DOES INDOOR ENVIRONMENTAL QUALITY AFFECT STUDENTS PERFORMANCE?

Paraskevi Vivian Dorizas*, Margarita-Niki Assimakopoulos, Constantinos Helmis, Mattheos Santamouris, John Sifnaios, Katerina Stathi

Faculty of Physics, Departments of Environmental Physics and Meteorology, University of Athens, University Campus, Athens, 157 84, Greece
**Corresponding author: p.dorizas@phys.uoa.gr*

ABSTRACT

There is little knowledge on if and how indoor environmental quality influences students' attendance and productivity. However, this issue has been of growing interest the recent years in the scientific community and results are showing that student learning performance is significantly affected by indoor environmental quality factors. In the present study the learning performance is examined through numerical test scores achieved by primary school students in their classrooms. The assessment of indoor environmental quality parameters such as thermal, visual, acoustic and air quality and the evaluation of Sick Building Syndrome (SBS) symptoms was conducted through questionnaires handed out to the same sample of students. Main objective of this paper is to investigate whether the degradation of the indoor environmental quality can impact the overall performance of students.

KEYWORDS

Indoor Environmental Quality, Sick Building Syndrome, student performance, schools

1 INTRODUCTION

There is an increasing concern about the negative health effects of degraded indoor environments and some of the adverse consequences are respiratory symptoms (allergies, asthma, nose and throat irritation and cough), skin symptoms (eczema) or general symptoms (fatigue, concentration difficulty, and headache) which are usually referred as Sick Building Syndrome (SBS) symptoms (WHO, 1982). The term 'Indoor Environmental Quality' (IEQ) refers to the quality of a building's environment in relation to the Indoor Air Quality (IAQ), the thermal comfort conditions as well as to the lighting and acoustics comfort (Mendell and Heath 2005).

The last ten years the scientific interest has been focused on the effects of the degraded indoor environment on the performance and productivity of students and office workers (Wargocki et al.,1999, Wargocki et al., 2000, Witterseh et al., 2004, Mendell and Heath, 2005). However the existing documentation regarding the negative effects that poor IEQ has on students' performance and attendance is still not sufficient for the creation of schools' guidelines aiming to decrease the adverse health effects and increase students' achievements (Mendell and Heath, 2005). Thus, a further knowledge on how the poor IEQ in classrooms can affect students' performance is of great importance.

The main objectives of the present study are: 1. to investigate how the students evaluated the IEQ (IAQ, Thermal comfort, lighting, acoustics) of their classrooms, 2. to evaluate their possible sick building syndrome symptoms (SBS) and 3. to assess their performance in relation to the corresponding pollutant concentration levels and to the evaluation of the IEQ.

2 METHODOLOGY

This study was carried out in nine primary schools of the Attika basin in Greece during April and May 2013 (Figure 1). The main characteristics of the schools and the classrooms where the measurements were conducted are summarized in Table 1.

Figure 1: Map of Attika (left) and locations of schools (right)

Table 1: Schools' characteristics and measurement period

School name	School code name	Measurement period (Number of measurement days)	Classroom's floor area (m^2)	Classroom's volume (m^3)	Classroom's number of Students	Classrooms' orientation
Acharnae 14	1	1-5/4/13 (5 days)	53	165	17	North
Thrakomakedones 1	14	8-12/4/13 (5 days)	64	198	25	Northwest
Axharnae 4	4	14-18/4/13&24/4/13 (5 days)	50	155	24	Southwest
Pallini 3	3	19&22/4/13 (2 days)	46	137	25	West
Acharnae 18	18	23/4/13 (1 day)	47	138	18	South
Acharnae 12	12	13-17/5/13 (5 days)	49	157	25	South
Thrakomakedones 2	2	20-24/5/13 (5 days)	50	162	25	East
Acharnae 8	8	27-29/5/13 (3 days)	52	159	19	West
Acharnae 11	11	31/5/13 (1day)	55	172	15	South

This study consists of three parts. The first part involves the measurements of concentration levels of CO, CO_2 and VOC and their analysis. The second part consists of the questionnaire survey for the subjective evaluation of the IEQ by the students and the third part includes the completion of performance tests. School headmasters' and parents' consent was necessary as the study required the participation of students. The students participated in the survey were in total 193 and the total number of answered subjective questionnaires was 655, while the total conducted performance tests were 1310. It should be mentioned that there were cases where the same students filled the same questionnaires more than one time, depending on the days of the survey's duration (Table 1, columns 2 &3).

2.1 Measurements of chemical parameters

The concentrations of CO, CO_2 and VOCs were measured in one classroom per school (the one the survey was carried on) using MultiRAE IR (RAE Systems) in units of parts per million (ppm) from 7:00 a.m. until about 14.30 p.m. However, in order to compare the pollutant concentrations to the test scores, the 15 min average of the pollutants was calculated for the corresponding time the test were filled in by the students.

2.2 Questionnaires for the subjective evaluation of IEQ

The questionnaire used for the subjective evaluation of the IEQ by the students, was divided in the following sections: 1. personal information (age, gender), 2. perception of indoor environmental conditions at that certain time (thermal comfort, IAQ, lighting and acoustics) and 3. SBS symptoms. For the evaluation of the IEQ conditions a 7-point answering scale as mentioned on the Appendix E of the CBE Occupant survey of ASHRAE 2010 was used. The SBS symptoms were answered using single Yes and No answers (HETA 1997). The questionnaires were handed out to students once every day at approximately the same time (at 10:15), just 15 min after the pupils came into the classrooms right after a 20 min break on their third class for the day.

2.3 Performance Tests

The performance tests and operative protocol were taken from the SINPHONIE project, the Schools Indoor Pollution and Health: Observation Network in Europe aiming to improve the air quality in schools. The test consisted from two parts. The first part (1a and 2a) involved 36 numerical exercises including addition, subtraction and multiplication. Students had to solve the math test in 10 min. In the second part of the test (1b and 2b), students were given a 'code' of symbols, in which each symbol was associated to a digit number. They had 120 sec. to complete the relevant symbols at a given series of numbers. This test (of both parts) was repeated by the students twice a day, during the first and last hour of lessons. The math test of the last hour was slightly changed to the one of the first hour however the code test was the same. An initial aim of this part was to investigate to the extent that is possible, if the degradation of the IAQ in classrooms throughout the day, would affect students' performance.

3 RESULTS & DISCUSSION

3.1 Subjective evaluation of IEQ

Figures 2 to 5 present the distribution of votes for the evaluation of the four major categories of the IEQ. In particular, Figure 2 presents the acceptability of the thermal environment in the 9 schools by the students. The greatest percentage of unacceptable votes appeared in schools 8, and 2, while all students of school 18 assessed the thermal environment as acceptable. In

the rest of the schools a maximum of 20% evaluated the thermal environment as unacceptable.

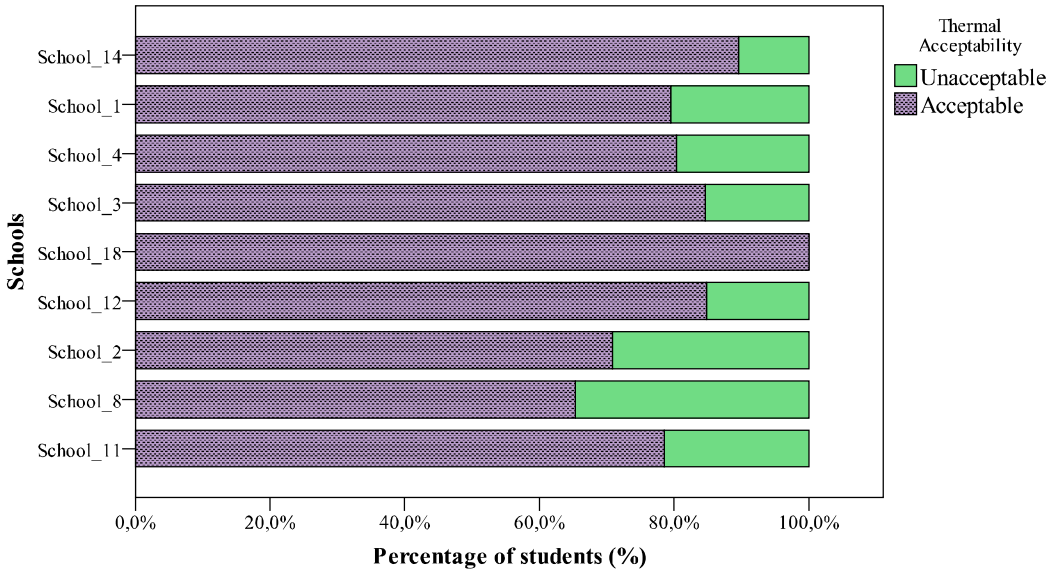

Figure 2: Distribution of votes for the assessment of the thermal environment per school

Figure 3 presents the distribution of votes per school that answer to the question: 'How satisfied are you with the air quality in the classroom'. An answering scale from zero to six was given to the students, where the vote of zero-(0) corresponds to 'very satisfied' and six-(6) to 'very dissatisfied'. In school 18 the students seemed to be the most satisfied with the air quality compared to the other schools, while school 8 had the most dissatisfied votes. Also school 2 had the less satisfied votes and a lot of dissatisfied ones (votes greater than 3). In the rest of the schools there is approximately an equal distribution (~20%) of votes from 0 to 3.

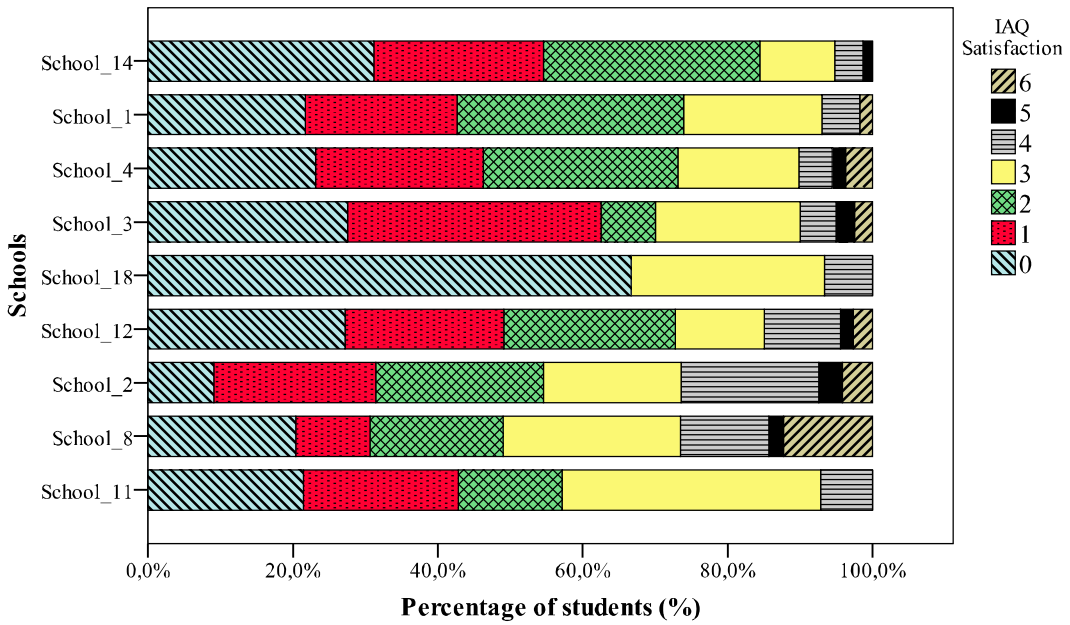

Figure 3: Distribution of IAQ satisfaction votes per school (0: totally satisfied, 6: totally dissatisfied)

The distribution of votes per school answering to the question of 'How satisfied are you with the visual comfort of the lighting?' is illustrated in Figure 4. In the 7-point scale zero-0 corresponds to 'very satisfied', while six-6 to 'very dissatisfied'. Schools 18 and 11 had the

greatest percentage of satisfied votes and none dissatisfied ones (equal or greater than 3). Schools 4, 14 and 1 had the most complains about the visual comfort of the lighting.

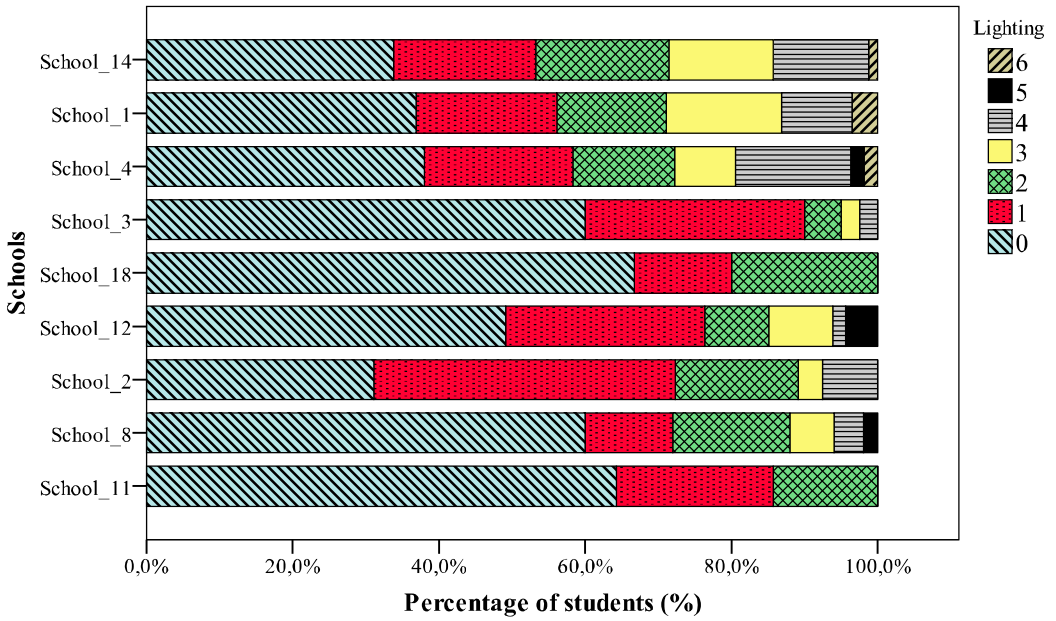

Figure 4: Distribution of votes referring to lighting satisfaction per school (0: very satisfied, 6: very dissatisfied)

Figure 5 shows the distributions of votes answering to the question of 'How satisfied are you with the noise level in your classroom?'. Once again the vote of zero-0 refers to very satisfied, while six-6 refers to very dissatisfied with the noise levels. Students in schools 1 and 11 seemed to be the most dissatisfied with the acoustics of their classrooms, while the students of schools 3 and 14 were the more satisfied as more than 50% of their students voted zero-0 meaning that they were totally satisfied with the acoustics in their classrooms without any votes of 5 and 6.

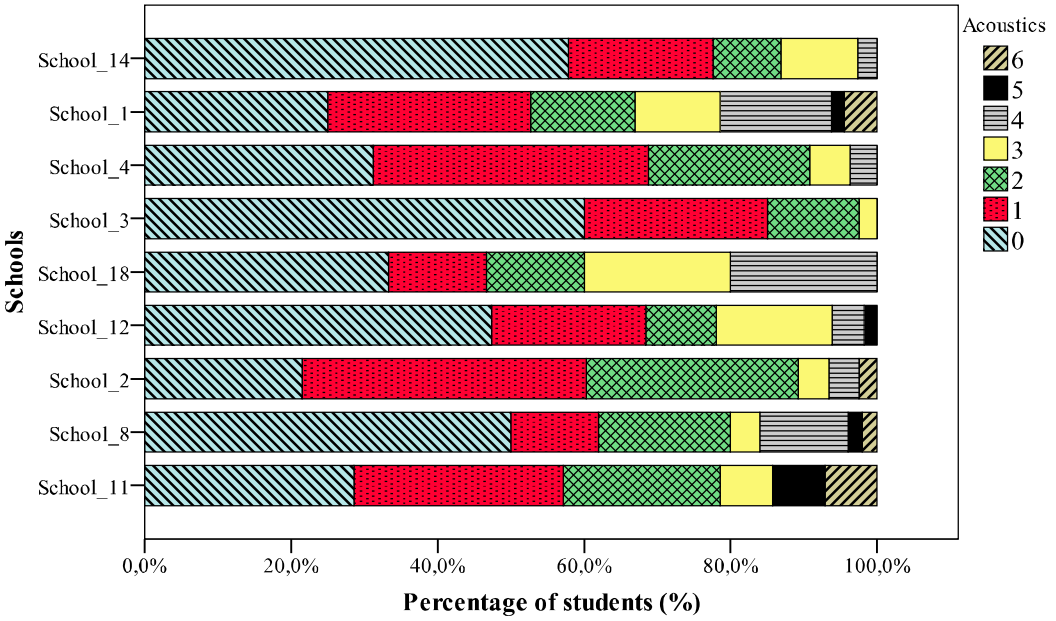

Figure 5: Distribution of satisfaction votes referring to acoustics satisfaction per school (0: totally satisfied, 6: totally dissatisfied)

The distribution of votes answering to the question: 'Overall, do the IEQ conditions of your classroom enhance or interfere with your performance?' where vote of zero-(0) corresponds to 'enhances' and vote of six-(6) to 'interferes', is presented in box plots in Figure 6 and in for

most of the schools the dispersal is identical. The greatest percentages of votes in all schools lie between zero and three. For schools 14 and 3 the distributions were exactly the same and most of the students of these schools believed that the IEQ enhanced their performance.

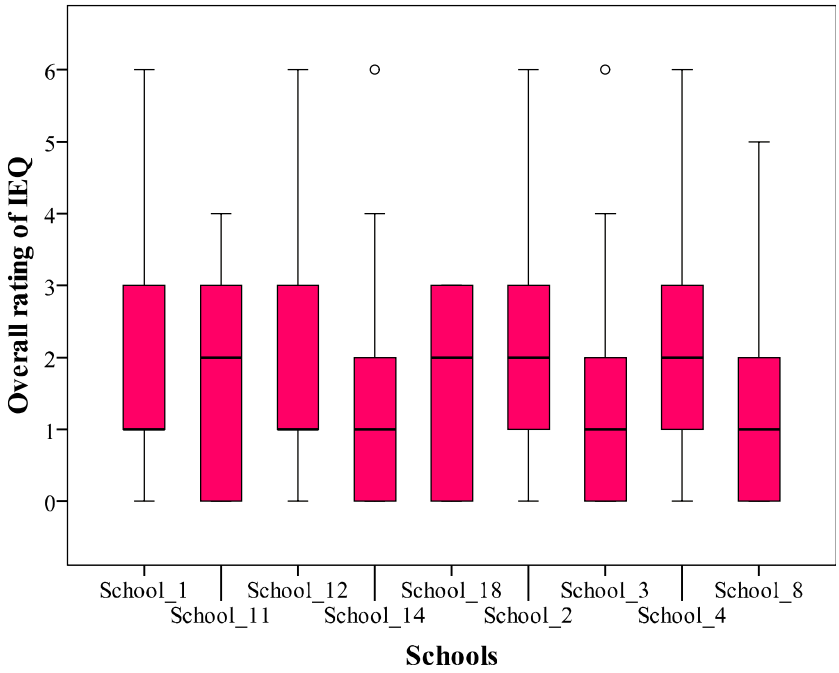

Figure 6: Distribution of votes referring on if the overall IEQ conditions encourage or not students' performance

3.2 Sick Building Syndrome-SBS symptoms

In this section the findings from the survey referring to the SBS symptoms are presented. The distribution of the percentages of students having SBS symptoms per school is indicated in Figure 7. The symptoms that occur more frequently are: allergies, fatigue, nose and throat irritation, coughing and concentration difficulty. The symptoms of headache, asthma, eye irritation and eczema are rare.

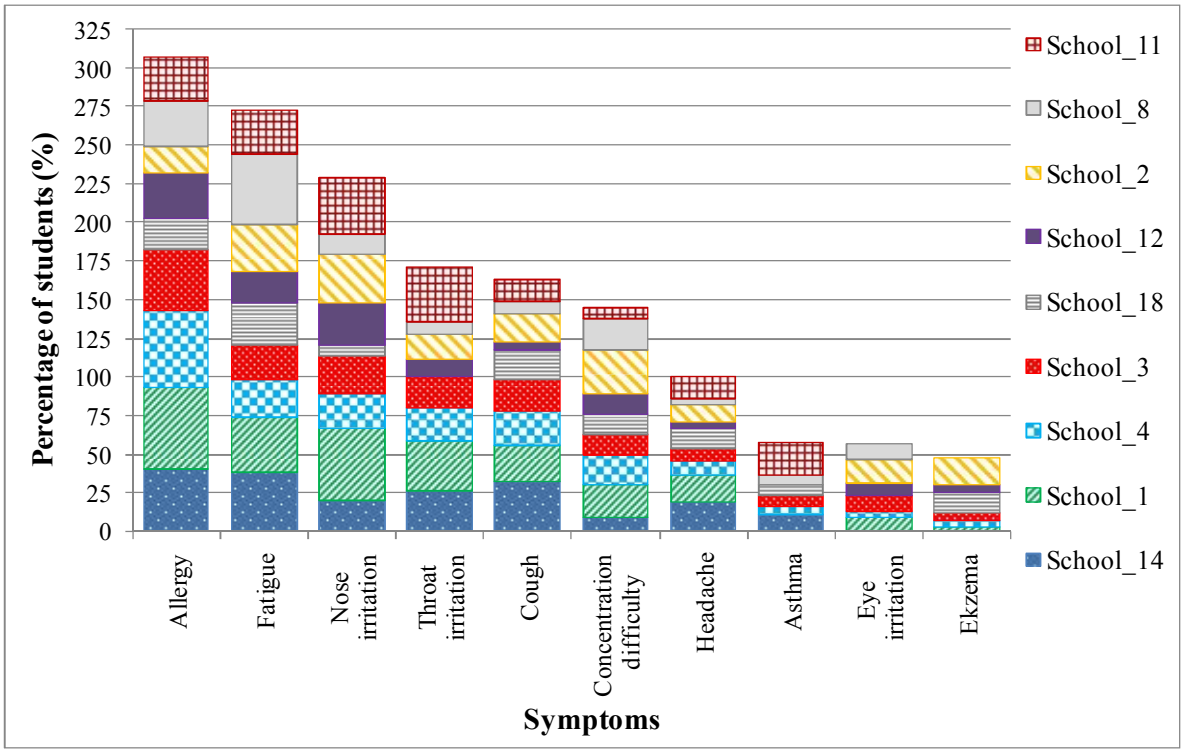

Figure 7: Distribution of students' sick building syndrome symptoms per school

In order to get a more clear virtual representation of the distribution of symptoms per school and to separate the schools whose large proportion of students is suffering from certain SBS symptoms, the dataset was divided in two parts. The one where the symptoms appear to a percentage of equal and greater than 25% of the total students per school (Figure 8) and to the one that the symptoms appear to less than 25% of the students per school (Figure 9). Great percentages of students in schools 1, 11, 14, 2 seemed to suffer more by certain symptoms (Figure 8). At least one out of four students complains about symptoms such as allergies, fatigue, nose and throat irritation, cough and difficulty in concentration (Figure 8). Figure 9 illustrates the distribution of symptoms that appear in less than 25% of the students per school. The symptoms in this case are much more, and are almost evenly distributed in each of the schools.

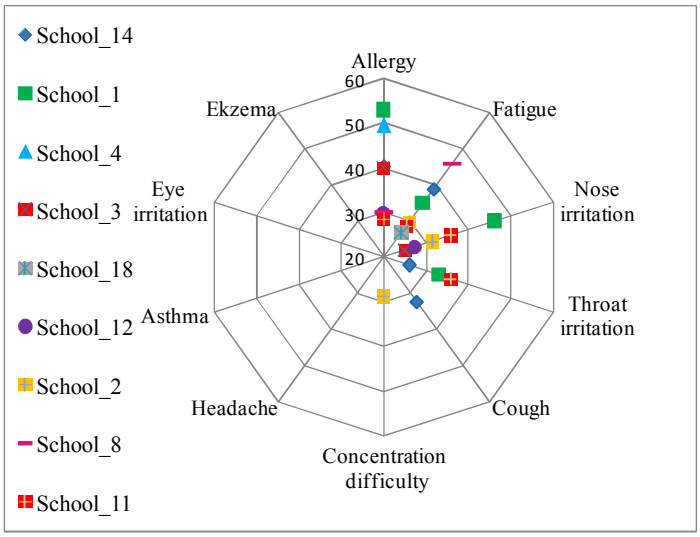

Figure 8: Distribution of students' sick building syndrome symptoms per school for cases of equal and greater than 25% of the total students per school

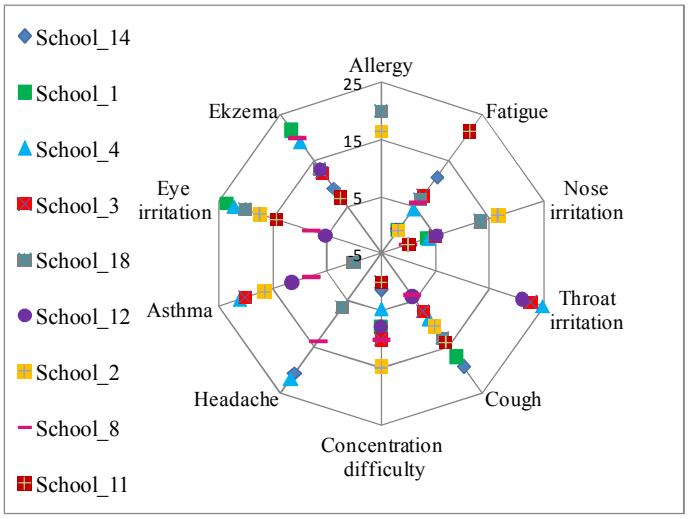

Figure 9: Distribution of students' sick building syndrome symptoms per school for cases of less than 25% of the total students per school

3.3 Performance scores vs pollutant concentrations

In order to assess the effect the pollutant concentration levels have on students' performance, the correlation coefficients were calculated between the scores achieved on the tests by the students to the corresponding concentration levels of CO, VOC and CO_2 that occurred at the time the tests were carried on. Table 2 presents the Pearson's (on the left) and Spearman's (on the right) correlations coefficients between the pollutants and the test scores. The significant correlations are marked with asterisks. As it can be seen the scores of both the 1b and 2b tests ('code test' of the first and the last hour) seemed to significantly negatively correlate to CO and CO_2, meaning that the greater the scores achieved the less concentrations occurred. The correlations were significant mainly at the level of significance 0.01.

Table 2: Pearson's (left table) and Spearman's rho (right table) correlation coefficients between test scores and pollutant levels

Pearson correlation coefficient	**CO**	**VOC**	**CO2**
Test 1a	0.014	-0.008	-0.02
Test 1b	-0.196**	-0.093*	-0.082*
Test 2a	-0.008	0.054	0.032
Test 2b	-0.013**	-0.025	-0.110**

Spearman's correlation coefficient	**CO**	**VOC**	**CO2**
Test 1a	0.039	0.025	-0.104**
Test 1b	-0.055	-0.005	-0.063
Test 2a	0.008	0.024	-0.049
Test 2b	-0.120**	-0.058	-0.208**

**Correlation is significant at the 0.01 level, *Correlation is significant at the 0.05 level

Figure 10 indicates the average scores achieved per school at each of the two 'code tests' of the first and last hour of lesson. As it can be seen, the scores of the test 2b are greater than in test 1b for all the schools. On the same figure the distribution of the average CO_2 concentrations per school are presented. In most of the cases (7 out of 9 schools) the CO_2 concentrations during the test 2b are below than the corresponding ones of the 1b test. The greater CO_2 concentrations indicate inadequate levels of ventilation which in turn also affects students' performance.

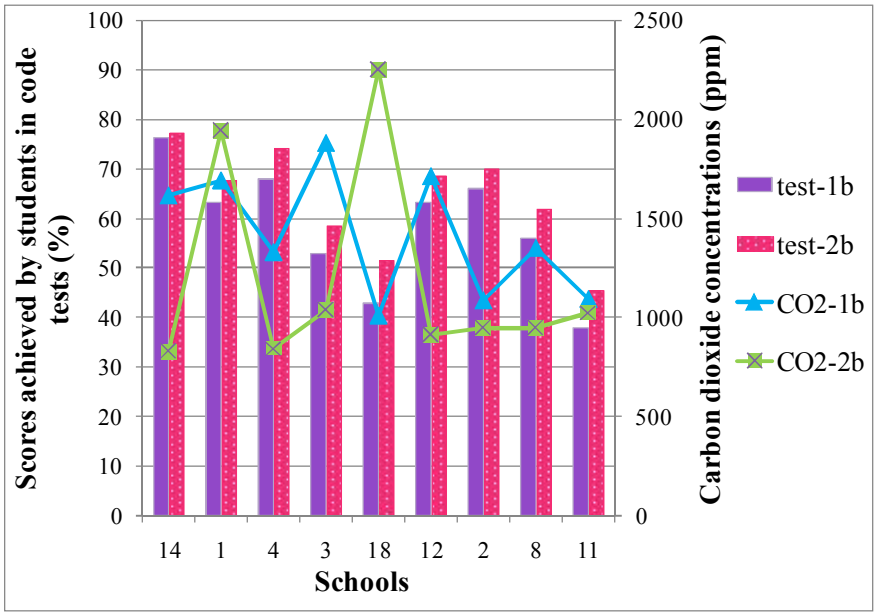

Figure 10: Averaged test scores per school and corresponding CO_2 concentrations

The correlation coefficients between the test scores and the subjective evaluation of the IEQ are shown in Table 3. Negative significant correlations mean that the greater the test scores achieved, the closer to zero (meaning satisfied, please refer to previous paragraph 3.1) are the votes of the evaluation of IEQ. Acoustics, lighting the overall rating of the IEQ on if it enhances the productivity or not and the subjective percentage of people dissatisfied (PPD) with the thermal environment seemed to be the main parameters correlating to the test scores achieved by the students.

Table 3: Pearson's and Spearman's correlation coefficients between test scores and the subjective evaluation of the IEQ

Correlation coefficients	Tests	IAQ satisfaction	Air: Fresh-Stuffy	Odor	Lighting	Acoustics	Overall rating	Subjective PPD
Pearson	Test 1a	-0.016	-0.004	-0.036	-0.081*	-0.140**	-0.083*	0.114*
	Test 1b	-0.073	-0.131**	-0.072	0.089*	-0.116**	-0.121**	0.071
Spearman's	Test 1a	-0.058	-0.051	-0.068	-0.108**	-0.152**	-0.091*	0.122**
	Test 1b	-0.067	-0.112	-0.061	0.101**	-0.07	-0.096*	0.080*

**Correlation is significant at the 0.01 level, *Correlation is significant at the 0.05 level

4 CONCLUSIONS

The main conclusions arisen from this study are: 1.Thermal comfort: in only two out of nine schools percentages of greater than 20% but less than 40% of the students evaluated the thermal environment as unacceptable. In the rest of the schools, the unacceptable votes were less than 20%. 2. IAQ: the average value of totally satisfied with the IAQ in most of the schools is approximately 20% excluding school 18 where the totally satisfied exceeded 60% of the students. Schools 2 and 8 had the highest percentages (~25%) of dis-satisfied votes (greater than 3) compared to the other schools. 3. Lighting: compared to the evaluation of IAQ, the percentage of students in all the schools that are totally satisfied with the visual

comfort is much greater. 4. Acoustics: strong differences in the distribution of votes from school to school. 5. Students in most of the schools believed that the overall IEQ enhances their performance as most of the votes lied from 3 and below. 6. Allergy, fatigue, nose and throat irritation seemed to be the main SBS symptoms of students that appeared to greater than 25 % of the students in the schools. 7. Significant negative correlations appeared between the test scores and CO and CO_2 meaning that there is evidence that the degradation of IAQ affects students' performance 8. The test scores also correlated to the evaluation of the IEQ by the students.

5 ACKNOWLEDGEMENTS

This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: Heracleitus II. Investing in knowledge society through the European Social Fund. We are greatly indebted to the school directors, pupils and parents without whose consent this study would have not been possible.

6 REFERENCES

ASHRAE (2010). American Society of Heating, Refrigetating and Air-Conditioning Engineers, Inc. Performance Measurement Protocols for Commercial Buildings, Atlanta, 236-257.

HETA (1997). National Institute for Occupational Safety and Health's (NIOSH), Health Hazard Evaluation and Technical Assistance (HETA). Indoor Air Quality and Work Environment Symptoms Survey, Appendix 3, 297.

Mendell M.J. and Heath G.A (2005). Do Indoor Pollutants and Thermal Conditions in Schools Influence Student Performance? A critical Review of the Literature. *Indoor Air* 15: 27-32.

SINPHONIE, project. Schools Indoor Pollution and Health: Observatory Network in Europe Available at: http://www.sinphonie.eu/about, accessed on July 24th, 2013.

Wargocki, P. Wyon, D.P., Baik, Y.K., Clausen G. and Fanger, O. (1999). Perceived Air Quality, Sick Building Syndrome (SBS) and Productivity in an Office with Two Different Pollution Loads. *Indoor Air.* 9:165-179.

Wargocki, P., Wyon, D.P., Sundell, J., Clausen, G. and Fanger, O. (2000). The effects of Outdoor Air Supply Rate in an Office on Perceived Air Quality, Sick Building Syndrome (SBS) Symptoms and Productivity. *Indoor Air.* 10:222-236.

WHO (1982). World Health Organization. *Indoor Air Pollutants: Exposure and Health Effects.* Copenhagen, WHO Regional Office for Europe (Euro Reports and Studies no. 78).

Witterseh, T., Wyon, T. and Clausen, G. (2004). The effects of moderate heat stress and open-plan office noise distraction on SBS symptoms and on the performance of the office work. *Indoor Air.* 14: 30-40