Topic B12: Productivity and economics

SOCIO-ECONOMIC CONSEQUENCES OF IMPROVED INDOOR AIR QUALITY IN DANISH PRIMARY SCHOOLS

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SUMMARY

This paper reports an attempt to estimate the socio-economic effects of upgrading the indoor air quality in Danish schools to the level of Swedish schools. The OECD “PISA” score is used to quantify the effects together with the Danish Rational Economic Agent Model (DREAM). The following effects are taken into consideration: a) increased PISA score increases productivity; b) increased PISA score reduces the duration of primary education; c) improved indoor air quality reduces absenteeism in teachers. The results show that improved air quality in Danish schools could result in an increase in the Gross Domestic Product (GDP) of €173 million per annum, and in the public finances of €37 million per annum.

INTRODUCTION

In recent air quality measurements in 320 schools in Denmark, carbon dioxide (CO_2) concentrations exceeded 1,000 ppm in more than 50% of classrooms (Clausen et al., 2009; Toftum et al., 2014). The air quality in these classrooms did not meet the requirements of the Danish Building Code nor the Danish Working Environment Authority because the outdoor ventilation rates were too low. For comparison, similar measurements in Norway and Sweden showed that only in no more than 20% of classrooms were the CO_2 concentrations above 1,000 ppm (Figure 1). As a part of the on-going renovation process of many Danish schools, the indoor air quality in these schools will be improved to meet the current codes and regulations. As a result, it is to be expected that performance of typical school tasks by children and their progress in learning will be improved. (Haverinen-Shaughnessy et al., 2010; Wargocki and Wyon, 2013). It is therefore relevant to examine whether the expected improvements of indoor air quality in schools will produce tangible socio-economic benefits.

One way to improve indoor air quality, if other methods such as source control are not available, is to increase the rate of outdoor air supply. The effects of increased ventilation can be shown by the reduced levels of CO_2 in occupied volumes (Wargocki et al., 2014). Danish Building Regulations (2010) require that ventilation rates in schools correspond to 6 litres of outdoor air per second per person, including a component to handle bioeffluents and the emissions from other sources. This is considerably lower than in Sweden, where the Building Code requires 8.4 l/s/person. Wargocki and Wyon (2013) studied the effect of increased classroom ventilation and indoor air quality on the performance of schoolwork in Danish and Swedish schools: the pupils completed the language-based and math tasks significantly faster when the ventilation rate had been increased. Similar results were seen by Bakó-Biró et al. (2012) in UK schools.

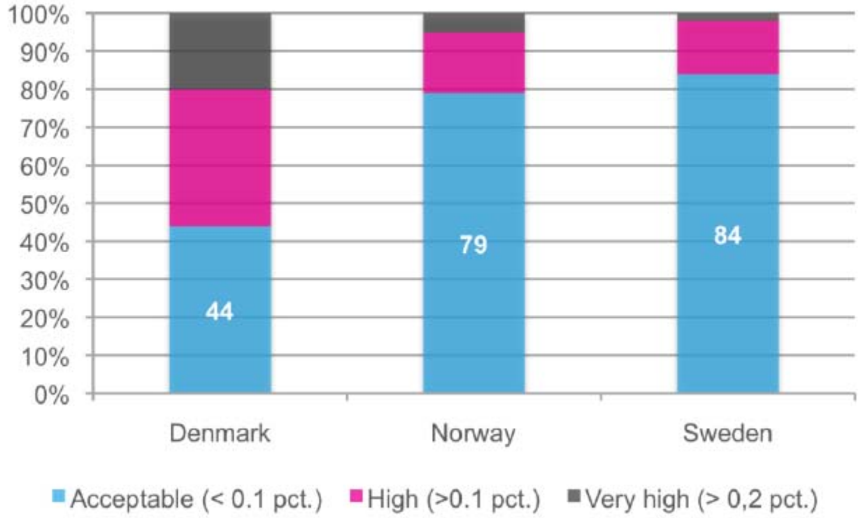

Figure 1. Classroom CO_2 concentration measured in a large sample of schools in Denmark, Norway and Sweden (Clausen et al., 2009).

The objective of the present work was to estimate the potential future socio-economic benefits of improving indoor air quality in Danish schools.

METHODS

An improvement of air quality was defined by assuming that all Danish schools would be ventilated with the outdoor air supply rate required by the Swedish code. It was further assumed that all Danish schools meet the ventilation requirements of the Danish Building Code, which according to Clausen et al. (2011) does not seem to be the case in over 50% of Danish schools. The benefits estimated in the present work are therefore quite conservative.

The performance results obtained by Wargocki and Wyon (2013) were used to estimate the effects of improving classroom air quality. This leads to a prediction that changing ventilation rate from 6 to 8.4 L/s per person, i.e. from the Danish to Swedish requirement, would improve the performance of typical schoolwork by an average of 6%. This improvement corresponds to approximately 1/10 of the standard deviation of the average performance of pupils on the tests presented in these studies, independently of the classroom conditions. Assuming a Normal distribution, this means that in a class of 25 children, improving ventilation would cause the median pupil (13th best) to perform as well as the 12th best pupil performs without improved ventilation; all other pupils would improve their performance in a similar way.

The above results were used to estimate the effects on learning as expressed by the improved score in the Programme of International Student Assessment (PISA). 0.1 standard deviation corresponds to about 10 PISA points (there are 500 PISA points that can be obtained and the standard deviation is 100 PISA points). Improving the ventilation in all primary and senior Danish schools for children aged 7-15 years to Swedish levels would improve pupils' test results (reading, comprehension, maths, nature studies, sciences etc.) by ten points in OECD's PISA study. This improvement is moderate. Denmark would move up to the position just above average in the OECD, and there would still be a long way to the top (Figure 2). Nevertheless, an improvement of ten points would bring significant long-term benefits in the form of a better-educated and thus more productive labour force.

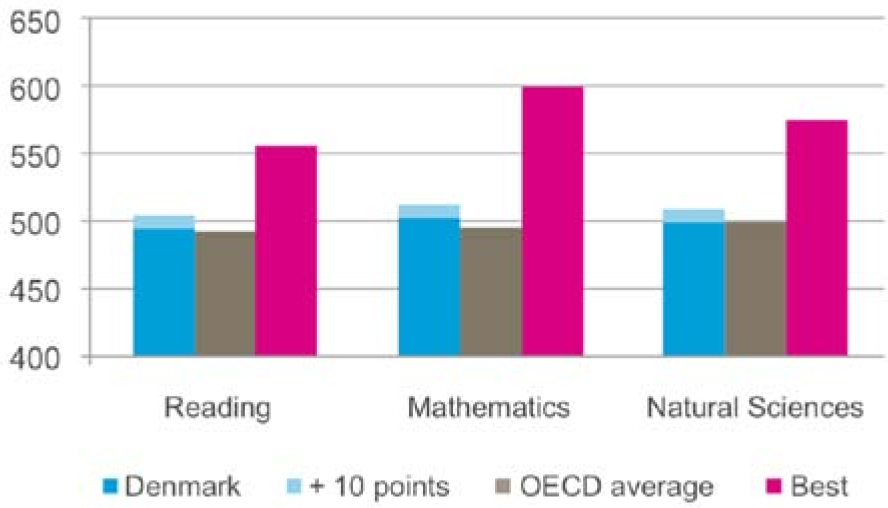

Figure 2. Estimated PISA score with increased ventilation in Danish classrooms (corresponding to +10 PISA points), compared to OECD average and OECD best

An improvement in PISA results would not only result in better-educated adults. It is also highly probable that it would result in a slight reduction in the number of pupils who need to take 10th Grade in the Danish elementary school system; this grade is taken primarily by students who perform below the average and have learning problems. A study made by The Danish Evaluation Institute (2011) shows that pupils opting for 10th Grade in public schools achieve poorer marks than the average pupil does. The 10th Class is voluntary and allows more time to prepare for further education. In a Post-School environment, pupils opting for 10^{th} Grade are evaluated as having different reasons for their choice not necessarily poor grades.

Ten PISA points corresponds in the Danish education system to approximately 4% fewer pupils taking 10th grade. Increasing ventilation to the Swedish level would result in 4% more pupils completing their primary education a year earlier and thus having an extra productive year on the labour market. In the present estimations, this number was assumed to be 2% considering its high level of uncertainty. Thus, an improved PISA result was inferred to reduce the group deciding to take 10^{th} grade from 55% to 53% per year.

OECD (2010) has shown that the countries with better test results in schools have higher growth rates. Thus, a higher PISA score may be indicative of improved productivity and income in adult life. Using the estimates of OECD (2010), the 10-point improvement in PISA was assumed to result in an increase in growth rate of 0.17%. This assumption is supported by Chetty et al. (2010) whose analysis of data from the STAR project in the US showed that children with better scores in the kindergarten class had a higher annual salary 25 years later.

Improved indoor air quality reduces the absence rates of both pupils (Shendell et al. 2004; Mendell et al. 2013) and teachers (Milton et al., 2000). Since it is difficult to make reasonable estimates of the cost of pupils' absence, although attempts have been made by others, e.g. Mendell et al. (2013), or of the effect of short term absenteeism on learning, it was decided that to estimate only the socio-economic consequences of a reduction in the absence rate of teachers. Based on the work of Milton et al. (2000) changing the ventilation rate from 6 to 8.4 L/s/person would reduce sick leave by 4%, which corresponds to ca. 0.5 days each year or 0.2% of a working year.

The following three effects were therefore included in modelling:

a) Increased productivity in adult life
b) Fewer pupils taking Tenth grade
c) Reduced teacher sick leave

The Danish Rational Economic Agent Model (DREAM, 2014) was used to estimate the economic effects in terms of improved public finances and of an increase in the gross domestic product (GDP). The DREAM model is the official Danish financial model that is used by the Danish Ministry of Finance and many other national organisations to evaluate the effects of political decisions and new policies.

RESULTS

The results of the calculations made using the DREAM model are presented in Table 1.They show how increasing classroom ventilation and thus classroom air quality would influence the public primary budget balance and the GDP. It shows the average annual increase and the trend of the effect in the next 20 years; 20 years is the limit of the Dream Model.

Table 1. Macro-economic effects of improved classroom ventilation; annual effect (increase) and trend of this effect (increasing, decreasing or no change) are shown. The figures reflect 2011 prices. Trends are from 2012 to 2050. Figures are rounded and therefore do not add exactly. Danish GDP was €243,000 million in 2012.

	Average annual increase	Trend of effect
Public primary budget balance - total	€37 million	Increasing
of which – a) increased productivity	€16 million	Increasing
– b) fewer pupils in Tenth Class	€15 million	Increasing
– c) lower teacher sick leave	€6 million	No change
GDP total	€173 million	Increasing
of which – a) increased productivity	€106 million	Increasing
– b) fewer pupils in Tenth Class	€67 million	Increasing
– c) lower teacher sick leave	None	N/A

DISCUSSION

Better PISA results were estimated to increase productivity and personal income in later life. The effect was estimated to be least in the short term. The effect is expected to be gradually phased in over a ten-year period as more and more pupils will be educated in classrooms with better indoor air quality and they will experience better classroom air quality for a longer duration during the course of their elementary education. The effect will be much larger in the future when more pupils complete education in schools with better air quality and enter the job market. The estimation of the effect is limited to 20 years due to limitations of the DREAM model. However, the OECD estimates that this effect will continue to increase as the level of education is constantly improving. The long-term estimates are admittedly quite inaccurate and have a high degree of uncertainty so it is difficult to estimate how long the effect will continue, as for example it is difficult to predict how education will take place in the future and even what "going to school" will mean.

Better PISA-results were estimated to reduce the number of pupils taking the 10th Grade. This effect, as with the productivity above, is expected to be phased in gradually over a ten-year period. The effect will be least in the short term and larger in the long term. With fewer pupils taking the 10th grade, more persons are expected to have an extra year on the job market.

Increased ventilation was estimated to reduce teacher sick leave. The effect will be seen immediately and will be permanent.

Pupils' absenteeism was not included in the present estimations. Also not included is the fact that fewer sick days for the youngest children will mean fewer days off work for the parents or caretakers. Mendell et al. (2013) attempted to estimate this effect based on their study in California but there is little or no other information available on this issue in the scientific literature. There are no data on how absenteeism affects learning so this effect was also not included. This means that the observed estimates are quite conservative, not least because improved classroom air quality is likely to improve the morale, level of satisfaction and the behaviour of children; this can translate into reduced sick leave but no reliable data on these effects are available. Finally, it was assumed that all Danish schools do meet the Danish Building code at present, although many measurements in Danish schools (Clausen et al., 2011) show that this is not the case.

The report prepared for the Danish Ministry of Energy (Hviid et al., 2013) evaluated different solutions for classroom ventilation, their applicability and the investment costs in case of their implementation. Three solutions were identified as potentially applicable in Danish schools: central mechanical ventilation, hybrid (mixed mode) ventilation and automatically controlled natural ventilation (when cross ventilation is ensured). The cost of installing each of these three solutions in the existing schools were estimated for a 70 m² classroom yielding €13,000 for central mechanical ventilation, €10,300 for mixed-mode hybrid ventilation and €3,700 for automatically controlled natural ventilation. With 1312 primary schools in Denmark and estimated number of classrooms at 26,240, the first cost of installing ventilation in 50% of the Danish classrooms would thus be €171 million for mechanical ventilation, €135 million for hybrid ventilation, and €49 million for automatically controlled natural ventilation. These costs will thus have similar order of magnitude as the estimated annual increase in GDP (Table 1).

The approach used to calculate the economic benefits applies to Danish conditions but it is believed that it can be adapted to perform similar economic estimates in other countries.

CONCLUSIONS

Improving classroom air quality in Danish schools was estimated to bring significant socio-economic benefits. Using the DREAM model, improving classroom air quality in Danish schools to the level that is already compulsory in Sweden was estimated to yield an average annual increase in GDP of €173 million and an average annual increase in the public budget of €37 million in the next 20 years, the effect generally increasing as more pupils complete their education under favourable working conditions.

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