Fraunhofer-Institut für Bauphysik IBP

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Study Report

Impact of the indoor environment on learning in schools in Europe

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Introduction

Our children spend most of their time during the day in a classroom where they should learn things that are important for their later achievement in education and finally in their profession. The classrooms should therefore promote a good learning environment. The indoor environment should not hinder the learning of the children, e.g. with a high noise level, overheated rooms or inadequate lighting conditions or a stuffy and unhealthy air. Unfortunately, many schools do not provide an adequate indoor environment. Many schools fail to provide a sufficient outdoor air supply rate and are too warm in the summer months.

About 18% of the European population can be considered as being pupil or student (ISCED levels 1-6). In total these are about 95 Million persons. [1]

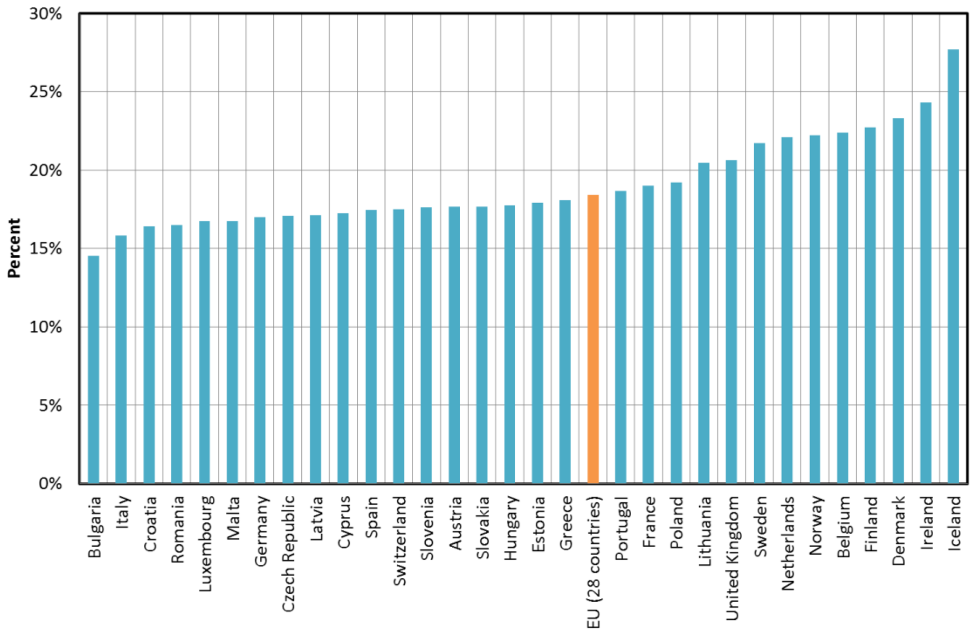

Figure 1: Percentage of pupils and students (ISCED levels 1-6) of the total population in 2012 in Europe [1]. The ISCED levels is a standardized description of levels of education, levels 1 to 6 range from early primary education to education at bachelor level.

State of play

The situation in classrooms has been improved largely in the late 19th and early 20th century. Schools were upgraded from frequently disregarded or sometimes even rotten and forgotten buildings to an at that time modern status (see e.g. [2]). However, still we did not yet reach a level that provide our pupils with their optimum indoor environment.

We know that for example daylight factors should be around 5% and higher in order to achieve the required 300-500 lx [3] during overcast days without additional electric lighting. Ventilation rates should yield at least CO_2-concentrations at a reasonable 1000 to 2000 ppm [4] to achieve a hygienically unobtrusive indoor air quality. While levels below 1000 ppm are considered as hygienically unproblematic a level between 1000 – 1400 ppm is considered to be an appropriate hygienically level [4], whereas above and especially towards 2000 ppm, is becoming hygienically unacceptable for long exposures. Still, we find that most of the classrooms do not fulfil these criteria on such proper indoor environments, for example [5] found in a field study that approximately 87%of the investigated classrooms were below the accepted ventilation standard.

Ventilation

Typical values for the CO_2-concentration in classrooms vary broadly. In different studies values between approximately 750ppm up to 6000 ppm are reported (see e.g. [4]). The figure below shows measured values of CO_2 concentrations in schools in six European countries. The average values are all within the recommended values, but in many schools the recommendations are exceeded. Renovation should focus on these schools with poor indoor air quality.

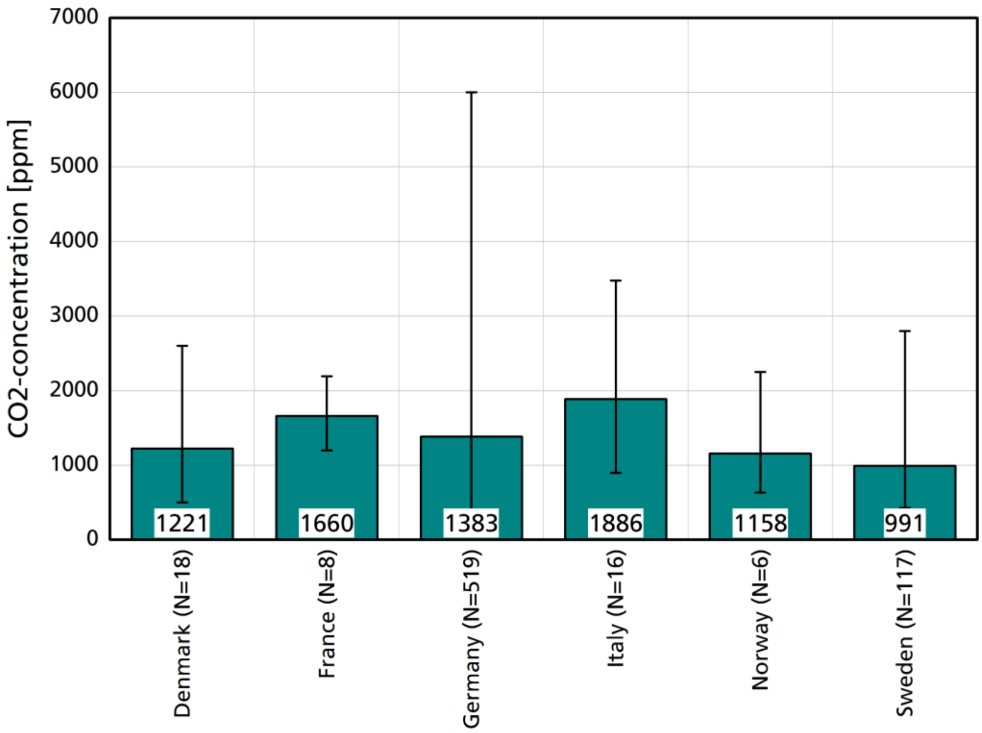

Figure 2: Measured values of CO_2 concentrations in schools in six European countries (see e.g. [4]). The bars depict mean values, also stated as numbers, the whiskers indicate the minima and maxima from the underlying studies.

As classrooms are densely occupied spaces with a metabolic production of CO_2 by the occupants, the CO_2-concentration is directly dependent on the ventilation rate. Typical recommended values lie between 1000-2000 ppm, while levels below 1000 ppm are considered as hygienically unproblematic and above 2000 ppm as hygienically inacceptable [4]. Obviously such values are not reached very often, which is most likely associated with unsufficient ventilation behaviour of the occupants, especially during winter.

Daylight

Lighting levels in classrooms should reach at least 300 lx and 500 lx for special-subject classrooms [3]. Thus, if using daylight, the daylight factor should be at least around 3-5% to achieve these levels in a typical overcast day situation (for which 10,000 lx can be assumed outside) without additional electric lighting. Typically medium to good daylight availability can be reached, if the ratio between window area to floor area is larger than 20%. Still, the inhomogeneous daylight distribution to be taken into consideration for single sided windows, especially in combination with deep rooms. In a German study on the situation in 100 classrooms this ratio was typically between 30%-60% and the daylight factor was in two thirds of the classrooms assessed as good to medium according to DIN V 18599 [6].

Study Results

Ventilation rate and learning behavior

The literature search lead to around 200 different publications dated from 1965 to 2015. Among these, seven original studies focused dedicatedly on the influence of different ventilation rates on the performance of children at schoolwork. Although doable, a meta-analytic synthesis is not meaningful due to the small basis of studies. The main limitation of these studies is that the ventilation rates are mainly below the recommended standard and findings are hence limited to this particular range of ventilation. What happens if ventilation rate is increased much above the recommended standard, is unknown yet.

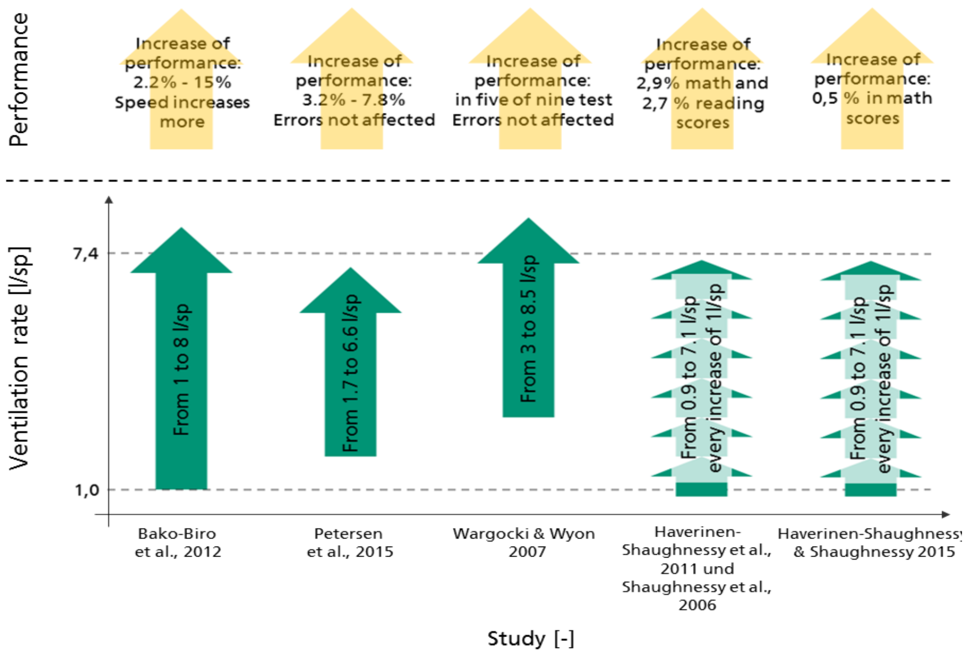

Figure 3: Overview about the influence of ventilation rate on learning outcomes from the most important studies. They share the conclusion, that performance, in the sense of working speed, seems to increase if ventilation rates are increased.

This systematic review demonstrates, that if airing strategies within schools are adopted properly to achieve the recommended ventilation rates of 7.4 l/s according to the ASHRAE standard 62.1 [7] the overall performance, in the sense of speed, could be increased by 2.2% to 15%. As the measure of learning outcome is different for all studies it is still impossible to generalise this outcome. However, all reviewed studies come to the similar conclusion, that error frequency is not improved at a higher ventilation rate - considering that all studies refer to very low levels of measured ventilation rates (1 l/s per person) which are far below the recommended standard. There are no studies with ventilation rates above 8.5 l/s per person. Some studies stated that almost all schools that were investigated have ventilation rates far below the standard and have no HVAC system.

CO_2-concentrations and learning behaviour

The scientific literature on CO_2-concentrations and learning behaviour is similarly scarce as the one on ventilation rates. The literature search has leaded to five publications in which CO_2-concentrations in schools and their influence on learning was investigated.

If ventilation is assessed by CO_2-concentration, the influence is not as clear as before. Attention and concentration seems to be better at lower levels, but the CO_2-conditions are very different in the studies. They have in common that attention and concentration seems to be better when CO_2-levels are reduced.

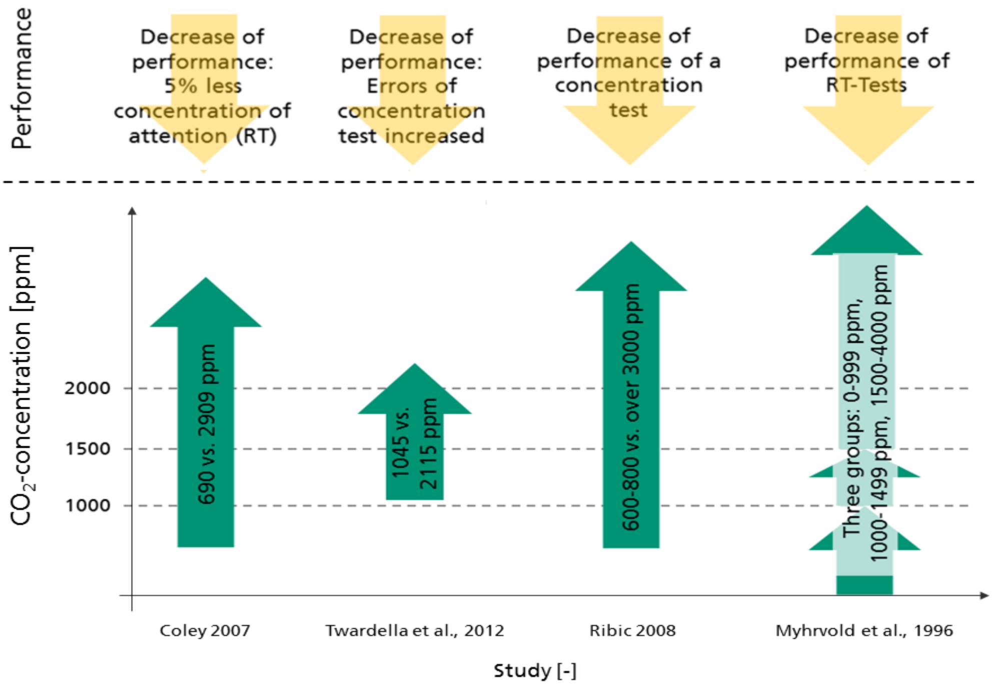

Figure 4: Overview about the influence of CO_2-concentration on learning outcomes from the most important studies. They have in common that attention and concentration seems to be better when CO_2-levels are reduced. (RT = reaction time of the tasks)

Ventilation and absenteeism

The relationship between ventilation and absenteeism of pupils and students has been investigated by four studies, however their study design has be very different.

CO_2-concentrations seem to affect attendance. A 1000 ppm-rise in CO_2-concentration leads to an increased absenteeism of 10-20% in one study [8], in another study [9], every increase of 100 ppm leads to an decrease in annual attendance of about 0,2%. Thus there seems to be an influence of CO_2-concentration on attendance, however the dimension is unclear yet (factor of 10 between the studies) and may be related very strongly to specific school conditions. If ventilation rates would be increased over the recommended values (which in fact is not the case in many schools, as outlined above), the illness-caused absence rate seems to be reduced about 11-17%. [10]

Overall this indicates that insufficient ventilation is impacting absenteeism, however a general evidence cannot be given yet. Whatsoever this trend supports the importance of a proper design and operation of classroom with respect to ventilation.

Daylight in schools and its impact on learning

Overall there are very few systematic studies that focus on the influence of daylight and the presence of windows on learning: no systematic variation of conditions have been made, the influence of windows and daylight are partly mixed together. The literature search identified four studies, but there is no single study that controls clearly the illumination in the classrooms. Conclusions about the mere influence of daylight could hardly be drawn, as windows have also other beneficial influences, like the view out.

Those studies that are available suggest that the higher the daylight level the higher the achievement of the pupils. For example schools in the study [11] show a 7 to 18% higher performance in those classrooms with the most daylight compared to those classrooms with the lowest amount of daylight (while the daylight situations are not described in sufficient detail to draw further conclusions).

Overall daylighting conditions seem to have an influence on pupils' performance as well, however limited empirical evidence is available here.

Impacts

Important becomes the level of achievement in education, when it comes to the achievable earnings in work life, which are strongly dependent on the level of education. The higher the educational attainment level, the higher the earnings: those of 25-64 year old workers with tertiary education exceed the earnings at lower educational levels in all European countries [12]. Obviously the private returns on investment in tertiary education are substantial. However, education does not only pay off for individuals, but the public also benefits in the form of greater tax revenues and social contributions. The benefits of tertiary education exceed the costs by at least a factor of 1.5 and in singular cases (here: Hungary) up to the twelvefold [12].

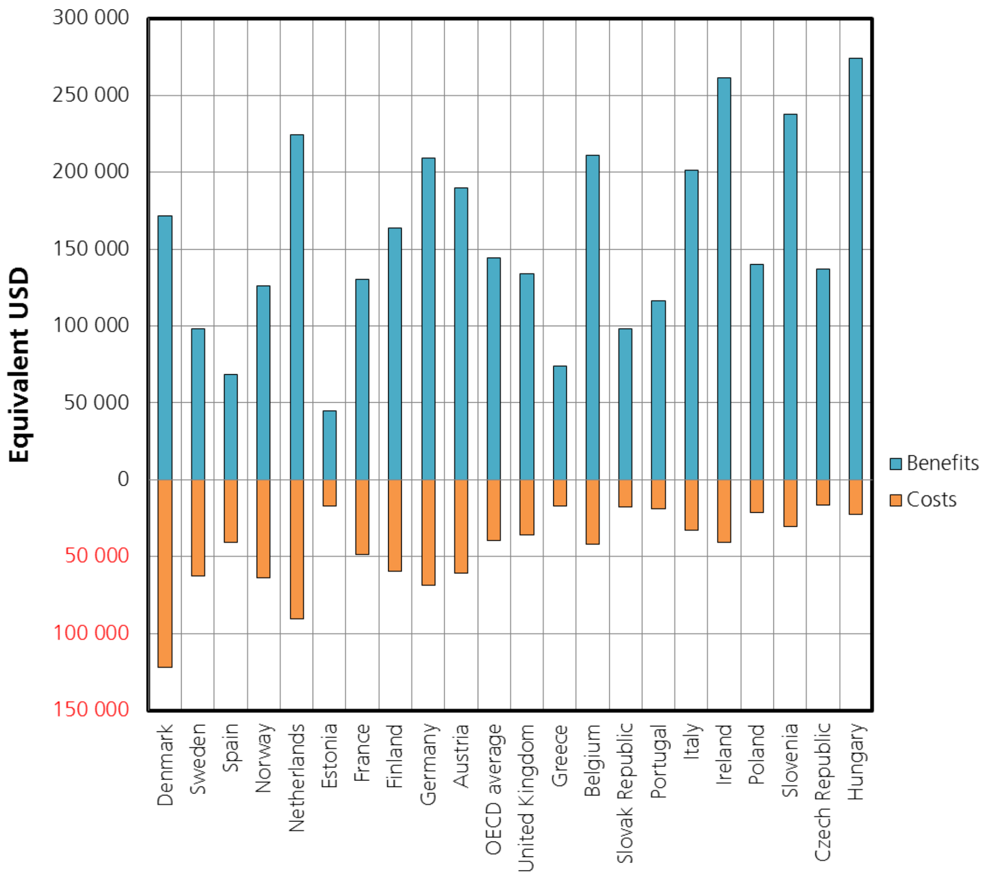

Figure 5: Public costs and benefits for a man attaining tertiary education (2009), as compared with returns from upper secondary or post-secondary non-tertiary education [12].

When comparing the educational level between countries, e.g. via a conditional test score based on the PISA tests performed in multiple countries, it has been shown, that a correlation to the conditional growth within those countries exists [13]. Across Europe the mean PISA score of Math and Science ranges between 439 (Cyprus) and 532 (Finland) [14]. Assuming an increase of performance of 2.8% (derived from Figure 3) this would lead to a 6.7% to 9.5% increase in conditional growth of the European countries.

As shown above an improved indoor environment contributes to an increased performance of pupils within school. Thus it should not just be our personal concern because of higher educational achievement but also in our public interest because of increased conditional growth to attach importance on a proper design and operation of our schools' indoor environment.

Improvements

Ventilation

Most of our schools have been designed for natural ventilation. If we make use of this opportunity and ventilate classrooms beyond the commonly applied airing strategy - which typically consists of ca. 10 minutes rush airing between lessons of 45 minutes - one can ensure the required air quality [15]. Anyhow this will need some change in behaviour as to arrange for venting during lessons.

If such is not feasible either mechanical ventilations systems or innovative approaches on natural ventilation are needed, which also address sufficiently high thermal comfort in winter. One approach is the use of motorized windows, vents or other openings for ventilation, which can be controlled automatically by sensing of outdoor and indoor parameters. Mechanical systems can ensure a dedicated level of air quality without detracting the thermal comfort in winter. In addition, the possibilities for cooling, filtering, sound attenuation and heat recovery belong to the benefits of mechanical ventilation systems. However, mechanical ventilation must be designed properly, be maintained regularly and can be noisy. Also the heating recovery of mechanical systems should not be overestimated in schools: Because of the high internal heat gain, the heating period is shorter than for other utilizations like residential buildings. To combine the advantages of natural and mechanical ventilation hybrid concepts have been developed [16]: fan assisted natural ventilation, stack and wind assisted mechanical system and mix modes. Fan assisted natural ventilation uses an extract or supply fan in combination with e.g. a natural air intake through wall or window. Therefore, a good design for successful natural ventilation is important, independently of the presence of a mechanical system.

Daylight

Daylight is the dominant and cost-free type of lighting, when considering the typical occupancy schedule of schools. To provide sufficient lighting levels a daylight factor around 5% should be achieved. This is typically the case if a window to floor area ratio above 20-30% is reached.

Daylight (and facade design) depends on latitude and climate. Especially at northern and central European latitudes, light transmission through the façade should be maximized when the sun shading systems are deactivated. This should be done by selecting glass types featuring high light transmission values, preferably very low shares of window bars/grids and frames, and by optimizing size and position of the windows. Avoiding glare is very important in schools and the necessary means must be used for the specific schools and surroundings. Roof lights are characterized by a luminous exposure which is about 50 % higher than at vertical façades, related to the surface area. They are much less critical with regard to glare problems and allow for a more even distribution of light across the room. Wherever possible under structural aspects, this type of daylight aperture should be considered. A daylight-responsive, occupancy-related control of lighting in classrooms is recommended. [17]

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