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Association between classroom ventilation mode and learning outcome in Danish schools

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ABSTRACT

Associations between learning, ventilation mode, and other classroom characteristics were investigated with data from a Danish test scheme and two widespread cross-sectional studies examining air quality in Danish schools. An academic achievement indicator as a measure of the learning outcome was calculated from the scores of a standardized Danish test scheme adjusted for a socioeconomic reference index. Pupils in schools with balanced mechanical ventilation had significantly higher achievement indicators than pupils in schools with natural ventilation, where airing took place mostly by manual window opening. Also, the carbon dioxide concentration was lower in classrooms with balanced mechanical ventilation. There was no consistent association between the achievement indicators and the person specific room volume, construction/renovation year, or the occupancy. Measurements of carbon dioxide concentrations and temperatures in 820 classrooms in 389 schools were available. In 56% and 66% of the classrooms included in the two studies, the measured CO_2 concentration was higher than 1000 ppm. The findings of this study add to the growing evidence that insufficient classroom ventilation have impacts on learning outcomes.

1. Introduction

Poor classroom environmental conditions are common and have been associated with reduced pupil well-being and performance of schoolwork e.g. Refs. [1–7]. Air-conditioning, classroom illumination, temperature control, building layout and age are among the additional factors that have been identified as potentially influencing the performance of pupils [8]. Also, several studies have shown elevated carbon dioxide concentrations in classrooms resulting from a lack of systems dedicated to achieving proper ventilation e.g. Ref. [9]. This is reflected in the high carbon dioxide concentrations typically measured in classrooms indicating insufficient ventilation. Reduced pupil well-being and performance caused by substandard classroom conditions may lead to a reduced learning outcome, which ultimately may have economic consequences both at individual and societal level [10,11].

Previous studies examining the effects on learning of the indoor environment in classrooms used mainly psychological and neurobehavioural tests to examine different skills needed for proper learning, such as the ability to concentrate and memorize [12–14], as well as shorter tests examining the ability to read, comprehend and calculate [4,5]. The latter study showed that poor classroom ventilation can significantly reduce the ability to perform these tests. Although the long-term learning outcomes are also expected to be affected by the absence of such skills, the connection between the progress in learning and psychological and neurobehavioural tests is not well documented.

General learning outcomes can be monitored with standardized tests, which are often developed by national or regional education departments. These tests monitor and benchmark both individual pupils and schools as well as evaluate the effectiveness of teaching methods and curricula. Haverinen-Shaughnessy et al. [6] used such tests to show that poor ventilation in classrooms reduced the number of pupils just passing language and math tests.

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Standardized tests are applied regularly during the school year, but it may be challenging to acquire matching and representative information on the classroom conditions. Furthermore, it cannot be ruled out that the test outcome is influenced by factors not related with the indoor environment in classrooms, including socio-economic status, teaching methods, or teacher quality.

Increased illness absence may be another consequence of poor classroom ventilation, which indirectly can lead to a decreased learning outcome. Ervasti et al. [15] found increased short-term sick leave among teachers in schools with poorly perceived indoor air quality. Shendell et al. [3] found student absence to decrease by 10–20% when the CO_2 concentration decreased by 1000 ppm in 434 American classrooms. A somewhat smaller effect size was found by Gaihre et al. [16] in their study in 60 naturally ventilated primary school classrooms in Scotland, where an increase of 100 ppm CO_2 was associated with a reduced annual attendance of 0.2%. Simons et al. [17] found high student absenteeism to be associated with poor ventilation rating (e.g. malfunctioning, dirty filters, blocked vents, etc.) in 2751 New York schools, and Simoni et al. [18] found that school children exposed to CO_2 levels below 1000 ppm had a significantly lower risk of dry cough and rhinitis. A recent and very comprehensive study in 162 Californian classrooms observed that pupil illness absence decreased by as much as 1.6% for each additional 1 l/(s person) increase in the ventilation rate [10]. Although these findings still need confirmation, they suggest that increasing classroom ventilation may substantially decrease illness absence and thereby indirectly affect the learning experience. However, although intuitively likely there is still no clear evidence of an association between the short-term absence of pupils and academic performance [2]. Furthermore, absence rates can be influenced by many factors not necessarily related with school environments, such as the health status of the pupils, the sensitivity of their immune system, conditions at home, etc.

The aim of this paper was to study associations between ventilation mode and other classroom-related parameters and learning as measured with the Danish national test scheme. Other classroom related parameters included school year, room volume, construction/renovation year, occupancy, window opening frequency, and window orientation. Also, the results of two cross-sectional studies examining the air quality in 820 classrooms from 389 Danish public schools will be presented.

The paper is organized as follows. Section 2 is devoted to the Materials and methods, which describes how data used in the analyses were obtained from two field studies in Danish schools and from a standardized national test scheme. The section also describes how data were processed and combined as well as the analyses used to study the associations between school characteristics and learning outcome. Section 3 presents the results of the measurements and observations in the field studies and, after combining field study data with records of national test scores, the associations between classroom characteristics and test scores. Section 4 discusses the findings and in particular the limitations of the study. Section 5 presents the conclusions.

2. Materials and methods

2.1. Approach

A retrospective analysis was performed in which results from the Danish national test scheme collected in the school year 2009–2010 were associated with parameters describing the ventilation conditions and other classroom characteristics in a subset of schools included in the two cross-sectional studies. This information was obtained through surveys in classrooms carried out in late 2009.

2.2. Assessment of classroom environments

The first cross-sectional study (*study I*) consisted of measurements from 311 elementary and high schools (Fig. 1). Indoor environmental conditions were measured in one to sixteen classrooms per school (732 classrooms in total from pre-school to elementary school through third year high school). *Study I* ran from September to October 2009.

Study I was organized by the Danish Science Communication (now Danish Science Factory, http://naturvidenskabsfestival.danishsciencefactory.dk) with scientific support from the authors of this paper. The Danish Science Factory is a non-profit organisation that works to engage pupils in the natural sciences through a yearly natural science festival. The 2009 festival aimed to engage pupils in examining the indoor environment in their classrooms. One-thousand classes signed up voluntarily for participation in the festival as a part of their science classes, but only 732 provided meaningful measurements. Locations of the schools participating in the festival were almost evenly distributed in Denmark.

Each class was provided with equipment to measure the CO_2 concentration, air temperature and mould (mould measurements are not reported in this paper). Spot measurements were performed by the pupils at the end of a lesson during which the pupils were asked to keep the windows in the classroom closed to mimic a worst-case though realistic heating season scenario. All other classroom behaviour and settings for heating and ventilation systems were unaffected by the measurements.

Each class made only one measurement of the CO_2 concentration during one lesson. This lesson could be selected without restrictions during the three-week experimental period (from 14th September until the 2nd October). During this period, the outdoor temperature varied between 0 °C during the coldest nights and up to 23 °C during the warmest days.

The CO_2 concentration was measured with a Kitagawa 126SF measurement tube (range: 200–4000 ppm, relative standard deviation: 10%). Temperature was measured with a thermometer provided by the school. The measurement data was then transferred to a central server via a dedicated homepage. Pupils and their teacher also entered information regarding the classroom characteristics, including ventilation mode, room volume, and occupancy.

The second cross-sectional study (*study II*) was performed from October to December 2009. It comprised continuous measurements in one randomly selected classroom at each of 88 randomly selected elementary schools. The CO_2 concentration was monitored at 5 min intervals during an average of 17 consecutive days (range 4–35 days). Measurements were performed with a Vaisala model GMW22 (CO_2 range: 0–5000 ppm ± 100 ppm + 2% of reading) connected to a HOBO data logger model U12-012 (signal range: ± 2 mV ± 2.5% of reading) that also monitored temperature and relative humidity in the classroom. The loggers were deployed in the schools by janitors or teachers, who were instructed on how to place them. During the measurements, teachers and pupils assessed perceptions of temperature, indoor air quality, odour, lighting, noise, and cleanliness of the classroom using a paper-based questionnaire. They also provided information on the classroom characteristics, including ventilation mode, room volume, and occupancy. CO_2 and temperature data were extracted for school days only, which were defined as weekdays from 8 am to 2 pm based on an evaluation of the typical school day of 20 of the participating classes, which spanned from around 8 am to between 1.30 p.m. and 2.30 p.m. For each school, grand means, maximum, and 20 min running mean for the occupancy period were calculated. During the study period, the outdoor temperature ranged from 0 °C to 15 °C. There was an overlap of ten schools between *study I and study II* resulting in a total of 389 unique schools.