Indoor Environmental Quality in Finnish Elementary Schools and Its Effects on Students' Health and Learning

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ABSTRACT

The aims were to assess indoor environmental quality (IEQ) in Finnish elementary school buildings, and to study associations between ventilation rate and student health and learning outcomes. The study population consisted of about one thousand sixth grade students from 59 schools in southern Finland. Students' learning outcomes were assessed based on mathematics test scores as a part of a national assessment program. In addition, students (with the help of their parents) responded to a questionnaire about their health. Indoor environmental quality in classrooms was assessed by on-site measurements of ventilation rates and temperatures. Background information of school building was collected from the Finnish register centre. Based on the measurements, mean ventilation rate per student was 3.0, 3.0 and 6.5 L/s/student for schools with natural, mechanical exhaust, and mechanical supply and exhaust ventilation systems, respectively. Mean temperature was 22.4^{0}C.There was no significant correlation between measured IEQ (ventilation and temperature) and school level health and learning outcomes in this sample of schools. In conclusion, mean ventilation rate per student did not meet building code regulations in naturally ventilated schools and schools with mechanical exhaust only. Mean temperature was within the recommended range. Relatively small number of schools limits the conclusions about the associations between IEQ, health, and learning. More detailed analyses including multi-level analyses and non-linear modeling is required for more definite conclusions.

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ABBREVIATIONS

^{0}C	Degree Celsius
AHU	Air Handling Unit
AQ	Air Quality
ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
BRI	Building-Related Illness
FNBE	Finish National Board of Education
FPRC	Finnish Population Register Centre
HVAC	Heating, Ventilation, and Air Conditioning
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
MVOCs	Microbial Volatile Organic Compounds
NBCF	National building code of Finland
PAH	Polycyclic Aromatic Hydrocarbon
PAQ	Poor Air Quality
POM	Particle bound Organic Matter
SBS	Sick Building Syndrome
SD	Standard Deviation
SPOF	State Provincial Offices of Finland
U.S.A	United States of America
US EPA	United States Environmental Protection Agency
VOCs	Volatile Organic Compounds
WHO	World Health Organization

Contents

1 INTRODUCTION

Most children spend majority of their time indoors. In Finland, up to eight hours can be spent in school for a period of five days (Monday to Friday), which make children to get exposed to any contaminant present in the air they breathe. Indoor environmental quality (IEQ) is influenced by outdoor environmental quality and also pollutants generated indoors. There have been a few studies done on schools' indoor environment when compared to that of other buildings such as offices and industrial buildings, even though children, unlike adults are more susceptible to air pollution and they cannot make decision about their school environment (Wargocki and Wyon, 2006). Children are more susceptible to pollutants present in the air than adult, because their tissues and organs are immature and continue to rapidly develop, and they breathe higher volumes of air relative to their body weights (Mendell and Heath, 2005 and Cartieaux *et al.*, 2011). Environmental problems may be more common in school building than in other buildings due to low funding for operation and maintenance of facilities (Mendell and Heath, 2005).

Different studies carried out show that school classrooms can be polluted by various indoor pollutants, which includes molds, bacteria, allergens, particles, volatile organic compounds (VOCs), and formaldehyde (Zhao *et al*., 2008). Ventilation is an important factor affecting IEQ of buildings. Mechanical ventilation may reduce the amount of pollutants entering indoor from outdoor while the concentration of outdoor pollutants that enter indoor environment is close to unity when direct ventilation is used (Chen *et al.*, 2011).

The state of different school buildings may have effect on their IEQ. An old school building may have its ventilation systems not performing at the optimal level, whereas a new building or a recently renovated school building may have a modern mechanical ventilation system that will reduce the amount of pollutants from outdoor to the minimum. The material for building construction may vary due to the year of construction and availability of funds for construction. Old school buildings may be constructed with materials that will affect IEQ, for example, asbestos and lead (Flynn *et al*., 2000). Old school buildings may also have less insulation and leakier structures, thus more exposed to cold (Espejord, 2000).

According to Nandasena *et al.,* (2010) ‘Exposure to air pollutants is related to a variety of health effects, depending on the type of pollutant, amount of the pollutant exposed to, duration and frequency of exposure, and associated toxicity of the specific pollutant’. Health effects that can be caused or exacerbated by indoor environmental pollutants in children include breathing difficulties, asthma and allergies, pneumonia and other respiratory infections, lower respiratory symptoms, etc. This in turn may result in decrease performance due to health issues or may require intermittent absenteeism from school. Eide *et al.* (2010) concluded that ‘Children with poor health have lower educational attainment, lower social status, worse adult health outcomes, and a higher likelihood of engaging in risky behaviors than their healthy peers’.

This study was conducted as a part of large research project on Indoor Environmental Quality and Academic Performance in Schools (Haverinen-Shaughnessy et al. 2012). This work is focused on studying associations between IEQ in schools and group level health and learning outcomes among 6^{th} grade students in Finland.

2 Review of the literature

2.1 Interacting factors of IEQ

IEQ is affected by various interacting factors, including building occupants, climate, building construction (original design or later modification during renovation) and mechanical systems, construction techniques and contaminant sources (e.g. excess moisture and microbial growth, processes and activities within the building, building and furnishing materials, and outdoor sources) (US EPA., 2010). Human activities that affect IEQ in schools includes body odour, cosmetic odour, housekeeping activities (dust and dirt from the air, house cleaning materials, emission from trash and store supplies), those from building system includes materials from damaged asbestos, chemicals released from building components or furnishing e.g. volatile organic carbons or inorganic carbons, HVAC system problems that results in dirt and dust in ductwork or other components, refrigerant leaks and improper venting, and outdoor contaminants (fumes from vehicle exhaust, pollen from plants, etc.) (US EPA., 2010).

2.2 Components of the Indoor Environment

IEQ is an interplay between physical, chemical and biological factors (Table 1). Biological contaminants include allergens from animal dander, dust mites, moulds and bacteria, while chemical contaminants comes from combustion products e.g. environmental tobacco smoke, residue from biomass burning (particulate matters), gases (CO_2, CO, SO_2,NO_x, O_3, NH_3) and off-gassing emissions e.g. formaldehyde and VOCs (Dales *et al.*, 2008). The physical factors of indoor environment can have direct effect on building occupants, modify body’s response to indoor pollutants, and can interact with indoor pollutants (Levin, 1995). These include air temperature, pressure, humidity, and air movement. Table 1 shows different indoor environmental factors and Figure 1 illustrates different components affecting IEQ.

Table 1. Different physical, chemical, biological and particle factors that affect IEQ.

	Indoor Environmental Quality		
Physical factors	Chemical factors	Biological factors	Particulate matter
Temperature Humidity Air pressure, Air movement (draught) Lighting Noise Cleanliness	(Organic) VOCs, PAH e.g. Benzo[a]pyrene, Formaldehyde (Inorganic) CO_2, CO, SO_2,NO_x, O_3, NH_3, Radon (Odours)	Moulds (fungi) Bacteria Plant pollen Dust mites Animal dander	Dust Tobacco smoke Fibres (e.g. asbestos) Combustion by-products

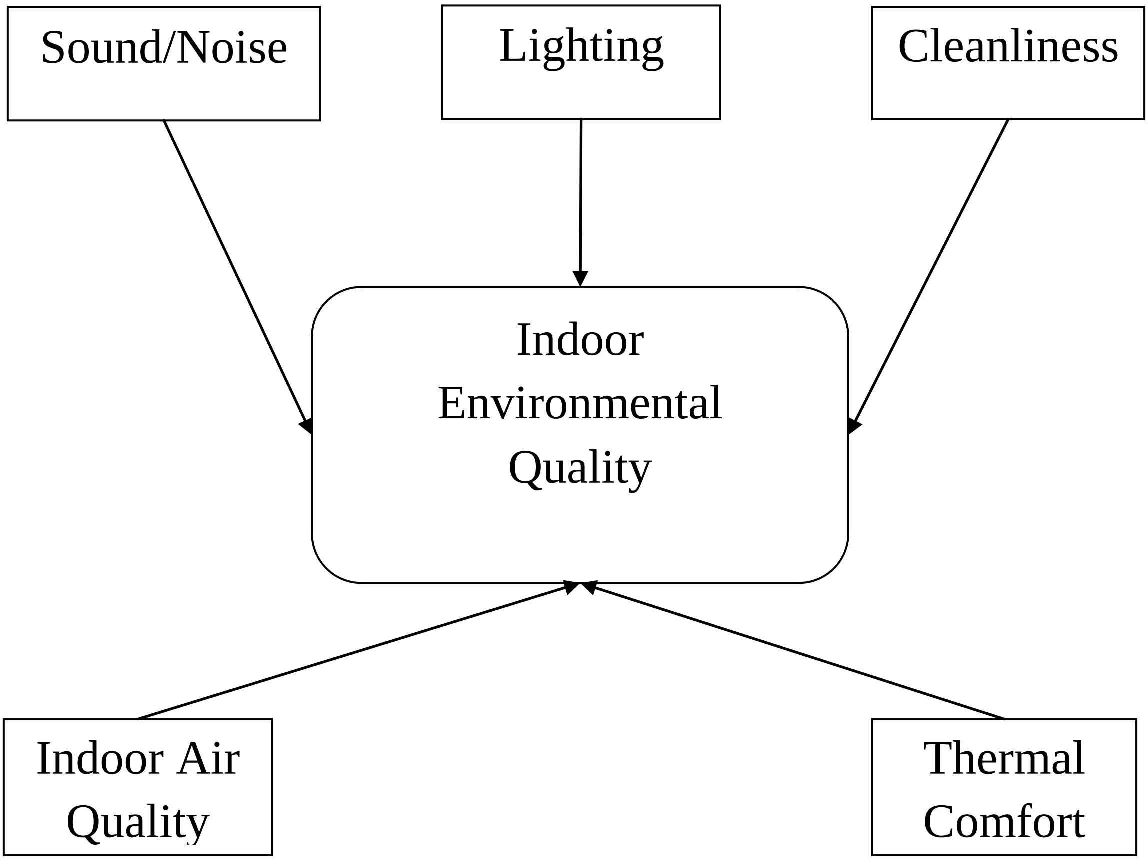

Figure 1. Different components affecting IEQ

2.3 IEQ and Ventilation

Ventilation is the process of replacing noxious air in space with fresh air. Pasanen (1998) defines ventilation as the process of supplying or removing conditioned or non-conditioned air by natural or mechanical means to or from any space. It involves the exchange of indoor air to the outside and even circulation of air within a building. This helps to remove excessive moisture, odour and contaminants as well as introducing outside air so as to prevent the stagnation of indoor air. Ventilation can be done mechanically by the use of air handling unit (AHU) which manipulates outside air that will go indoor by removing contaminants present, or naturally. Natural ventilation can be maximised by opening windows for outside air to enter indoor freely. Different types of mechanical ventilation systems include 1) mechanical exhaust ventilation system, in which a centrally placed fans continually extracts the right amount of air from the indoor environment, and 2) mechanical supply and exhaust ventilation where centrally located fans continually introduce and extract the right amount of air from the indoor environment (WHO, 2009).

A recent review conducted in the U.S.A on indoor air, ventilation, and health symptoms in schools strongly suggest that many classrooms are inadequately ventilated leading to health symptoms (Daisey *et al.,* 2003). Sundell *et al.,* (2011) reported that a lower ventilation rate is associated with inflammation, respiratory functions, asthma symptoms, and short-term sick leave while there is a reduction in allergic conditions among children of Nordic countries when ventilation rates is above 0.5 air change per hour. A study that investigated 10 naturally ventilated schools in Shanghai, China, concluded that asthma symptoms in pupils were caused by outdoor air pollution from traffic (Mi *et al.,* 2006). Ventilation system may also be a source of odorous and stuffy air (Pasanen *et al*., 1995). Ventilation rate per student has been assigned a reference value of 6l/s per student in Finland since 1987 (Ministry of Environment and Palonen *et al*., 2009). In general, poor building designs, as well as poor maintenance of heating, ventilation and air conditioning systems can result in insufficient ventilation of classrooms (Shendell *et al.,* 2004a).

2.4 IEQ and Health

Indoor air have been shown to contain contaminants that at an increased concentration can exacerbate pre-existing health conditions such as asthma, or cause a health condition such as cough to occur (Flynn *et al*., 2000). The contaminants in indoor air vary from biological to chemical contaminants. Bacterial, moulds, VOCs, particle bound organic matter (POM), and micro particles have been reported and confirmed to cause health problems in school children (Cartieaux *et al.,* 2011). Biological contaminants (e.g. moulds, dust mites, cockroaches) can exacerbate pre-existing asthma (Dales *et al.,* 2008).

Exposure to chemical contaminants as well as environmental tobacco smoke can adversely affect lung function in children (Dales *et al.,* 2008). Microbial Volatile Organic Compounds (MVOCs) and plasticizers in school environment may pose a risk factor for asthmatic symptoms in children (Kim *et al.,* 2007). Lack of thermal comfort in school is associated with headaches, drowsiness, and eye and upper airways discomfort (Andersen and Gyntelberg, 2011).

2.5 IEQ and Building Condition

Different building types may have different IEQ characteristics, which could be partly attributed to building age and construction materials. For example, old school buildings may have asbestos in them, and ventilation system may be old, and can be of natural type. Some 77% of 39 Swedish schools that were measured for building code regulations did not meet the requirements (Wargocki *et al.*, 2005).

School buildings are commonly in need of extensive repairs. Some 63% of U.S.A students, corresponding to about 14 million students, attended schools with substandard building (Mendell and Heath, 2005). A Swedish study that investigated eight primary schools found high levels of MVOCs and plasticizer in new buildings as a result of emissions from building materials (Kim *et al.*, 2007). Sick building syndrome (SBS) is commonly reported in school buildings. SBS describe situations in which building occupants experience acute health effects that appear to be linked to time spent in building (Saijo *et al.*, 2010 and Zhang *et al.*, 2011). SBS can also occur in newly built buildings (Saijo *et al.*, 2011).

Building-related illnesses (BRI) include cough, fever, and allergic disease, which often require prolonged recovery time and can become chronic to an individual. BRI are described as clinically verifiable diseases with symptoms that persist even after the occupant leaves the building. Seltzer (1994) listed four mechanisms by which illness can be induced by BRI agent. They include (1) immunologic, (2) infectious, (3) toxic, or (4) irritant. Some agents may work through more than one mechanism.

2.6 IEQ and Thermal Comfort

Thermal comfort is a state of mind in which a person is satisfied with the thermal environment; it is a result of the body's heat exchange with the environment (ASHRAE standard 55, 2004 and Van Hoof *et al*., 2010). It adds to a person's total environmental contentment, welfare, and performance (Van hoof, 2008).
It has been estimated that to achieve thermal comfort for eighty-five percent of building dwellers, indoor temperature should be lower than 24^0C (Andersen and Gyntelberg, 2011).

Air temperature, radiant temperature, humidity and air speed as well as clothing and metabolic rate influences thermal comfort (ASHRAE standard 55, 2004).

People feel more comfortable in air conditioned rooms. Naturally ventilated buildings in China could not meet ASHRAE standard 55 that stipulates criteria of 80% acceptability (Yang and Zhang, 2007). A thermal study that uses 0.7 clo uniform on 36 school pupils of each gender show that indoor temperature should not exceed 23^0C (Andersen and Gyntelberg, 2011). A pilot study on portable classrooms suggested that there was no provision for comfort for occupants in the classrooms (Shendell *et al.,* 2004a). Increasing air exchange may improve thermal comfort and air quality (Cartieaux *et al.,* 2011).

2.7 IEQ and Student Academic Performance

There are limited studies on IEQ and its effect on student performance (Shendell *et al.,* 2004b). Relationships between IEQ, student health, attendance, and performance have been demonstrated in some studies (Shendell *et al.,* 2004b). In a study by Wargocki and Wyon (2006), poor air quality and high temperature had a negative effect on students' performance. A preliminary study carried out in U.S.A found a significant association between inadequate ventilation and student academic performance (Shaughnessy *et al.*, 2006). In a later study, substandard ventilation in classrooms was found to have a linear relationship with student academic performance (Haverinen-Shaughnessy *et al.,* 2011). There is a beneficial effect of improved ventilation on student's academic performance (Bakó-Biró *et al.*, 2007).

A 2011 eye witness report on modern indoor climate research in Denmark states that moderate heat stress reduces mental performance and learning of school children (Andersen and Gyntelberg, 2011). Thermal discomfort in school is associated with reduced attention, concentration, productivity, and comfort (Langiano *et al.,* 2008). A review of indoor pollutant attributed an adverse influence of poor IEQ on attendance and performance of students through health outcomes (Mendell and Heath, 2005). IEQ factors can affect students performance by affecting teachers health which results in sick-leave or non effective teaching (Mendell and Heath, 2005). When classroom conditions improve; student performance improves (Wargocki et al., 2005).

2.8 Schools, IEQ and health in Finland

There are about 3300 schools (primary and secondary) in Finland with approximately 578, 000 students (Palonen *et al.,* 2009). Moisture and mould damage in Finnish school buildings has been reported as a cause of health symptoms in pupils (Meklin *et al.,* 2002 and Patovirta *et al.,* 2004). A clinical study of Finnish pupils found a relationship between mould damaged school and asthma in students (Taskinen *et al.,* 1997). Remediation of moisture damage has reduced health symptoms prevalence in Finnish school buildings (Haverinen-Shaughnessy *et al.*, 2004 and Meklin *et al.*, 2005).

A Finnish study of 10 schools with 56 classrooms conducted in the 1990's found an average ventilation rate in classrooms to be 3.5L/s or 1.2L/s per square meter (Palonen *et al.,* 2009). Between 25-30% of 108 classrooms in 60 schools studied in Southern Finland were in crucial need of replacement or repair of their ventilation system and ventilation was inadequate in majority of the classrooms (Palonen *et al.,* 2009). The National building code of Finland gives the current ventilation standard of 6l/s per student or 3l/s per m^2 (Kurnitski, 2007).

Palonen *et al.,* (2009) and Kurnitski, (2007) affirmed that an improved Finnish classroom ventilation rate of about 10L/s per person coupled with a better thermal comfort will increase the speed of students to perform classroom tasks.

Putus *et al.*, (2004) found an association between chemical and microbial indoor air contaminants in a school building in Finland, and adverse effects such as asthmatic symptoms, respiratory irritation, eyes symptoms and prevalence of common viral respiratory infection. However, no relationship existed between the exposures and doctor diagnosed asthma, other allergic diseases and bacterial respiratory disease. Health symptoms have also been related to IEQ among Finnish school teachers (Patovirta *et al.*, 2004 and Haverinen-Shaughnessy *et al.*, 2007).

3 AIMS OF THE STUDY

The general aim of this work is to study the associations between IEQ in schools and pupils' learning outcomes in Finland. It also aims to study the effects of classrooms IEQ on students' health. The specific aims were:

- To determine if the average ventilation rate per student, ventilation rate per m^2 and temperature is in agreement with that stipulated in the building code regulations.
- To investigate if the age of the school building correlated with classroom indoor temperature and ventilation rate per student.
- To investigate correlation between number of student in a classroom and ventilation rate per student.
- To investigate if ventilation rate in school is associated with students' learning outcomes.
- To investigate if health symptoms of students are associated with their classroom conditions.

4 MATERIAL AND METHODS

4.1 Data from the Finish register

Southern Finland elementary schools and sixth grade students were studied in this research. There are 2802 Finish elementary schools with 3749 buildings, but Finnish Population Register Centre (FPRC) database had information on 3514 buildings. This information includes year of construction, type of heating, type of ventilation, floor area, structure type, and construction materials.

To get the above information, data from all buildings classified as building for ``education`` (N=7562) were reviewed. Elementary schools in Finland were identified with name and address by using the listings and matching data from the Finish National Board of Education (FNBE) and the State Provincial Offices of Finland (SPOF).

The difference between total elementary school buildings and those gotten from FPRC database were due to inaccurate information or missing data. The FPRC data provide the exact locations (coordinates) of the buildings: they were used in Map search for verification and matching the schools with corresponding building sites.

A total of 59 schools from Southern Finland were included in the field measurements. Figure 2 shows the map of Finland (ArcMap 9.1) with geographic distribution of Finnish elementary schools, while Figure 3 shows the map of Finland with geographic distribution of Southern Finland elementary schools studied.

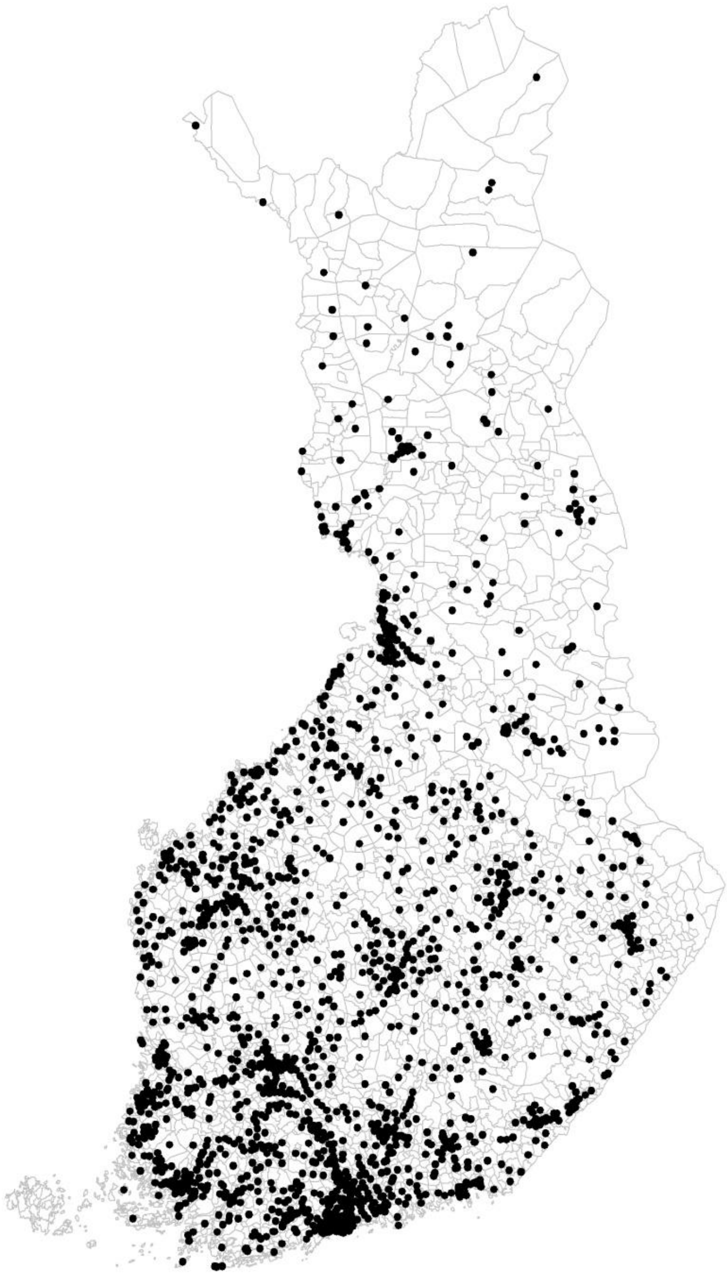

Figure 2. Geographic distribution of Finnish elementary schools (Figure prepared with ESRI ArcMAP 9.1 by Ari Paanala based on spatial information collected from schools, 2012)

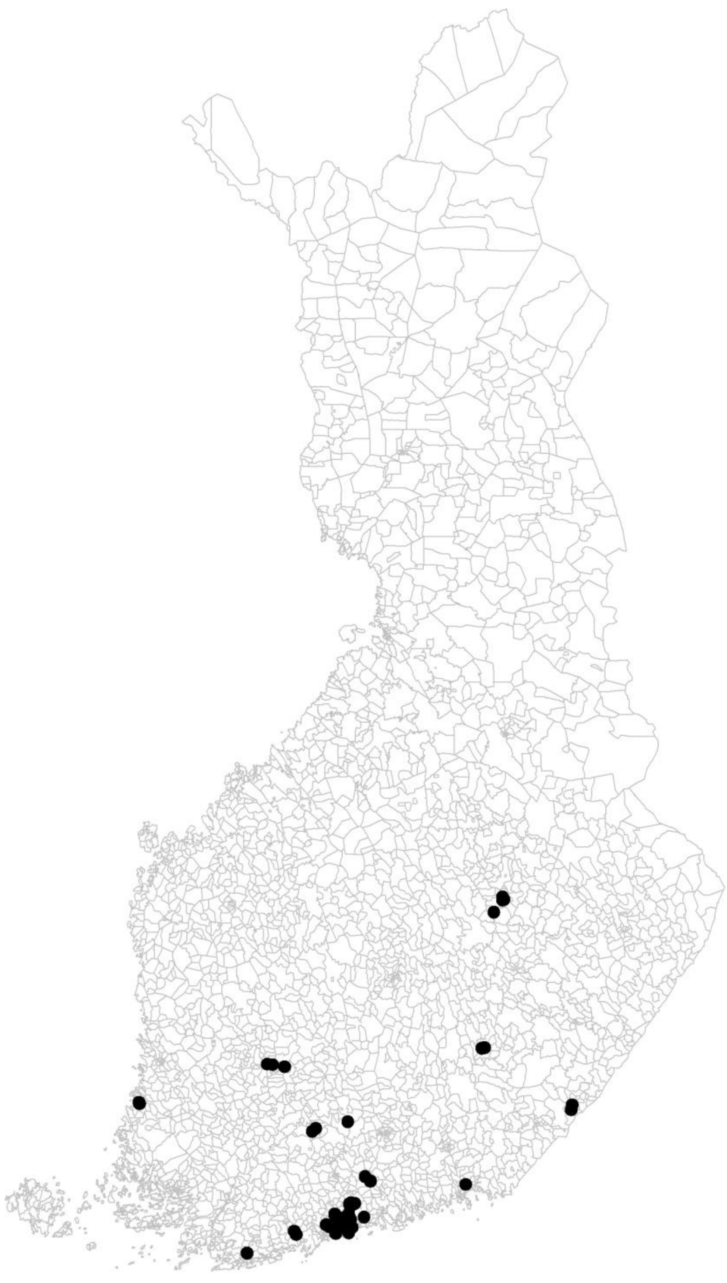

Figure 3. Geographic distribution of sampled Southern Finland elementary schools (Figure prepared with ESRI ArcMAP 9.1 by Ari Paanala based on spatial information collected from schools, 2012)

4.2 Data concerning the learning outcomes

Learning outcomes were assessed based on mathematics tests performance of students. Students' gender, first language, and test performance were taken into consideration. Stratified random sampling was used to collect data about learning outcomes from the pupils (Niemi, 2007). The overall percentage of correct answers was used as the main measure of mathematics achievement.

4.3 Data from health questionnaire

Health questionnaires were sent to school offices and were distributed by school teaching personnel to the sixth grade students, who attended the schools sampled for learning outcome assessment. (This was done after the completion of learning assessment in the schools sampled). The questionnaire could also be filled online (internet) through the project website. The questionnaires were to be filled by the students with the help of their parents. The questions asked were based on social economic status (6 questions), students' health and well being (18 questions), home environment (6 questions), one question on school environment, four questions on living habits (e.g. eating and sleeping), and two questions on learning (advantages or disadvantages), making a total of 37 questions.

For confidentiality reasons, manual matching of health questionnaire was done with mathematics test results. Students that answered anonymously to the health questionnaire could not be matched.

4.4 Physical Measurement

On site investigation was done in the spring and summer of 2007. A total of 107 classrooms from 59 schools assessed for learning outcomes were investigated. Data were collected by interviewing maintenance personnel, studying of school blueprint and walk-through utilizing pre-designed check-lists. Ventilation systems were examined and sixth grade classrooms were selected for ventilation rate measurement based on exhaust air flow or CO_2 measurement.

CO_2 levels were measured for a period of 5-10 days for classrooms with passive stack ventilation system while for classrooms with mechanical exhaust ventilation, exhaust air flow were measured from exhaust air vents in the classrooms. Room temperatures were measured from the same selected classrooms for several weeks using data-loggers. The number of sixth grade students in the measured classrooms with math score was 2130, the number of student that filled the health questionnaire was 1054, and 997 students had both math test and questionnaire response.

4.5 Data Analysis

PASW (Predictive Analytics Software) Statistics, version 18 was used to analyze all the data collected. The descriptive statistics including mean, minimum, maximum and standard deviation for continuous variables were calculated.

Majority of the data collected were not normally distributed, therefore non-parametric method of correlations (Spearman's rho) was used for measured variables and those from FPRC.

Factor analysis was performed on the measured parameters for variable reduction purposes. The analysis was based on Eigen values greater than 1, using Varimax rotation. Also, independent sample median test and independent samples Mann – Whitney U test were used to check for differences between non normally distributed samples that were divided into two groups (required and not required), while independent samples T-test was used for normally distributed samples.

5 RESULTS

5.1 Measurements from school building

A total of 107 sixth grade classrooms from 59 Southern Finland schools were assessed for number of students, ventilation, temperature, construction, renovation, airflow, etc. Information about the schools studied such as year of construction, floor area, number of floors and time of HVAC upgrade were received from FPRC. Out of the 59 schools assessed, the newest was constructed in 2001 while the oldest school was constructed in 1875. The latest HVAC upgrade was done in 2006. However, not all schools were upgraded; in that case the age of ventilation system corresponds with the year of construction. Table 2 outlined the descriptive statistics (mean, median, standard deviation, minimum and maximum) of various parameters received from (FPRC).

Table 2. Descriptive statistics of school buildings from Finnish register.

Attribute	Mean	Median	SD	Min.	Max
Year constructed	1967	1971	23.8	1875	2001
Floor area (m^2)	3115.5	3413.5	2060.4	100.0	8730.0
Number of floors	1.9	2.0	0.9	1.0	4.0
Volume (m^3)	12742.7	13460.0	8438.8	600.0	36677.0
HVAC upgrade (year)	1986	1998	22.4	1914	2006

On-site measurements included number of students, classroom height, area, airflow or CO_2 measurements, and temperature measurements. Based on the measurements, ventilation rates per meter square, ventilation rates per student, mean temperature, as well as minimum and maximum temperature were calculated. The mean (min – max) number of students in a sixth grade classroom was approximately 24.0 (8 - 47), ventilation per student (L/s/student) was 5.7 (1.0 – 20.0), class room height was 319.5 cm (265.0 cm-385.0 cm). Table 3 gives the descriptive statistics (mean, median, standard deviation, minimum and maximum) of the various parameters.

Table 3. Descriptive statistics of classroom parameters measured.

Attribute	Mean	Median	SD	Min.	Max
Number of students	24.0	24.0	5.3	8.0	47.0
Area (m^2)	61.0	60.0	9.2	40.0	99.0
Height (cm)	319.5	320.0	23.2	265.0	385.0
Airflow design (L/s)	166.4	173.5	50.8	56.0	400.0
Airflow measurement (L/s)	127.9	125.0	70.7	30.0	400.0
Ventilation/m^2 (L/s/m^2)	2.1	1.9	1.1	0.5	5.0
Ventilation per student (L/s/student)	5.7	4.7	3.8	1.0	20.0
Mean temperature (^{0}C)	22.4	22.3	1.0	20.4	24.5
Max temp (^{0}C)	23.7	23.5	1.2	21.4	28.3
Min temp (^{0}C)	21.2	21.2	1.1	18.7	23.5

Factor analysis was performed on all the school parameters (from Finnish register and those measured); the rotated component matrix is shown in Table 4. Five components were extracted, clustering variables related to 1) ventilation, 2) temperature, 3) classroom dimensions, 4) floor area, number of students and ventilation per student and 5) size and age of the building. One variable (marked bold) from each component was selected for further analyses: Ventilation per student, mean temperature, floor area, number of students and year of construction.

Table 4. Varimax rotated component matrix

	Component				
	1	2	3	4	5
Ventilation/m^2	.941				
Airflow measurement	.928				
Ventilation per student	**.865**			-.310	
HVAC upgrade	.638				
Minimum temperature		.938			
Mean temperature		**.922**			
Maximum temperature		.736			
Volume			.963		
Floor area			**.944**		
No of floors			.537		.487
Area				.895	
Number of students				**.867**	
Year constructed					**-.888**
Height					.736

Spearman's rho correlations for selected parameters are shown in Table 5.

The number of students in a classroom correlated significantly with ventilation per student. Ventilation per student correlated with number of students inside classroom, and mean temperature. Mean temperature correlated with ventilation per student. Year of construction and floor area did not correlate significantly with any of the parameters chosen. Table 16 in the appendix shows the correlations between all school buildings parameters.

Table 5. Correlations: Spearman's rho.

	N	No. of student	Ventilation/ student	Mean Temp.	Year of construction	Floor area
No. of student	107	1.000	-.359**	-.063	-.162	.181
Ventilation/ student	105	-.359**	1.000	-.303**	.217	-.233
Mean Temp.	95	-.063	-.303**	1.000	.042	-.107
Year of construction	59	-.162	.217	.042	1.000	-.173
Floor area	6	.181	-.233	-.107	-.173	1.000

(N = Number of classrooms studied, ** shows significant correlation)

5.2 Information about the students

Information about students' backgrounds, including age, gender, and home factors (exposure to pets, mould, house location, etc.), were analysed and presented in Table 6.

Table 6. Students' background.

Attribute	Mean	Median	SD	Min.	Max
Age	12.5	12.5	0.1	12.3	13.0
Gender (% of boys)	46.8	48.9	12.4	21.1	74.3
% students that have pet currently	69.6	69.2	12.4	42.3	94.4
% students that had pet earlier	14.9	15.0	9.5	0	50.0
% with furry animals	15.2	13.0	9.4	1.0	58.0
% exposed to ETS in home	0.9	1.0	9.4	0	4.0
% moisture damage in current home	1.3	1.0	1.3	0	7.0
% mould in current home	0.3	0.0	0.7	0	3.0
% stuffiness or mould odour in current home	0.6	0.0	1.2	0	6.0
% live in city center	10.9	3.3	17.1	0	71.4
% live in suburb	64.4	84.2	37.2	0	100.0
% live in fringe area	10.1	.0	20.9	0	85.7
% live in densely populated area	14.6	.0	26.9	0	100.0
% live in apartment building	29.5	28.6	27.4	0	84.3
% live in a row house	15.2	12.5	12.9	0	100.0
% live in a family house or duplex	53.0	54.2	29.8	0	100.0
% live in a farm	2.3	.0	7.6	0	41.2
% mother has a university degree	23.8	25.0	14.0	0	57.1
% father has university degree	22.7	20.0	15.1	0	54.5
mean hours sleep per night	8.8	8.9	0.3	7.8	9.3
% take naps regularly	0.4	0.0	1.5	0	6.3
% eats breakfast daily	87.0	89.3	10.2	50.0	100.0
% eats breakfast twice a week	6.5	5.6	7.2	0	30.0
% exercise 3 times a week	65.3	66.7	13.7	25.0	100.0
% need personal tutoring	8.9	7.4	7.7	0	31.6
% first language Finnish	96.2	100.0	6.3	77.9	100.0
% first language Swedish	.30	.0	1.7	.0	11.1
% other language	3.5	0.0	6.0	.0	22.2
number of students that responded to health questionnaire	24.0	20.0	15.3	2.0	88.0
% correct answers in math test (mean)	62.9	63.8	8.6	37.3	75.5

The school background of the students was also analysed. The number of year spent in current school, percentage missed school days, mean days missed and IEQ factors causing discomfort for the students are shown in Table 7.

Table 7. Students' school background.

Attribute	Mean	Median	SD	Min.	Max
years in current school	5.2	5.3	0.5	3.6	6.0
% missed school days	53.1	52.6	13.5	17.6	100.0
number of days missed, mean	3.6	3.4	1.3	1.8	8.0
% too high temp. in classroom weekly	7.0	4.7	9.8	0	50.0
% too high temp. in classroom daily	2.8	0	4.1	0	14.3
% too low temp. in classroom weekly	1.3	0	2.8	0	10.5
% too low temp. in classroom daily	0.7	0	2.1	0	10.5
% stuffy air or poor IAQ weekly	22.3	16.7	17.8	0	73.5
% stuffy air or poor IAQ daily	9.4	6.2	10.9	0	50.0
% mould odour weekly	1.2	0	3.6	0	20.5
% other unpleasant odour weekly	4.7	2.9	6.0	0	28.6
% noise weekly	32.8	29.1	20.4	0	100.0
% dust weekly	7.7	7.0	7.2	0	31.3
% mould odour daily	0.3	0	1.6	0	10.3
% other unpleasant odour daily	2.2	0	3.6	0	14.3
% noise daily	19.1	14.3	18.8	0	100.0
% dust daily	2.7	0	4.8	0	25.0

Selected health outcomes, collected by a questionnaire, were analysed statistically and presented in Table 8.

Table 8. Students' health status

Attribute	Mean	Median	SD	Min.	Max
% weekly stuffy nose	9.8	10.0	6.8	0	33.3
% weekly rhinitis	5.5	5.3	5.0	0	17.6
% weekly sore throat	2.0	0	3.3	0	11.1
% weekly dry cough	1.9	0	2.9	0	10.5
% weekly wheezing	0.8	0	2.6	0	16.7
% weekly eye symptom	3.1	0	4.2	0	16.7
% weekly fever	0.7	0	1.7	0	6.7
%weekly backpain	1.7	0	3.0	0	11.8
% weekly fatigue	9.0	8.3	7.0	0	33.3
% weekly headache	6.5	4.3	7.1	0	33.3
% weekly difficulties in concentration	3.3	0	4.4	0	16.7
% symptoms associated with school	3.0	3.0	0	0	3.0
% asthma	8.0	6.0	6.3	0	22.2
% allergic rhinitis	21.2	20.0	10.1	0	50.0
% dysphasia	0.9	0	2.3	0	11.1
% dyslexia	0.1	0	0.6	0	3.7
% ADHD	0.7	0	1.7	0	5.6

5.3 Relationship between measured IEQ and student perceived IEQ

Pupils' responses to perceived environment factors (including too high or too low temperature in classroom, poor air quality (PAQ), noise, and dust/lack of cleanliness) were analysed together with the measured data extracted by factor analysis from Table 4 (mean temperature, and ventilation per student). The results are presented in Table 9.

Mean temperature had significant correlation with self-reported poor air quality daily and dust weekly, while ventilation per student correlated with self-reported poor air quality daily. Table 16 (in the appendix) show complete bivariate correlations between all the variables.

Table 9. Correlations: Spearman's rho.

	% too high temp.in class weekly	% too high temp.in class daily	% too low temp.in class weekly	% too low temp.in class daily	Poor air quality weekly	Poor air quality daily	noise weekly	noise daily	Dust weekly	Dust daily
Mean temp	.197	.165	-.046	.008	.215	.409**	-.073	-.135	.285*	.238
Vent./ student	-.060	-.201	.027	-.251	-.197	-.300**	.103	-.118	-.153	-.115

5.4 Correlation between IEQ and student health

The level of correlation was analyzed between measured indoor environmental quality indicators and pupils' health status. No significant correlation existed between any of the variables analyzed as shown in Table 10.

Table 10. Correlations: Spearman's rho.

	Ventilation per student	Ventilation per m^2	Mean temp.	Maximum temp.	Minimum temp.
General health status (poor)	-.136	-.100	.247	.205	.237
Mean days missed	-.088	-.069	.157	.139	.066
Missed school days due to respiratory infections	.047	.025	.024	-.021	-.037
Weekly fatigue	-.122	-.132	.054	.105	.060
Weekly headache	-.148	-.156	.231	.259	.258
Weekly difficulties in concentration	-.073	-.115	-.066	-.052	-.010
Asthma	.178	.169	.190	.144	.166

5.5 Correlation between IEQ and student academic performance

Ventilation and temperature measurements were also analyzed with students' learning outcomes by finding the level of correlation using non-parametric (Spearman's rho) correlation. The result as shown in Table 11 depicts no significant correlation between the measured IEQ and students' learning outcomes.

Table 11. Correlations: Spearman's rho

	Ventilation per student	Ventilation per m^2	Mean temp.	Maximum temp.	Minimum temp.
Learning outcomes	-.015	-.066	.016	.069	.086

5.6 Ventilation rate per student and ventilation per m^2 with different ventilation types.

In the 107 classrooms from 59 schools investigated, 78.5% had mechanical supply and exhaust ventilation type (84 classrooms), 17 classrooms (15.9%) had natural type of ventilation, while only 6 classrooms (5.6%) had mechanical exhaust ventilation system only. Table 12 and Table 13 show descriptive statistics for ventilation rate per student and ventilation rate per m^2 for each of the ventilation type respectively. The mean ventilation rate per student was 3.0, 3.0 and 6.5 L/s/student for schools with natural, mechanical exhaust, and mechanical supply and exhaust ventilation systems, respectively while the mean ventilation per m^2 was 1.1, 1.2 and 2.4 L/s/m^2 in the same order.

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Table 12. Ventilation rate per student for different ventilation type

	Ventilation per student (L/s per student)			
Ventilation type	Mean	S.D	Minimum	Maximum
Natural	3.0	.9	1.8	4.7
Mechanical exhaust	3.0	1.8	1.0	4.6
Mechanical supply and exhaust	6.5	3.9	1.2	20.0

Table 13. Ventilation rate per m² for different ventilation type

	Ventilation per m^2 ($L/s/m^2$)			
Ventilation type	Mean	S.D	Minimum	Maximum
Natural	1.1	.3	.7	1.5
Mechanical exhaust	1.2	.6	.5	1.7
Mechanical supply and exhaust	2.4	1.1	.5	5.0

5.7 Reference ventilation per student, learning outcomes and health outcomes

Ventilation per student in schools was divided into 2 categories: 1) those with ventilation rate 6 L/s per student and more, and 2) those with less than 6 L/s per student. Analyses from the 54 schools measured show that 31 (57.4%) schools have lower than required ventilation rate per student (i.e. 6 L/s per student). The mean (min – max) test score was 63.8 (37.7 – 75.5) % in group 1 and 62.3 (37.3 – 74.7) % in group 2. Independent sample median test and Independent samples Mann – Whitney U test show that the difference is not statistically significant (p values 1.000 and 0.448 respectively).

There was also no significant difference between selected health outcomes (poor general health status, mean days missed, missed school days due to respiratory infections, weekly fatigue, weekly headache, weekly difficulties in concentration, and asthma) between schools with lower ventilation rate per student and those with required ventilation rate per student when Independent samples median and Independent samples Mann – Whitney U test were used to analysed them. The p - values are shown in Tables 13 and 14 respectively for Independent samples median test and Independent samples Mann – Whitney U test respectively.

Table 14. Hypothesis test summary (Independent samples median test)

	Null hypothesis	p - value	Decision
1	The medians of poor general health status are the same across categories of ventilation per student (high or low).	.395	Retain the null hypothesis
2	The medians of mean days missed are the same across categories of ventilation per student (high or low).	.659	Retain the null hypothesis
3	The medians of missed school days due to respiratory infections are the same across categories of ventilation per student (high or low).	.501	Retain the null hypothesis
4	The medians of weekly fatigue are the same across categories of ventilation per student (high or low).	.659	Retain the null hypothesis
5	The medians of weekly headache are the same across categories of ventilation per student (high or low).	.318	Retain the null hypothesis
6	The medians of weekly difficulties in concentration are the same across categories of ventilation per student (high or low).	.442	Retain the null hypothesis
7	The medians of asthma are the same across categories of ventilation per student (high or low).	.501	Retain the null hypothesis

Table 15. Hypothesis test summary (Independent samples Mann – Whitney U Test)

	Null hypothesis	p - value	Decision
1	The distribution of poor general health status is the same across categories of ventilation per student (high or low).	.400	Retain the null hypothesis
2	The distribution of mean days missed is the same across categories of ventilation per student (high or low).	.828	Retain the null hypothesis
3	The distribution of missed school days due to respiratory infections is the same across categories of ventilation per student (high or low).	.255	Retain the null hypothesis
4	The distribution of weekly fatigue is the same across categories of ventilation per student (high or low).	.786	Retain the null hypothesis
5	The distribution of weekly headache is the same across categories of ventilation per student (high or low).	.326	Retain the null hypothesis
6	The distribution of weekly difficulties in concentration is the same across categories of ventilation per student (high or low).	.446	Retain the null hypothesis
7	The distribution of asthma is the same across categories of ventilation per student (high or low).	.556	Retain the null hypothesis

5.8 Reference temperature, learning outcomes and health outcomes

Mean temperature in schools was also divided into two categories of those having the required indoor mean temperature of 23^0C and lower and those with above 23^0C that is considered as thermal discomfort. Out of 51 schools assessed, 38 (74.5%) schools had a mean temperature of 23^0C and lower, while 13 (25.5%) schools had a higher mean temperature. Mean temperature was normally distributed according to Shapiro-Wilk test. Therefore Independent samples t-test was used to analyse the difference between mean temperature with learning outcomes and health outcomes. There was no significant difference between learning outcomes of students in school with thermal comfort and those without it (p value = 0.637).

There was also no significant difference between selected health outcomes: poor general health status (p = 0.101), mean days missed (p = 0.595), missed school days due to respiratory infections (p = 0.529), weekly fatigue (p = 0.520), weekly headache (p = 0.090), weekly difficulties in concentration (p = 0.936), and asthma (p = 0.648) of student in schools with required thermal comfort and those with higher mean temperature.

6 DISCUSSION

The study population consisted of about one thousand sixth grade students from 59 schools in southern Finland. The maximum age of the students studied was 13 years with mean age of 12 years and 6 months. A child normally starts schooling (grade 1) at the age of 7 years in Finland (FNBE). There were about the same number of boys and girls studied (47% boys and 53% girls), with majority of them studying in the same school since grade 1. This is a normal practice in Finland, where students change school mainly due to family relocation.

The average number of student in the classrooms studied was 24. The mean (319.5cm), minimum (265cm) and maximum height (385cm) of the classrooms conform to national building code of Finland (NBCF) regulations which stipulate the minimum height of a habitable room to be 250cm (Ministry of Environment). Classroom net area also exceeds the minimum area for a habitable room of $7m^2$ in the national building code (Ministry of Environment).

Airflow measurement (L/s) shows that the design was working below performance (Kurnitski, 2007). Although the observed difference was not further analysed, there exists a difference of 38.5 (L/s) between the mean of airflow design and its current performance. This may be as a result of lack of maintenance of ventilating apparatus or aged equipments (Palonen *et al*., 2009). This may result to lower ventilation than needed in the classrooms, and could cause a reduction in the quality of air indoors. Based on the ventilation capacity of the HVAC system, a lower performance from the design will result to a reduction in ventilation per m^2 and also ventilation per student.

The total average ventilation rate per student (5.7 L/s per student) was lower than the required 6 L/s per student according to NBCF (Ministry of Environment, Palonen *et al*., 2009 and Kurnitski, 2007). A total of 31 schools have less than 6 L/s per student ventilation rate. Mean ventilation per m^2 (2.1 L/s per m^2) also fall short of the standard (3 L/s per m^2) of NBCF (Kurnitski, 2007). When the ventilation rate per student and ventilation rate per m^2 was analysed based on the type of ventilation (natural, mechanical exhaust and mechanical supply and exhaust), natural ventilation and mechanical exhaust ventilation had lower than required ventilation rate per student of 3.0 L/s per student each, while mechanical supply and exhaust air ventilated classrooms had a ventilation rate of 6.5 L/s per student which conforms with NBCF regulation for ventilation rate per student. Ventilation rate per m^2 was also higher for mechanical supply and exhaust ventilation system when compared to the other two types but none of them met the requirement of 3 $L/s/m^2$ of NBCF (Kurnitski, 2007). Also Bornehag et al., (2005) reported that buildings with mechanical supply and exhaust ventilation system had a higher ventilation rates than those with natural and mechanical exhaust ventilation. There were few classrooms using natural ventilation and mechanical exhaust ventilation (6 and 17 respectively) when compared to those using mechanical supply and exhaust air ventilation (84 classrooms), which may have effect on the data analysis.

Mean temperature in classroom (22.4 ^{0}C) was within the requirement of 23 ^{0}C or lower and majority of the schools studied (74.5%) met the requirement (Andersen and Gyntelberg, 2011).

A negative correlation existed between number of student in a classroom and ventilation per student. It means that when the number of student in a classroom increases, the amount of ventilation to individual student decreases and vice versa. It appears that the number of students in a classroom should not be too high so as to give way for adequate ventilation of the classrooms. An inverse correlation between mean temperature and ventilation per student also show that a high classroom temperature may be related to reduced ventilation rate and vice versa. There was very little or no effect of floor area on ventilation per student, mean temperature, and number of students in a classroom because there was no significant correlation between it and the IEQ parameters mentioned. The negative correlation (-.233) it had with ventilation per student (although not statistically significant) means that a smaller classroom size is related to higher ventilation rate per student. A bigger classroom will likely have a large number of students in it, which may correspond to lower ventilation rate per student unless the air flow is adjusted for the number of students.

Year of construction had no significant correlation with ventilation rate per student, mean temperature and number of students in a classroom but there exist a positive non significant correlation of .217 with ventilation rate per student. Ventilation system type has been changed over time from the initial natural ventilation to mechanical exhaust and more recently to mechanical supply and exhaust ventilation, which has been shown to provide better ventilation (Bornehag et al., 2005).

Mean temperature measured had a significant positive correlation with student perceived poor air quality daily and dust weekly. An increase in classroom indoor temperature therefore has an effect on perceived IAQ and this supports earlier works done in this regard (Ashrae standard 55, 2004, Shaughnessy *et al*., 2006 and Yang and Zhang, 2007). Ventilation rate per student had an inverse significant correlation with poor air quality daily. This may be as a result of insufficient amount of outdoor air entering classroom as well as HVAC systems not performing well due to lack of proper maintenance already reported by Palonen *et al.*, (2009). There was also a negative correlation (-.251) between ventilation rate per student and student perceived too high temperature in the classroom daily. This further supports the claim that reduced ventilation rate may be related to high classroom temperature as already stated above.

Although there was no significant correlation between IEQ indicators and pupils' health outcomes, mean, maximum, and minimum temperature had some positive correlation with poor health status, weekly headache, and asthma. Ventilation rate per student and ventilation rate per m^2 also showed some positive correlation with asthma. This depicts that when the mentioned IEQ parameters increases, the selected health status may also increase among the student (Daisey *et al.*, 2003 and Sundell *et al.*, 2011).

The result of no significant correlation found between IEQ and learning outcomes established that IEQ had very little effect on the group level performance of the students studied.

Although the mean, minimum, and maximum scores were all higher for students in schools with the required ventilation rate per student of 6 L/s per student and higher when compared to those from schools with a lower than required ventilation rate per student, there was no statistically significant differences between the two groups. Also, the comparisons of students' health and learning outcomes based on whether indoor temperature met the requirement or not showed that the outcomes were not different among the groups of students in schools with the required indoor temperature and those whose indoor temperature was not up to requirement. There was a p-value of 0.09 for weekly headache; a larger school sample may show that thermal discomfort in schools can result to headache for students.

7 CONCLUSIONS

Based on the result, the following conclusions can be drawn;

- The average ventilation rate per student did not meet building code regulations in naturally ventilated schools and schools with mechanical exhaust only. The mean temperature was within the recommended range.

- The age of the school building did not correlate with classroom indoor temperature and ventilation rate per student. There is need for efficient ventilation in order to meet the building code requirement.

- Ventilation rate per student decreases as the number of students in a classroom increases. Ventilation rates should therefore be adjusted for the maximum number of student in a classroom.

- No statistically significant correlation was observed between ventilation rate and students' learning outcomes.

- Relatively small number of schools limits the conclusions about the associations between IEQ, health, and learning. More detailed analyses including multi-level analyses and non-linear modeling is required for more definite conclusions.

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9 Appendix

9.1 Table 16. Correlations between measured variables and those from FPRC

	N	No. of student	Ventilation/ student	Area	Height	Air Flow Measurement	Ventilation Measurement	Ventilation/m2	Mean Temp.	Min. Temp.	Max. Temp	Year of construction	HVAC upgrade	No. of floors	Floor area	Volume
No. of student	107	1.000	-.359**	.276**	-.001	-.031	.117	-.110	-.063	-.239*	.025	-.162	-.183	.148	.181	.204
Ventilation/ student	105	-.359**	1.000	-.207*	-.307**	.926**	-.944**	.944**	-.303**	-.080	-.370**	.217	.703**	-.313*	-.233	-.225
Area	107	.276**	-.207*	1.000	.050	-.100	.245*	-.262**	.153	.062	.153	-.174	-.184	-.042	-.050	-.026
Height	107	-.001	-.307**	.050	1.000	-.297**	.401**	-.304**	.159	.085	.186	-.474**	-.409**	.286*	.209	.238
Air Flow Measurement	105	-.031	.926**	-.100	-.297**	1.000	-.967**	.971**	-.313**	-.137	-.359**	.146	.709**	-.262*	-.192	-.166
Ventilation Measurement	105	.117	-.944**	.245*	.401**	-.967**	1.000	-.991**	.339**	.143	.386**	-.246	-.739	.254	.167	.140
Ventilation/m2	105	-.110	.944**	-.262**	-.304**	.971**	-.991**	1.000	-.350**	-.160	-.390**	.211	.714**	-.248	-.152	-.131
Mean Temp.	95	-.063	-.303**	.153	.159	-.313**	.339**	-.350**	1.000	.862**	.881**	.042	-.249*	.019	-.107	-.175
Min. Temp	95	-.239*	-.080	.062	.085	-.137	.143	-.160	.862**	1.000	.631**	.009	-.058	.092	-.121	-.194
Max. Temp	95	.025	-.370**	.153	.186	-.359**	.386**	-.390**	.881**	.631**	1.000	.083	-.246	-.103	-.171	-.243
Year of construction	59	-.162	.217	-.174	-.474**	.146	-.246	.211	.042	.009	.083	1.000	.224	-.527**	-.173	-.164
HVAC upgrade	70	-.183	.703**	-.184	-.409**	.709**	-.739**	.714**	-.249*	-.058	-.246	.224	1.000	-.234	-.100	-.123
No. of floors	62	.148	-.313*	-.042	.286*	-.262*	.254	-.248	.019	.092	-.103	-.527**	-.234	1.000	.449**	.516**
Floor area	62	.181	-.233	-.050	.209	-.192	.167	-.152	-.107	-.121	-.171	-.173	-.100	.449**	1.000	.949**
Volume	57	.204	-.225	-.026	.238	-.166	.140	-.131	-.175	-.194	-.243	-.164	-.123	.516**	.949**	1.000

9.2 *Table 17.* Relationship between measured IEQ and student perceived IEQ

	Mean temp	Vent./ student	% too high temp.in class weekly	% too high temp.in class daily	% too low temp.in class weekly	% too low temp.in class daily	Poor air quality weekly	Poor air quality daily	noise weekly	noise daily	Dust weekly	Dust daily
Mean temp	1.000	-.350*	.197	.165	-.046	.008	.215	.409**	-.073	-.135	.285*	.238
Vent./ student	-.350*	1.000	-.060	-.201	.027	-.251	-.197	-.300**	.103	-.118	-.153	-.115
% too high temp.in class weekly	.197	-.060	1.000	.745**	-.029	.077	.519**	.559**	.239	.175	.280*	.468**
% too high temp.in class daily	.165	-.201	.745**	1.000	-.060	.051	.427**	.589**	.140	.102	.156	.268
% too low temp.in class weekly	-.046	.027	-.029	-.060	1.000	.700**	.011	.041	.283*	.207	.254	.297*
% too low temp.in class daily	.008	-.251	.077	.051	.700**	1.000	.138	.185	.434**	.424**	.240	.360**
Poor air quality weekly	.215	-.197	.519**	.427**	.011	.138	1.000	.759**	.463**	.442**	.421**	.588**
Poor air quality daily	.409**	-.300*	.559**	.589**	.041	.185	.759**	1.000	.324*	.335*	.514**	.628**
noise weekly	-.073	-.103	.239	.140	.283*	.434**	.463**	.324*	1.000	.862**	.209	.246
noise daily	-.135	-.118	.175	.102	.207	.424**	.442**	.335*	.862**	1.000	.234	.309*
Dust weekly	.285*	-.153	.280*	.156	.254	.240	.421**	.514**	.209	.234	1.000	.695**
Dust daily	.238	-.115	.468**	.268	.297*	.360**	.588**	.628**	.246	.309*	.695**	1.000