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What does the scientific literature tell us about the ventilation–health relationship in public and residential buildings?

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A B S T R A C T

Objective of this paper is to examine whether the available epidemiological evidence provides information on the link between outdoor air ventilation rates and health, and whether it can be used for regulatory purposes when setting ventilation requirements for non-industrial built environments.

Effects on health were seen for a wide range of outdoor ventilation rates from 6 to 7 L/s per person, which were the lowest ventilation rates at which no effects on any health outcomes were observed in field studies, up to 25–40 L/s per person, which were in some studies the lowest outdoor ventilation rates at which no effects on health outcomes were seen. These data show that, in general, higher ventilation rates in many cases will reduce health outcomes, and that there are the minimum rates, at which some health outcomes can be avoided. But these data have many limitations, such as crude estimation of outdoor ventilation rates, diversity and variability of ventilation rates at which effects were seen, a diversity of outcomes (in case of health otcomes being mainly acute not chronic). Among other limitations there are incomplete data on the strength of pollution sources and exposures as well as a wide range of sensibility of the exposed populations.

The available data do not provide a sound basis for determining specific outdoor air ventilation rates that can be universally applicable in different public and residential buildings to protect against health risks. They cannot be used for regulative purposes, unless the required ventilation rates are related to actual exposures and are prescribed only when full advantage of other methods for controlling exposures has been taken.

Contents

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1. Introduction

Outdoor air ventilation is commonly recognized as a method for controlling exposures and is thus one of the key methods for preventing health problems due to inadequate indoor air quality (IAQ) [1]. Ventilation is the process of exchanging indoor (polluted) air with outdoor air, which should preferably be clean. The purpose is to create optimal conditions for the occupants of indoor environments, taking into account their health, comfort and cognitive and physical performance, by providing air for breathing while removing and/or diluting any contaminants that are present indoors. Ventilation is in some cases also used to control the indoor thermal environment (temperature and moisture) by providing heating or cooling and by adjusting the humidity (by adding or removing moisture).

Ventilation of indoor spaces with outdoor air is essential. It is currently used because it is expected to play an important role in reducing the burden of disease (BoD) related to exposures indoors. This role of ventilation has been recognized since ancient times, when Egyptians discovered that stone carvers in closed spaces without sufficient ventilation experienced more respiratory problems than those working outdoors. The role of ventilation for reducing BoD has been confirmed on many subsequent occasions, when insufficient ventilation was found to be associated with increased morbidity and even mortality [2,3]. Despite numerous experiments and the tradition, experience and evidence accumulated over centuries, the fundamental question on how much ventilation is actually needed indoors is still not entirely resolved despite the consensus reached by the standard committees. In a recent paper, some of the issues that have been addressed in the development of ventilation standards have been reviewed and discussed, and they include the scientific bases for ventilation requirements, perceived indoor air quality, contaminant sources from occupants and the building, outdoor air quality, airborne contaminant limits, indoor carbon dioxide concentrations, and performance-based design [4].

During the last century, recommended ventilation rates were 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 was used to set the requirements [3,5,6]. Currently, following the classical experiments of Yaglou et al. [7], it has become conventional to use sensory discomfort defined as percentage dissatisfied with air quality as an outcome to determine ventilation requirements. This approach is still adopted by most of the major ventilation standards around the world [8,9].

In the definition of the existing ventilation standards, health and comfort are mentioned, but justification for the individual values is not sufficiently documented. Of specific concern is the level of ventilation that will reduce and/or eliminate any known risks for health from poor IAQ. To this end it can be queried whether the approach for setting the requirements adopted by the present standards and codes will effectively provide sufficient protection against BoD attributable to low IAQ conditions. This BoD has recently been estimated in Europe in IAIAQ project [10,11] and in the US [12]. In Europe, this BoD has been estimated to reach two million disability-adjusted life years (DALY) in European countries (EU-27 minus Malta), excluding smoking [10]. More than half of this BoD is attributable to indoor exposure to pollutants originating outdoors, in particular those related to traffic and the combustion of solid fuels. The rest is attributable to pollutants originating from indoor sources including building materials, furnishing, building equipment, combustion and consumer products, as well as people and their activities and any processes occurring indoors that can become a source of indoor pollutants (i.e. can cause the release of pollutants). In the U.S., estimations of BoD were made for the residential sector, including smoking [12]. They resulted in a slightly higher but generally comparable figure: 400–1100 DALYs were estimated to be lost annually per 100,000 persons. These DALY's were mostly attributable to indoor exposures to PM2.5, formaldehyde and acrolein.

To verify whether ventilation requirements stipulated by the current standards and codes are sufficient to reduce the BoD, the results from previous research studies can be used, including laboratory or field experiments that investigated the relationship between ventilation rate and different outcomes related to health and/or sensory effects (odor intensity and quality). Most of these studies have been summarized and critically assessed in previously published literature reviews [13–26]. The main conclusions of some of these reviews are listed in Table 1.

Summarizing the results presented in Table 1, the reviews show that multiple health outcomes are associated with changes in ventilation rates, and show also ventilation rates, at which no health effects were observed assuming that ventilation rate with outdoor air is a primary mean for controlling exposures. Following these principles, they suggest that providing ventilation rates above 0.5 air changes per hour (h^{-1}) in homes has been shown to reduce infestation with house dust mites (HDMs) in Nordic countries with a moderate to cold climate; these rates are thus 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 a level at all [23]. Mendell [13] suggested that outdoor air ventilation rates should be above the rate of 10 L/s per person to reduce the prevalence of self-