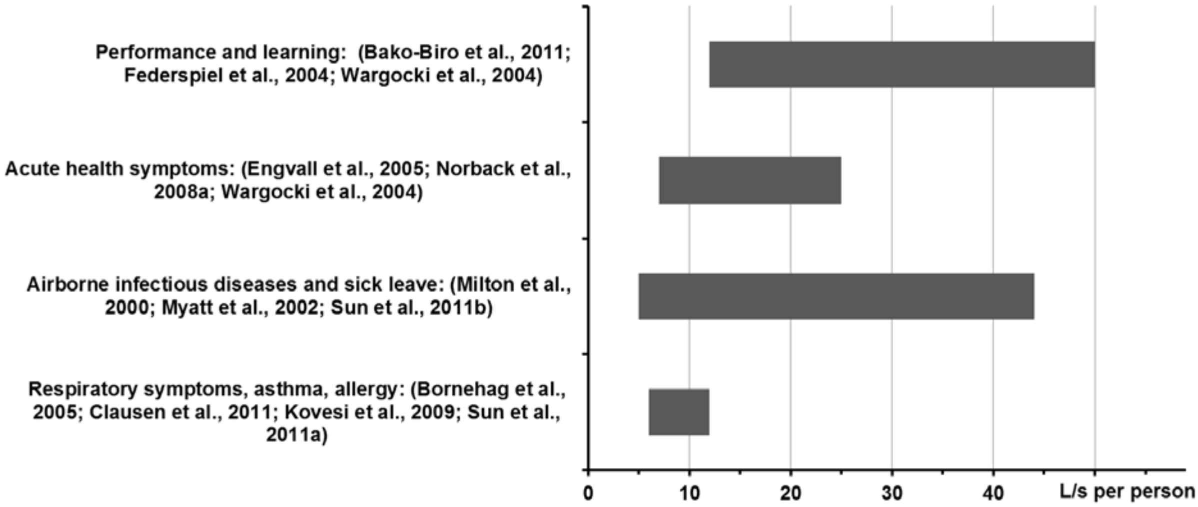

Figure 1: Ranges of the lowest ventilation rates reported by the reviewed studies, at which no effects on some health outcomes were observed

The ventilation rates shown in Figure 1 are based on a very limited evidence, however they still form an indication of the level of ventilation with no observable adverse health effect, at least for some outcomes; an implicit assumption is that in case of these studies the strength of pollution sources was low, as well. Figure 1 implies that ventilation rates can be as low as 6-7 L/s per person but it is course not possible to generalize these rates and use them as the universal benchmark for minimum (base) ventilation rates, which protect against health risks. This is not only because the data are scarce but also because they do not stem from the sufficiently representative and large population of buildings and no information is available on whether other methods were actually entertained to further reduce the exposures in the buildings where the studies were performed.

The main drawbacks of the current information on the associations between ventilation and health can generally be ascribed to weak experimental design, poor quality of ventilation measurements and measurements of health outcomes, improper characterization of buildings, where the measurements were carried out, and the lack of detailed characterization of indoor air pollution sources and the resulting exposures. Previous studies focused primarily on acute health symptoms: unspecific symptoms of irritation of eyes, nose and mucous membranes, malaise, fatigue and headaches experienced by building occupants (WHO, 1982). These symptoms were generally self-reported by building occupants and not clinically confirmed. None of the reviewed studies assessed the impact of building ventilation rates on chronic health effects, such as respiratory and cardiovascular diseases, or cancer. Many studies did not perform adequate airflow measurements nor provide sufficient detail on the measuring instruments used, their calibration and other parameters allowing evaluation of the quality of measurement. These considerations apply both to direct ventilation measurements of air flows and to the measurements using tracer gases and proxies of ventilation such CO_2. Therefore, exposures that are related to ventilation may not be properly approximated and may not reflect the actual exposures. Considerable number of previous studies was cross-sectional. They mapped the existing situation at the time when the measurements were carried out, and suggested the potential association between ventilation and health using sophisticated statistical analyses controlling for confounding and adjusting for predefined variables such as age, gender, health and smoking status, etc. These designs are sensitive to many disturbing factors, as they do not control the specific factors that are the object of investigation. The results do not provide causal relationships, but only associations. Finally, many studies reviewed in the present work did not generally consider that adverse health outcomes that can be associated with higher exposure to outdoor air pollutants indoors, implicitly assuming that outdoor air was clean.

Current scientific evidence is too limited to identify ventilation rates that can adequately control specific exposures. This is because there are limit values for exposure only for few pollutants having their origin both indoors and outdoors. For these pollutants, guidelines have been established by WHO (2006, 2009, 2010) or in the context of the European project "INDEX" (Koistinen et al., 2008). Additionally, there is insufficient knowledge on the emission of pollutants, and the combined effects of low-dose mixtures of pollutants typical for non-industrial environments are not well understood. Finally, indoor pollutant levels depend on ventilation rates: some pollutants can be affected largely by changing ventilation rates while some only moderately or to a very low extent (Fisk, 2012). Another complication is the method of supplying the air to achieve ventilation: Ventilation system can be a resource or a risk factor. Installation of mechanical ventilation system would usually increase ventilation rates and thus would reduce exposures and consequently contribute to reduction of health risks; it can also to some extent reduce some pollutants having outdoor origin in case the efficient filtration and/or air cleaning systems are installed often being an integral part of ventilation system. Operation of the system without diligent maintenance, operation procedures and frequent cleaning can cause on the other hand that the systems can become a strong pollution source. Then the air delivered by the ventilation system will become polluted and will elevate rather than decrease the exposures causing subsequently an increase in health risk. In such case supplying the air using natural forces (natural ventilation systems) will be seen as more beneficial but only in areas where the outdoor air is not polluted and in case when the outdoor ventilation rates are not compromised, e.g. due to too low temperatures (in cold and moderate climates) or too high and humid outdoor air (in tropical and subtropical climates).

Because there is insufficient evidence regarding the potential health risks of different indoor exposures, until the main cause (contaminant or mixture of contaminants) has been identified, ventilation is often used as the only *panacea* that can reduce exposures. Considering the present results, it may be unwise to use a principle that by default assumes that one size fits all. Thus, universal recommendations regarding ventilation requirements cannot be applied across the entire building stock not considering exposures and independently of exposures, unless the rates are unrealistically high, as mentioned earlier. Consequently, a systematic approach needs to be developed for defining ventilation rates, which ensures that ventilation is designed on the basis of the actual exposures relevant for the specific outcome (health, comfort or cognitive performance), taking into account local outdoor air quality and the condition (cleanliness) of ventilation system. Such approach would admit that health is related to exposures and ventilation is only a factor modifying this relationship and not directly related to health. No such approach exists at present. The framework was however proposed by the HealthVent project (Wargocki et al., 2013).

CONCLUSIONS

Currently available epidemiological data show, that in general, higher ventilation rates in many cases will reduce health outcomes however, they do not provide sound basis for outdoor air ventilation requirements that can be universally applicable in different public and residential buildings to protect against health risks.

The available data have many limitations such as insufficient statistical power, incomplete data on the strength of pollution sources and on the ventilation systems, diversity and variability of ventilation rates at which effects have been seen, no standardized duration of exposures and diversity of the outcomes as well as different sensibility of populations exposed. Only short-term (acute) health effects have been examined, and there have been no studies providing information on the chronic health effects.

Further research on ventilation and health must be multidisciplinary and should characterize exposures in a systematic way. It should improve knowledge on the connection between sources, indoor air, concentrations and exposures, ventilation rates and ventilation systems and health outcomes.

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