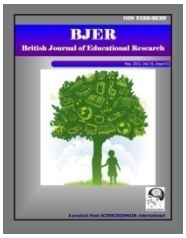

British Journal of Educational Research
2(1): 42-58, 2012

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Sixth Grade Pupils' Health and Performance and Indoor Environmental Quality in Finnish School Buildings

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Research Article

Received 18th August 2011
Accepted 22nd October 2011
Online Ready 28th October 2011

ABSTRACT

Aims: The aim was to study the health and academic performance of school children alongside the indoor environmental quality in Finnish elementary schools.
Study design: Cross-sectional study.
Place and duration of study: Data were collected between March 2007 and April 2008.
Methodology: As part of a national testing program, all sixth grade students in a random sample of 334 schools were tested in mathematics. Health questionnaires were administered to the same students. Data on school buildings were collected by questionnaires from school principals. Additional data were collected by on-site-inspections and measurements from a sub-sample of schools. The resulting database consists of multi-level information on elementary schools, student health and learning outcomes.
Results: After adjusting for student background variables, those who had never experienced high indoor temperatures in classrooms achieved 4.0% (95%CI 0.4-7.4) more correct answers than those who experienced it daily. Pupils who did not miss school days due to respiratory infections had 1.1% (95% CI 0.1-2.2%) more correct answers on the math achievement test, than those who did. Other significant associations were observed between math achievement and both headache and difficulties in concentration.
Conclusion: Math achievement was associated with missed school days due to

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respiratory infections, headache, difficulties in concentration, and indoor temperatures perceived as too high in the classroom. In the future, more detailed analyses are needed to assess the role of these health symptoms in relation to the effects of classroom IEQ on learning outcomes.

Keywords: Indoor air quality; learning and health outcomes; linear mixed models; math achievement; thermal comfort.

1. INTRODUCTION

The majority of children spend a considerable amount of time in school buildings throughout the years they are developing most, physically and mentally. A variety of conditions exist in school buildings that may be detrimental to health, while budgetary shortfalls in school maintenance are common. Thus far, a limited amount of information about the importance of the physical school environment on students' health and learning outcomes has been collected.

Indoor environmental quality (IEQ) in schools is a function of numerous factors, many of which have the potential to cause illness, resulting in absence from school and associated health symptoms that decrease performance while at school. In the scientific literature, poor IEQ has been associated with adverse health effects and absenteeism, but there are limited data linking poor IEQ in the classrooms to the academic performance of students (Mendell and Heath, 2005, Daisey et al., 2003). Whereas it is assumed that poor IEQ results in reduced attendance and learning potential — which consecutively may result in reduced performance — these hypotheses have not been widely tested using standardized metrics for learning outcomes. A multidisciplinary assessment of IEQ, health, and performance is required to develop and motivate protective environmental guidelines needed in schools.

The best documented risk factors for poor IEQ are too high or low indoor temperature and insufficient ventilation, which are commonly found to be outside the recommended ranges in school buildings (Schilte et al., 2005; Shendell et al., 2004; Smedje and Norbäck, 2000; Walden, 2004). One obstacle to improving IEQ in schools is the misconception that the associated cost may not bring any positive return in terms of learning outcomes. Recent studies from Denmark and the United States have indicated that student performance in elementary schools may be affected by IEQ in classrooms (Wargocki and Wyon, 2006; Shaughnessy et al., 2006; Haverinen-Shaughnessy et al., 2011), but these associations have not been widely assessed. Therefore, we started a research program in Finland with a primary objective to comprehensively study IEQ in school buildings alongside the health and academic performance of school children.

Our research was based on the following assumptions: 1) Health and the academic performance of students may be associated with IEQ in schools; 2) academic performance is ideally assessed using the results of standardized tests, such as nationwide exams on mathematics; 3) data on student health can be collected by questionnaires; and 4) IEQ can be estimated by collecting qualitative, self-reported and/or observational information on the school buildings, the condition and performance of heating, ventilation, and air conditioning (HVAC) systems, as well as measured ventilation rates and thermal conditions. In this paper we describe the study protocol, the composition of the database, and the general characteristics of the Finnish elementary school buildings (i.e. schools providing the first to six years of basic education). More detailed analyses are reported in relation to pupils' health, perceived discomfort related to IEQ in classrooms, and their potential association with test results in mathematics.

2. MATERIALS AND METHODS

Our database consists of 1) data received from Finnish Population Register Centre; 2) data collected from elementary school principals by questionnaire; 3) data received from the Finnish National Board of Education; 4) data collected from pupils by questionnaire; and 5) measurement data collected from a sub-sample of schools. The results presented in this paper are mainly based on 3) and 4). Composition of the database is shown in Figure 1.

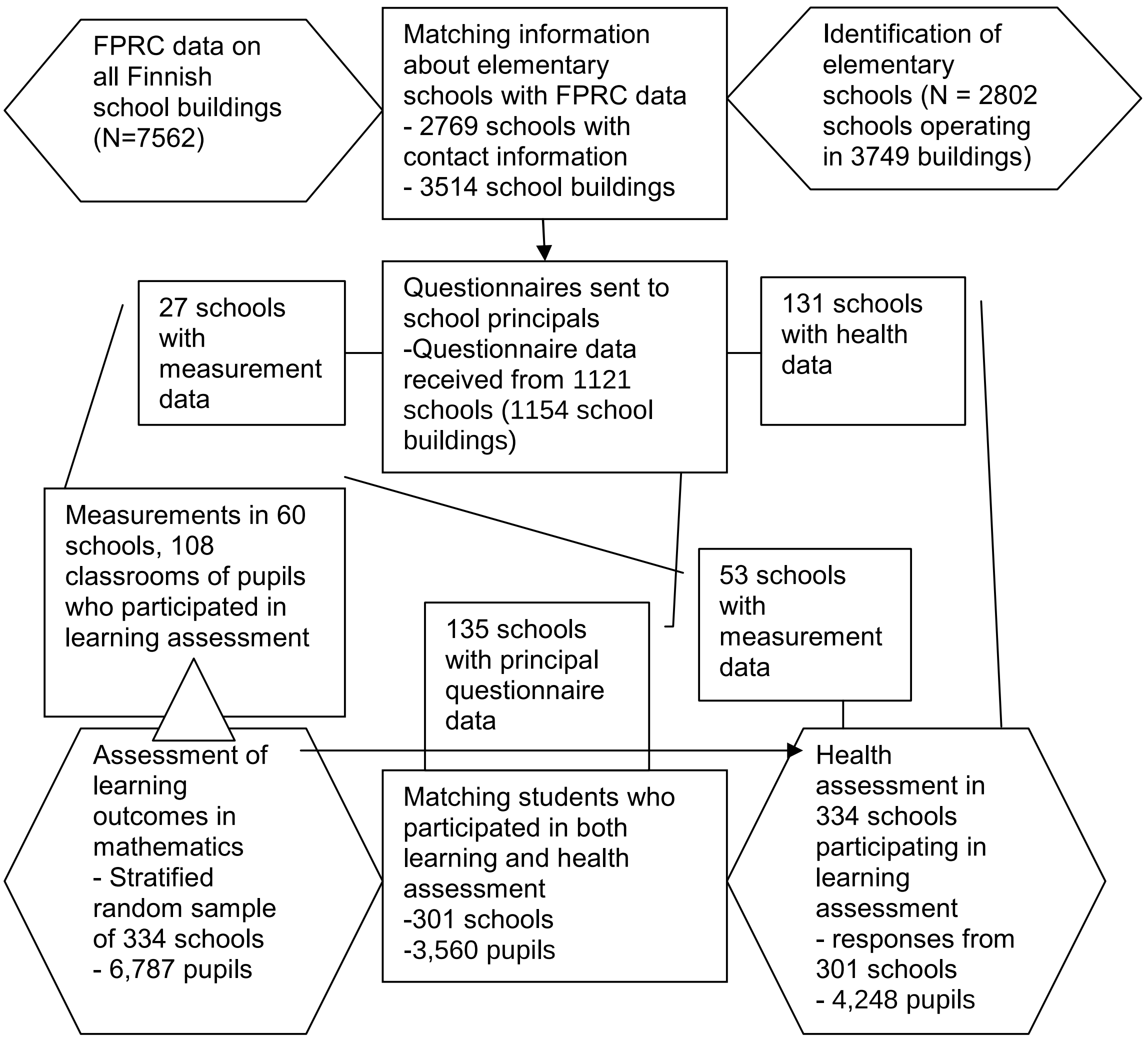

Figure 1: Composition of the database.

2.1 Data from the Finnish Population Register Centre

Background information on the school building stock was acquired from the Finnish Population Register Centre (FPRC) database in early 2007. Information is classified based on the building type or use. In order to attain the necessary information on the school buildings of interest we first reviewed data from all buildings classified as buildings used for "education" (N=7562). We then used listings from the Finnish National Board of Education and the State Provincial Offices of Finland to identify elementary schools by name and address, and matched these data. The resulting dataset includes a total of 2802 elementary schools, consisting of 3749 buildings. The FPRC data consisted of information on 3514 elementary school buildings, such as year of construction, and type of heating and ventilation. Differences between the data sources for the number of school buildings were linked to missing or inaccurate information.

2.2 Questionnaire for School Principals

The lists of Finnish elementary schools obtained from the Finnish National Board of Education and the State Provincial Offices of Finland were cross-verified, and the available school principals' email addresses (N=2769) were gathered and an invitation to respond to a questionnaire at the end of 2007 was sent out. The principals were instructed to follow a link to the project website, where they could find a printable version of the questionnaire, to be returned by regular mail, or they could complete it over the Internet. To maximize the response rate, three reminders were emailed over the course of three months. The Digium software service was used for data collection (http://www.digium.fi/en/), and the Internet connection used secure protocols.

The questionnaire included a total of 18 general questions about the school building. For validation of the questionnaire, six questions provided information corresponding to what was obtained from the FPRC database. In addition, the questionnaire included ten questions about heating, ventilation and thermal comfort, 13 questions about the condition of the building and renovations (i.e. year and type of renovation), and nine questions about dampness and mould, i.e. data not available from registries. In cases where the school unit consisted of more than one building, the principal was asked to complete a separate questionnaire from each building that accommodated sixth grade classrooms. If considered necessary, they were instructed to ask for support from school technical personnel in answering the questions or from the municipality. We received a total of 1154 questionnaire responses from 1121 schools (response rate 40%). The vast majority of principals responded via the Internet (only five questionnaires were returned by mail).

2.3 Data Concerning the Learning Outcomes

In the spring of 2007, the Finnish National Board of Education (OPH) assessed learning outcomes in mathematics in the sixth grade, pupils' attitudes towards mathematics, and other factors that may be connected with learning outcomes (Niemi, 2007). The assessment was based on the performance agreement signed between the Finnish National Board of Education and the Ministry of Education. The data were collected using stratified random sampling. The random sample incorporated 334 schools, including 40 Swedish-language schools, constituting approximately 11% of all elementary schools and sixth grade students. All pupils in the selected schools were tested (response rate 100%). There were a total of 6,787 pupils, 601 of whom spoke Swedish as their first language.

In order to improve the validity and reliability, tests were devised to comprehensively measure key objectives and core content set out for mathematics instruction within the National Core Curricula for Basic Education (1994 and 2004), issued by OPH. Learning outcomes were assessed on the basis of two different tests: half of the pupils completed the first test and the other half did the second test. Both tests included three types of problems: ten mental calculations, eight multiple-choice questions, and 12 production assignments. The scores of the two tests were calibrated into the same scale with one-parametric Rasch modelling. The Cronbach's alpha (a measure of reliability varying from zero to one) for the mental calculation section was 0.67 for the first test and 0.66 for the second test. For the multiple-choice section it was 0.63 for both tests, and for the production assessment section it was 0.85 for the first test and 0.84 for the second test (Niemi, 2007).

For the purpose of this study, the authors received student level data from the OPH, including school and classroom identification information, student gender and first language, the overall percentage of correct answers, and the percentage of correct answers for each individual type of problems. In this paper, the overall percentage of correct answers was used as the main measure of math achievement.

2.4 Health Questionnaire

A health questionnaire study was conducted by the authors in the same sample of schools (a total of 6,787 pupils) as were involved in the learning assessment. The questionnaires were sent to the school offices in May 2007, after completion of the learning assessment. The teaching personnel were asked to distribute the questionnaires to all sixth grade students. The pupils were asked to respond to the questionnaire together with their parents, either by completing the paper questionnaire and returning it to their school in the provided closable envelope, or they could respond by completing the same questionnaire online. Participation in the health questionnaires was voluntary. Ethical approvals was sought from and given by a national ethics committee before data collection started.

The health questionnaire included a total of 37 questions, of which six were on socio-economical status (SES), 18 on student health and well-being, one on the school environment, and six on the home environment. This main section of the questionnaire was developed based on standardized questionnaires and has been successfully used in many studies relating to IEQ issues in schools and student health both in cross-sectional and intervention designs (Meklin et al., 2002, Haverinen-Shaughnessy et al., 2004). Additional questions were included with special reference to factors influencing learning: four questions on living habits (e.g. eating and sleeping), and two on factors that may either facilitate or restrict learning. These questions inquired on whether the parent considered the child to be gifted in one or several areas, or had learning difficulties. The questions related to being gifted were formulated as follows: “Do you think your child is especially gifted or more advanced than other children of the same age *mathematically*?”

The questionnaires were returned from 301 schools, a total of 4248 pupils. Only 90 pupils responded via the Internet. Some schools who did not participate reported having only a small number of sixth grade students in the school, or plans for the school to closed in the near future. The response rate from each school varied from 25% to 100%, resulting in an overall response rate of 60.3% in the sample of 301 schools. The number of sixth grade students responding to the questionnaire ranged from one to 88 per school. A total of 68 schools had less than five responses and a total of 110 schools had more than 15 responses.

We were able to match a total of 3560 (83.8%) respondents with their test results in mathematics. The matching was done manually, because pupils' names were not entered in the electronic data files for confidentiality reasons. The researchers gained access to the original test papers, each consisting of the individual pupil's name and an identification number. The identification number was collected for each pupil responding to the health questionnaire (with name), and entered in the database together with the questionnaire responses. Finally, the health data was merged with the learning data consisting of the same identification number. Pupils who responded to the health questionnaire anonymously could not be matched.

2.5 On-Site Investigations

A total of 60 schools that participated in the learning assessment were selected for the on-site investigations in spring and summer 2007. This convenience sample covered schools mainly located in Southern Finland and which had more than 15 sixth-grade students; each sixth-grade classroom (N=108) was included. Data were collected by interviewing the maintenance personnel, studying the blueprints/school design, and a walkthrough utilizing pre-designed checklists.

Ventilation systems were investigated, and ventilation rates in the selected classrooms were estimated based on exhaust air flow or carbon dioxide (CO2) measurements. Exhaust air flows were measured from exhaust vents in the classrooms that had mechanical exhaust ventilation or mechanical supply and exhaust ventilation. Classrooms with passive stack ventilation systems were measured for CO2 levels during a period of five to ten days. The air change rate was then estimated from tracer decay curves (CO2 as the tracer) after the final school hour when classrooms were unoccupied. Room temperatures were monitored from the same classrooms continuously for several weeks using data-loggers. Results of the on-site investigations have been reported on elsewhere (Palonen et al. 2009).

2.6 Data Analyses

All data were input into a database using PASW Statistics software version 18.0. The data were preliminarily assessed using descriptive statistics related to FPCR and questionnaire data. Factor analysis was performed for data reduction purposes with respect to health questionnaire data. Principal component method was used for factor extraction, with all factors whose eigenvalue exceed 1 retained. The final components selected were those obtained using Varimax rotation with Kaiser normalisation. The associations between students' test results in mathematics and student health and perceived IEQ in classrooms were studied using linear mixed models (LMM), where the school code was used as the subject variable. The covariance type selected was Identity (covariance structure for random effect with only one level). First, we constructed an unconditional means model, i.e. a basic school-effect model with no other predictors included (Singer, 1998). There followed a "basic model" in which we included all background variables as fixed effects. Intraclass correlation coefficients (ICCs) were used to estimate the proportion of the total variance associated with differences among schools.

3. RESULTS

Background information about the school buildings based on the FPRC and principal questionnaire data is presented in Table 1. More than half of the buildings were built over 50 years ago, and according to the principal questionnaire, 22.7% had undergone a comprehensive renovation. Most of the buildings were relatively small (median floor area 1288 m2 / seven classrooms). Other predominant building characteristics, according to the principal questionnaire, included a basement (66% of buildings had a basement), timber frames, mechanical ventilation, and oil heating.

Table 2 shows respondents' background information gathered from the health questionnaire and the corresponding numbers of those who were matched with their mathematics test results, which are broadly similar. While the average school-level math achievement score (i.e. mean percentage of correct answers) was 62.2% (61.3 – 63.1%) based on the unconditional means model, it was 67.0% (41.4 – 92.6%) based on the basic model, i.e. when controlling for all background variables (as in Table 2). The ICC for schools increased from 10.8% (unconditional means model) to 13.2% (basic model) when background variables were included. Correspondingly, the percentage of total variance among pupils within schools decreased from 89.2% (unconditional means model) to 40.5% (basic model).

Table 2 also shows the basic model estimates for the associations between math achievement and background variables. The strongest associations were observed between math achievement and the need for personal tutoring, pupils reported gifted mathematically and linguistically, parents' education, and Finnish language. For example, the pupils who needed personal tutoring regularly had an average of 19.3% lower scores as compared with those who did not need tutoring. Those who were reported gifted mathematically had an average of 17.7% higher scores than those who were not reported as gifted by their parents.

Table 1: Information about the school buildings.[a]

	FPRC N=3514	**Principal questionnaire N=1154**
Year of construction, mean / median	1957 / 1958	1954 / 1957
Floor area of the building [m2], mean / median	2098 / 1152	2343 / 1288
Number of classrooms, mean / median	-	11 / 7
Number of floors, mean / median	1.7 / 2	2 / 2
Building has a basement, %	-	66
Predominant frame material concrete, %	31.1	32.2
masonry, %	17.5	24.7
timber, %	49.6	37.9
other, %	1.9	5.2
Type of ventilation natural, %	-	18.3
mechanical exhaust, %	-	16.6
mechanical support and exhaust, %	49.5	59.2
Main source of heating district heating, %	32.5	42.1
oil, %	47.7	43.5
electricity, %	10.0	6.1
wood, pellet, %	6.6	5.5
other, %	1.1	2.8
Building undergone renovation, %	-	22.7

[a]*The sum of the proportion of school buildings in each category may be < 100% due to some missing information.*

In relation to the home environment and living habits, variables negatively associated with math achievement included living in multifamily buildings (i.e. apartments and row houses, 3.0–3.5% lower scores), and exposure to environmental tobacco smoke (ETS) (-3.4%), as well as sleeping hours (-0.8% per hour) and taking naps during the day (-3.1%), whereas having no pets and eating breakfast daily was associated with better test results (2% and 3.2% higher scores, respectively). Regular exercise (more than 30 minutes at least three times per week) also appeared to have an influence on the test results (+2.1%), although the association was not statistically significant at the 95th percentile confidence interval (p=0.055).

The health questionnaire included some 20 health symptoms with possible connections with IEQ and learning, one control symptom (urinary track symptoms), and "other" (data not shown). The respondents reported symptoms occurring weekly, monthly, or less often. Related to these 20 symptoms, five principal components were extracted explaining 55% of the total variance (Table 3). These components appeared to group symptoms into 1) upper respiratory, 2) lower respiratory, and 3) general symptoms, 4) muscular pain or tension, and 5) allergic symptoms, although there were cross-loadings greater than 0.4 for rhinitis and stuffy nose (1 upper respiratory & 5 allergic) and fever (1 upper & 2 lower respiratory).

Table 4 shows the prevalence of selected health symptoms/illnesses among the pupils. Again, almost identical results were observed for all respondents and those who were matched with their math test result, therefore only the latter values are shown. Some 70.2% of the respondents had flu or cold in the spring semester; 3.6% reported otitis, 3.4% sinusitis, 2.5% tonsillitis, and 2.2% bronchitis/pneumonia. Almost half (48%) of the pupils had missed school due to respiratory infections (Table 4), 14.1% had seen a doctor and 8.7% had received antibiotics. Reported flu/cold was most commonly associated with missed school days, whereas other types of respiratory infections were more commonly related to seeing a doctor and receiving antibiotics (data not shown).

Table 4 also shows the prevalence of reported discomfort caused by too high indoor temperatures and mould odour in classrooms. In addition to these variables, the two most common daily discomfort parameters were related to noise (12.8%) and stuffy air or poor indoor air quality (8.3%). There were significant correlations between all discomfort variables. For example, the Spearman correlation between discomfort caused by high indoor temperature and stuffy air or poor indoor air quality was 0.453 (p=0.000) (data not shown).

We also assessed the unconditional means and basic models (as in Table 2) with additional variables presented in Table 4. These results indicated that, after controlling for background variables, math achievement was associated significantly with missed school days due to respiratory infections, headache, difficulties in concentration, and reported discomfort caused by high indoor temperatures. However, the bivariate associations with general health status, allergic rhinitis, persisting cough, fever, back pain, fatigue, and reported discomfort caused by mould odour did not remain significant after controlling for background variables at the 95th percentile confidence interval.

Table 2: Pupils' background information and their associations with math achievement based on LMM modelling (basic model)

All	Pupils	Matched[b]	Estimates for fixed effects		
	N=4248	N=3560	Estimate	95%CI	P
	mean	mean			
Age	12.5	12.5	-0.3	-1.3 – 0.7	0.571
Years in current school	5.3	5.3	-0.0	-0.4 – 0.4	0.925
Average sleeping hours	8.8	8.8	-0.8	-(1.5 - 0.2)	0.007
	%	%			
Gender, boy	47.5	46.8	-0.3	-1.5 – 0.8	0.571
First language Finnish	90.4	91.4	6.9	2.2 - 11.6	0.004
Swedish	7.4	6.6	-4.0	-9.5 - 1.4	0.147
Other	2.2	2.0	0[a]		
Mother's education primary school	10.5	10.3	-6.2	-(8.2-4.1)	0.000
high school / equivalent	36.1	36.2	-3.5	-(4.8-2.3)	0.000
college / university	53.4	53.5	0[a]		
Father's education primary school	17.9	17.4	-5.0	-(6.8-3.3)	0.000
high school / equivalent	45.0	45.0	-3.7	-(5.0-2.5)	0.000
college / university	37.1	37.6	0[a]		
Living in a city centre	6.5	6.2	-2.4	-5.4 – 0.6	0.112
suburb close to a city	39.5	38.1	-0.5	-2.4 – 1.4	0.620
rural suburb area	22.3	23.3	-0.4	-2.1 – 1.3	0.633
rural area	31.7	32.3	0[a]		
Living in an apartment	16.1	14.6	-3.5	-(6.4 - 0.5)	0.020
row house	11.2	11.0	-3.0	-(5.8 - 0.1)	0.042
single family house	64.5	66.1	-0.9	-3.1- 1.3	0.428
Farm	8.3	8.4	0[a]		
No pets in home	27.8	27.4	2.0	0.2 – 3.8	0.031
pets currently	58.4	59.0	-0.4	-2.1 – 1.2	0.610
pets only previously	13.8	13.6	0[a]		
Exposed to ETS in home	3.9	3.5	-3.4	-(6.4 – 0.5)	0.023
Observed moisture damage, mould or mould odour in home	8.3	8.0	0.7	-1.3 - 2.7	0.487
Takes naps during the day	10.7	10.4	-3.1	-(4.9 – 1.3)	0.001

Table 2 continues...........

Eats breakfast daily	87.1	87.4	3.2	0.9 – 5.6	0.007
several times a week	6.5	6.2	1.3	-1.8 – 4.4	0.413
less often	6.4	6.4	0[a]		
Exercises > 3 times /week	65.1	65.9	2.1	-0.0 – 4.3	0.055
1-2 times / week	27.3	26.9	0.6	-1.7 – 2.8	0.634
less often	7.6	7.2	0[a]		
Gifted in mathematics	18.4	19.1	17.7	16.3-19.1	0.000
Gifted linguistically	20.5	21.3	5.0	3.6-6.4	0.000
Gifted musically	16.4	17.0	0.2	-1.3 - 1.6	0.792
Gifted in art	16.0	15.7	-2.4	-(4.0 - 0.9)	0.002
Gifted socially	21.0	20.8	- 2.4	- (3.7 – 1.0)	0.001
Gifted in sports	22.9	22.8	- 2.7	-(4.1 - 1.4)	0.000
Needs personal tutoring regularly	8.3	7.0	-19.3	-(21.5 - 17.0)	0.000
Doctor diagnosed dysphasia	0.7	0.5	1.1	-7.1 – 9.4	0.787
Doctor diagnosed dyslexia	0.2	0.1	3.7	-13.6 – 20.9	0.678
Doctor diagnosed ADHD	0.8	0.7	2.2	-4.7 – 9.0	0.535

[a] *This parameter is set to zero because it is redundant*

[b] *Matched students are those for whom both math achievement scores and health questionnaire responses were available.*

Table 3: Frequency of symptoms among all pupils and results from the factor analyses.

Rotated Component Matrix	Weekly	Monthly	Component				
	N(%)	N(%)	1	2	3	4	5
Dry or sore throat	90(2)	591(15)	.712		.191	.153	
Rhinitis	193(5)	881(22)	.631		.102		*.527*
Dry cough	75(2)	429(11)	.623	.189			
Cough with phlegm	67(2)	332(9)	.611	.227		.127	
Hoarseness	81(2)	328(8)	.570	.226	.155	.115	
Stuffy nose	354(9)	936(23)	*.555*		.116		.625
Fever over 37°C	40(1)	190(5)	*.415*	*.402*		.166	
Wheezing	30(1)	76(2)	.204	.811		.118	.103
Cough with wheezing	22(1)	45(1)	.142	.784		.218	
Dyspnea	47(1)	146(4)	.191	.675	.127		.189
Difficulties in sleeping	110(3)	389(10)		.184	.750		
Difficulties in concentration	138(4)	364(9)		.213	.710		
Fatigue	316(8)	1115(28)	.262		.685	.231	.118
Headache	255(6)	1150(29)	.255		.541	.244	.141
Muscular pain	116(3)	649(17)	.167		.230	.737	.132
Back pain	62(2)	300(8)	.159	.140	.168	.693	
Arthralgia	59(2)	183(5)		.278		.653	.133
Eye symptoms	85(2)	311(8)	.170	.175	.117		.658
Nasal bleeding	76(2)	253(7)	-.124	.210		.224	.599
Variance explained, %			14.8	12.1	10.8	9.3	8.4

4. DISCUSSION

Based on the results, more than half of the Finnish elementary school buildings are over 50 years old, and less than 23% had undergone renovation. On-site investigations in 60 schools in Southern Finland revealed the oldest mechanical supply and exhaust ventilation system still in its original condition was installed in 1954, and that all schools with passive stack ventilation system (i.e. natural ventilation) were constructed before 1955 (Palonen et al., 2009). Therefore, it appears evident that the school building stock is relatively old compared to the whole building stock in Finland, and that a large proportion of buildings is in need of comprehensive renovation/upgrading of their HVAC systems.

Where applicable, FPRC data and data from the school principals showed similar results, although the FPRC data did not cover all questions. Part of the information may also be outdated since the FPRC data are typically registered at the time of construction. For example it does not include the percentage of buildings that have undergone renovation (typically involving repairing/upgrading heating, ventilation, plumbing, and sewage systems, roofing, external walls and windows, as well as interior fabric).

Noise and stuffy air or poor indoor air quality in the classroom were the most common causes of discomfort reported. These are frequently reported causes of discomfort that are challenging to control in a school environment (Becker et al., 2007, Kruger et al., 2007).

Table 4: Prevalence of certain health and discomfort variables and their association with math achievement

	Matched N (%)	Estimate	Crude 95% CI	p	Estimate	Adjusted[b] 95% CI	p
General health							
Excellent	1916(54)	20.4	-0.4 – 41.2	0.055	8.8	-11.8 – 29.3	0.402
Good	1540(43)	17.0	-3.8 – 37.8	0.110	7.3	-13.2 – 27.8	0.484
Fair	54(2)	11.8	-9.6 – 33.2	0.280	6.2	-14.9 – 27.3	0.567
Poor	3(0)						
Missed school days due to respiratory infections	1719(48)	-0.8	-2.0 – 0.5	0.234	-1.1	-(2.2-0.1)	0.038
Allergic rhinitis	558(16)	1.8	0.1 – 3.4	0.040	-0.1	-1.6 – 1.4	0.885
Persisting cough	728(20)	-2.0	-(0.5 – 3.5)	0.010	0.8	-0.6 – 2.1	0.259
Wheezing							
weekly	22(1)	10.3	2.6 – 18.0	0.009	4.6	-2.2 – 11.4	0.187
Monthly	63(2)	0.1	-4.7 – 4.4	0.949	1.6	-2.5 – 5.7	0.439
less often	3143(88)	0[a]			0[a]		
Fever							
Weekly	29(1)	-7.3	-(14.0 – 0.6)	0.034	-2.8	-8.5 – 2.9	0.334
Monthly	149(4)	-5.2	-(8.2 – 2.1)	0.001	-2.1	-4.8 – 0.6	0.124
less often	3133(88)	0[a]			0[a]		
Back pain							
Weekly	49(1)	-4.0	-9.2 – 1.3	0.136	-1.2	-6.3 – 3.8	0.635
Monthly	252(7)	-2.7	-(5.0 – 0.3)	0.028	-2.0	-4.1 – 0.1	0.058
less often	2936(83)	0[a]			0[a]		
Fatigue							
Weekly	258(7)	-0.1	-2.5 – 2.2	0.904	0.4	-1.8 – 2.6	0.713
Monthly	925(26)	-1.8	-(3.3 – 0.4)	0.011	-0.5	-1.8 – 0.7	0.422
less often	2123(60)	0[a]			0[a]		
Headache							
Weekly	202(6)	-3.7	-(6.4 – 1.1)	0.006	-1.9	-4.2 – 0.5	0.123
Monthly	975(27)	-2.3	-(3.7 – 0.9)	0.001	-1.6	-(2.8 – 0.4)	0.011
less often	2201(62)	0[a]			0[a]		

Table 4 continues...........

Difficulties in concentration							
Weekly	102(3)	-10.2	-(13.8 – 6.6)	0.000	-3.6	-(7.1-0.1)	0.045
Monthly	287(8)	-11.0	-(13.2 – 8.8)	0.000	-5.5	-(7.6-3.5)	0.000
less often	2851(80)	0[a]			0[a]		
High indoor temperature							
Never	2030(57)	5.2	1.2 – 9.2	0.010	4.0	0.4 – 7.5	0.028
Occasionally	1243(35)	4.1	0.1 – 8.1	0.044	3.0	-0.5 - 6.6	0.096
Weekly	100(3)	3.2	-2.8 – 8.5	0.242	1.3	-3.3 - 6.0	0.573
Daily	89(3)	0[a]			0[a]		
Mould odour							
Never	3175(89)	7.6	0.0 – 15.2	0.049	3.1	-3.8 – 10.1	0.376
Occasionally	196(6)	4.5	-3.4 – 12.4	0.266	0.9	-6.3 – 8.2	0.798
Weekly	34(1)	6.3	-3.4 – 16.0	0.201	0.9	-7.8 – 9.6	0.839
Daily	24(1)	0[a]			0[a]		

[a]This parameter is set to zero because it is redundant [b]Adjusted for variables as in Table 2

It was also observed that discomfort related to stuffy air or poor indoor air quality and high indoor temperature were commonly reported simultaneously, which may be both related to poor thermal control and ventilation. An overlap between ventilation rate and indoor temperature measures was also observed in a study using measurement data collected from the US (Haverinen-Shaughnessy et al., 2009). They may therefore represent conceptually same IEQ-related factor and may lead to similar responses, which are difficult to separate from each other, especially with self-reported qualitative data.

The LMM modelling technique was utilized to fit models including the school effects. The school-effects models are designed for individual-level data nested within naturally occurring hierarchies (Singer, 1998), e.g. student within classes/schools. The model estimates suggested that schools have differences in their average math scores even after adjusting for student background. Accounting for the differences in the tests scores between schools by utilizing the LMM technique was considered important since the analyses presented in this paper were focused on associations between math achievement and other student level variables (i.e. questionnaire responses on health and discomfort caused by IEQ in classrooms). Further studies are needed in order to assess to what extent the school-level variation that was observed can be attributed to IEQ. There are many other factors that may also explain the differences. However, in Finland, where education is free for everyone (private schools are virtually non-existent) the majority of school children go to their neighbourhood school, where all teachers are required to have M.Sc. degrees. Therefore, these factors are not likely to explain school-level differences as much as in some other countries, where the students and teachers are more selective for their schools.

The results revealed associations between math achievement and many factors related to SES (e.g. parents' education), living habits (e.g. need for naps during the day, eating breakfast, and regular exercise) and physical home environment (e.g. type of residence, having pets, exposure to ETS). Most of these associations have been described in the literature (Cleveland et al., 2000, Rampersaud et al., 2005, Sirin, 2005, Shilts et al., 2009). However, the majority of background data related to learning assessments in Finland have previously been available only at the population level. This study had a unique opportunity to collect such information at the individual level. These data were intended to be primarily used to control the studied associations between math achievement, health, and IEQ for SES and other important background variables. However, it should be noted that controlling for SES is challenging, beginning with the selection of variables to be controlled for (Jeynes, 2002).

Based on a study conducted in the US (Haverinen-Shaughnessy et al., 2011), background factors that were considered important included family income (in the US study, measured by eligibility for the free lunch program), mobility, and language proficiency. In the current study, the primary variable accounting for SES was parents' education, which is commonly used in education research (Jeynes, 2002). Mobility was at least partially covered by years pupils had attended their current schools, and we also collected data on the first language. The tests were offered in both Finnish and Swedish, covering approximately 98% of the first languages of the pupils. However, first language appeared to have a relatively high impact on the math scores; the relative difference between Finnish and Swedish speaking pupils was almost 11%.

The data also included factors that may either facilitate or restrict learning, although it appeared that such information may not be considered fully independent from the learning outcomes studied. For example, it is likely that the parents draw from their child's previous math achievements when they rate the child as gifted in mathematics, and the previous achievement is likely to be correlated with the current and future achievements. However, the proportion of gifted students in a classroom may be an important factor in group level analyses, as suggested in the US study (Haverinen-Shaughnessy et al., 2011).

Factor analysis was performed with respect to the frequency of symptoms due to the large number of symptoms included in the questionnaire. These results may also be used in order to design shorter questionnaires in the future. However, more detailed group-level analyses in future studies are needed to be able to evaluate if there are certain health symptoms that may link the IEQ in the classroom to learning outcomes.

Missed school days due to respiratory infections, headache, and difficulties in concentration reduced the math achievement significantly in the LMM analyses. Respiratory infections, absenteeism and general symptoms, such as headache and difficulties in concentration, have also been associated with poor IEQ in the literature (Daisey et al., 2003). While allergic rhinitis and wheezing appeared to be associated with better test results in bivariate analyses, the association diminished after adjusting for background variables. Also general health status, persisting cough, fever, back pain, and fatigue showed bivariate associations with test results, but the associations did not remain significant in the multivariate models. Interestingly, reported discomfort caused by high indoor temperature appeared to be consistently associated with math achievement: the more frequent the discomfort, the larger the influence. On average, the pupils who never experienced discomfort achieved 4% higher scores in the math test than those who experienced it daily.

6. CONCLUSIONS

A large database was composed consisting of multi-level, representative information on Finnish elementary school buildings, their condition, IEQ parameters, and information about student health and learning outcomes. Based on the analyses, math achievement is associated with missed school days due to respiratory infections, headache and difficulties in concentration, and indoor temperatures perceived as being too high in the classroom.

ACKNOWLEDGEMENTS

The study was funded by the Academy of Finland Grants 114844 and 109062. The authors wish to thank Mr. Ari Paanala for helping to carry out the data collection, especially related to FPRC and principal questionnaire data by locating schools and their addresses and matching these data; Prof. Aino Nevalainen for providing expertise with respect to indoor air quality issues; and Mr. Mark Phillips for performing the language check. The authors also wish to thank the school personnel, the pupils and their parents for their participation in the study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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