Impact of Lighting on School Performance in European Classrooms

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1. Introduction

Children spend more time at school than anywhere else, other than their own home. Students attend school approximately 200 days each year, and 70% of this time is spent inside classrooms. In Europe, there are over 64 million students and almost 4.5 million teachers who spend many hours per day inside kindergartens, primary and secondary schools. Understanding the classroom setting and how it impacts children is important if we want to ensure the heath and success of future generations.

The classroom indoor environment is known to have an effect on student performance. Studies on air quality in schools have observed that reductions in school performance can be expected for classrooms and buildings with higher levels of pollutants [1][2]. Other aspects of the indoor environment have also been investigated, such as lighting conditions inside the classroom. There are numerous benefits of both natural light and light in general, and the hypothesis that better lighting conditions lead to better results should seem obvious. However, previous studies have yet to come to a consensus on the issue of lighting and school performance. While evaluations of both natural daylighting and artificial lighting are suggestive of a link, the strength of that link remains unclear. Often these studies are limited geographically [3][4][5], or by a small number of students [6], suggesting that further investigation is needed on a larger scale.

The present study investigates whether the overall lighting conditions in the classroom has an effect on student performance. Students' exposure to light was determined using both direct and indirect assessments of lighting conditions from a European study, conducted recently at the general population level. This study takes advantage of thousands of students in a European-wide analysis and has taken into consideration other known predictors of student learning, including social status and air quality.

2. Methods

Study Design

The Schools Indoor Pollution and Heath: Observatory Network in Europe (SINPHONIE) study is a cross-sectional investigation whose main goals, as indicated by its name, were to assess both indoor air in schools and outdoor air in the school vicinity and to better understand the relationship between indoor air pollution in schools and the health of the occupants. The study was conducted in 2011 and 2012, measuring levels of several air pollutants and school characteristics in 23 countries across Europe. Schoolchildren were assessed for general and respiratory health markers, and in some schools, students also completed cognitive tests in order to investigate the effects of the indoor environment on school performance. In addition to air quality measurements, several measurements on the schools' general environment were also taken, including assessments on the lighting conditions in each classroom. The study described in this report takes advantage of this additional data by exploring the possible relationship between the lighting in school and exam performance.

Figure 1. Schools across 23 European countries were included in the SINPHONIE study. Points indicate capital cities and do not reflect cities participating in the study.

Population

The cross-sectional study design allows us to take a simultaneous picture of a phenomenon in a large geographical zone, covering 148 classrooms in 54 schools and evaluating 2,837 students in total, with an age range of 8-12 years. There were approximately equal numbers of females and males, and of those who responded to the question on ethnic background, 82.5% were Caucasian, 1.9% Middle Eastern, 1.7% Black or Asian, and 12% were other ethnicities.

We observed no demographic bias in the students who took performance exams as compared to the SINPHONIE study at large. The ratio of each demographic (gender, race, education of mother) within the subgroup of test takers was similar to that of the larger project as a whole. We also do not observe any bias in terms of classroom characteristics such as ceiling height, window area or floor area, as they are essentially the same for both groups.

In the SINPHONIE study, the schools were divided into four geographic clusters (as shown in Figure 1) that correspond to the World Health Classification regions. This classification was used in the present study as well, primarily to understand any differences between countries with more or less daylight during the school year.

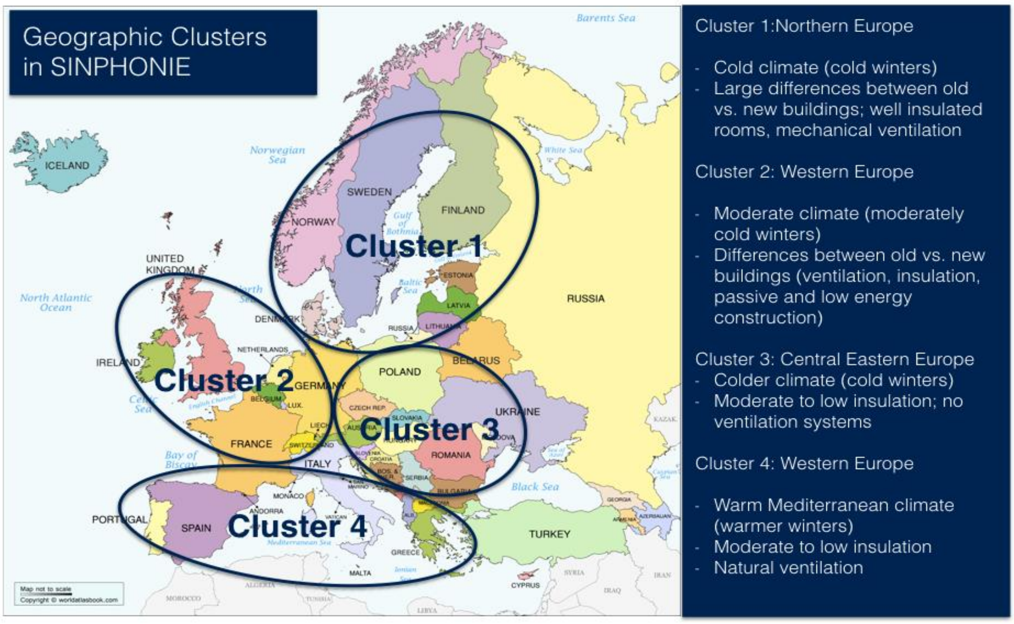

Figure 2. Geographic clusters in the SINPHONIE study

Light Assessment

Several classroom characteristics, relating to the lighting conditions, were included in order to assess the overall indoor environment. Several parameters such as ceiling height, floor area and window area were recorded, as well as the percentage of window area facing north, south, east or west. The orientation of the windows was considered as a binary variable, representing either a view on green space or a view onto a street or another building. Direct sunshine on surfaces in the classroom was also considered (with the option to answer yes or no) and the story number of the classroom was recorded. The type of lighting in each classroom was classed as either natural, artificial or a mixture of both. Concerning the windows themselves, the type of glazing (single, double, triple, double clear with filling or double clear with coating), the type of shading (internal, external, none or south-side only), the control of shading (individual or no control) and the ability to open the windows (all, some or not allowed) were also recorded.

Variables used from the SINPHONIE study				
Type	Variable	Mean Value	Standard Deviation	Range of Values
Continuous	Ceiling Height	3.288	0.426	2.5 - 4.9
	Floor Area	52.21	15.84	24 - 135.26
	Window Area	13.18	9.97	2.8 - 75
	CO_2	1540.46	892.28	171 - 4957
	Windows Facing N (%)	10.91	22.61	0 - 100
	Windows Facing S (%)	21.46	33.51	0 - 100

Variables used from the SINPHONIE study				
	Windows Facing E (%)	31.45	41.08	0 - 100
	Windows Facing W (%)	10.59	23.69	0 - 100
Categorical	Standard Orientation	-	-	Facing Street | Facing Garden
	Direct Sunshine	-	-	Yes | No
	Story #	-	-	here only 0,1,2,3 & 8
	Type of Lighting	-	-	Artificial | Mixture | Natural
	Type of Glazing	-	-	Single | Double | Triple Double with Filling
	Type of Shading	-	-	Internal | External | None
	Control of Shading	-	-	Individual | No Control
	Openable Windows	-	-	All | Some | No

Table 1. Collected data relevant to lighting.

The other variables considered relate to the location of the school and the season in which the tests were taken into account, as they impact the overall number of hours of daylight available. A daylight index was also introduced to account for the number of hours the sun was up for a given location. This index is highly correlated with season, and ranges from 1-13, where 1 represents the darkest four weeks of the year and 13 represents the lightest four weeks of the year. The index is the same for everyone regardless of latitude, and is calculated based on the test date alone.

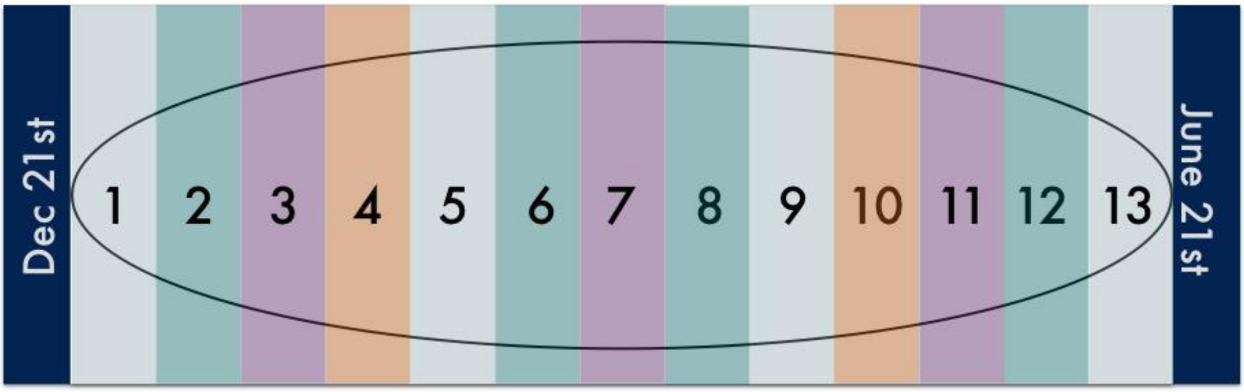

Figure 3. Picture of how the Daylight Indices correspond to days of the year, where the ellipse represents a full year. The closest 4 weeks (Dec 7th – Jan 3rd) surrounding December 21st are the darkest and correspond to Index 1. The next closest 2-week periods (Nov 23rd – Dec 6th and Jan 4th – Jan 17th) correspond to Index 2, and so on. The brightest 4 weeks of the year correspond to Index 13.

Additional variables describing lighting conditions				
Type	Variable	Mean Value	Standard Deviation	Range of Values
continuous	Window to Floor Ratio	0.2447	0.098	0.041 - 0.822
	Average National Latitude	46.666	5.818	35-61
	Average National Longitude	16.181	10.127	-8.2 - 33.4
	Crowding	21	7.2	1 – 44
categorical	Daylight Index	3.7	2.3	1 – 13
	Season	winter (most common)	-	Summer | Autumn Winter | Spring

Table 2. Additional data relevant to lighting and classroom characteristics. These data were determined from other variables in the SINPHONIE dataset.

Another measure included is the window to floor area ratio, which is simply a measure of how "big" the windows are compared to the classroom size. This variable was introduced because the window area alone does not describe the amount of natural light for a given space. While there is still some ambiguity, because the depth of the classroom was not recorded, it is still a better indicator of relative window size than the direct window area measurement.

Many of our variables are related to the windows and therefore indicative of the natural light available. Most classrooms had artificial lighting as well (>93%), and there was no data detailing usage of lighting systems. Thus, we consider the overall lighting conditions as a contribution of both natural and artificial sources rather than trying to distinguish between the two.

Performance Exams

Performance in the classroom was measured by an exam, consisting of mathematic and logic exercises. The exams were given at the beginning of the school day. The first section tested basic arithmetic skills and was graded as a percentage of correct answers. The second part of the exam tested logical translation skills and consisted of 119 elements, which were to be completed within 120 seconds. This section tested both logic and memory. Again, the score was based on a percentage of correct answers. The final score used in the analysis was an average of the two percentages from each section. The test did not differ for children in different grade levels.

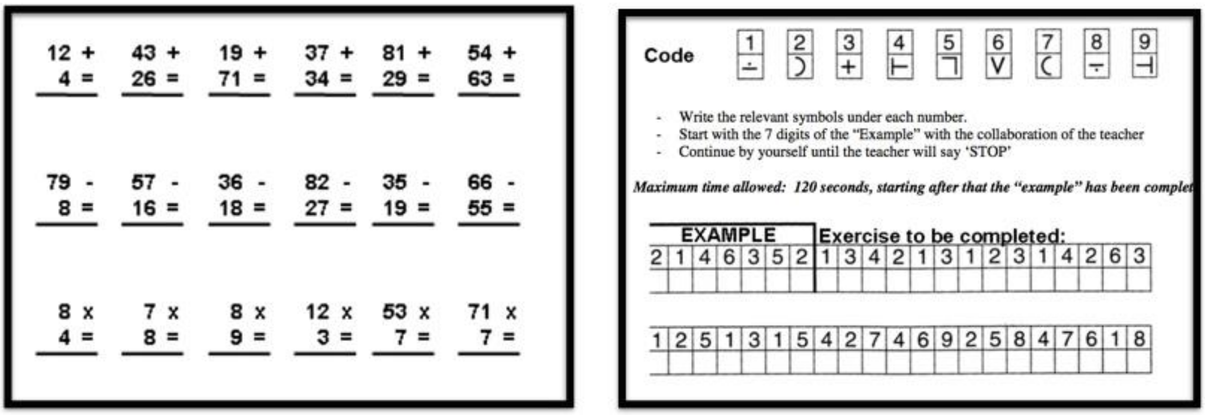

Figure 4. Example of the Performance Exam given. Section 1 (left) included basic arithmetic, while section 2 (right) tested ciphering skills and memory.

Number of Students by Country

	Schools	Classrooms	Students	Percentage of Students
Albania	6	18	526	18.5%
Belgium	3	8	141	5%
Bosnia & Herzegovina	3	8	125	4.4%
Czech Republic	5	15	303	10.6%
Estonia	4	14	220	7.8%
France	4	10	237	8.4%
Greece	2	6	95	3.3%
Hungary	6	9	196	6.9%
Italy	5	15	264	9.3%
Lithuania	5	15	245	8.6%
Portugal	6	15	231	8.1%
Serbia	5	15	254	9%
TOTAL	**54**	**148**	**2837**	**99.9%**

Table 3. Number of students by country.

Two different versions of the test (Test 1 and Test 2) were administered in different countries (see Table 4), with the exception of Serbia, where students took both versions. Aside from the detail presented in Table 1, both Test 1 and Test 2 are treated as a single test, since the basic content was similar even if individual questions were different. There was no difference in the demographics of the test takers according to the type of tests.

	Test 1	**Test 2**
Number of Students	1788	1292
% of Test Takers	63.2%	45.5%
Age Range	8-13	7-13

Number of Countries	8	5
Countries	Albania Belgium Bosnia & Herzegovina Estonia France Greece Hungary Serbia	Czech Republic Italy Lithuania Portugal Serbia

Table 4. Number of Students and Test Scores for each of the two performance exams used.

Statistical methods

Classic analysis was applied in order to determine associations between exam scores and lighting conditions. First, each of the variables was checked for a crude association with the mean score. To do this, we used either a univariate regression model for continuous variables (which looked for a linear relationship between the variable and the average score), or ANOVA or t-test for categorical variables, which identified whether or not the overall mean of the exam scores between the differing groups was significantly different. Multivariate linear models were used for assessing the relationship between light variables and performance after considering confounders.

3. Results

Descriptive Analyses

The exam score distributions for Test 1, Test 2 and for both tests combined are shown in Figure 5. The distributions and mean scores are similar for all three groups. In total, 2,831 scores, one for each student, were used in the final analysis.

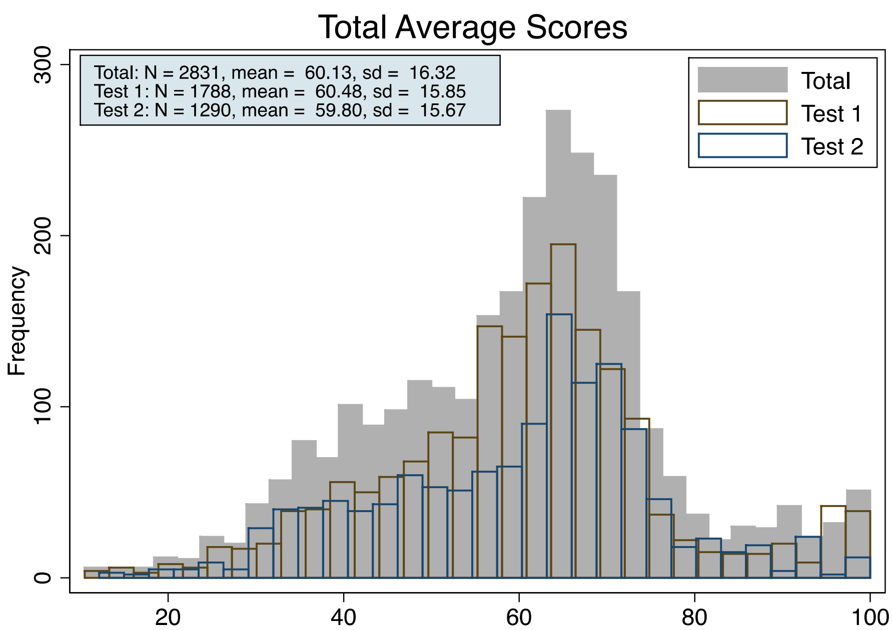

Figure 5. Total average test score for Test 1 (brown), Test 2 (blue) and for all students (grey). These scores represent the percentage of correct answers for both sections of the exam

Univariate Analyses

We find that several variables show a significant ($P < 0.05$) association with the average exam scores, with the exceptions of window orientation and floor area. The percentage of window area facing north, east or west were also not significant, however the percentage of window area facing south was. While significance alone does not tell us how strong an association is, it does help in determining which variables merit further investigation. The strength of the associations between each of the significant continuous variables and the mean exam scores are given in Table 5.

Variable	Coeficient	SD	t	P	CI (95%)
Celing Height	-5.751	.696	-8.27	0.000	-7.11 - 4.38
Window Area	.1799	.0318	5.65	0.000	.118 - .242
Window/Floor Area Ratio	29.239	2.939	9.95	0.000	23.477 - 35.002
% Window Facing South	.112	.00923	12.06	0.000	.0938 - .1303
Daylight Index	-.9435	.1311	-7.20	0.000	-1.201 - .6865
Latitude	1.14967	.0481	23.89	0.00	1.055 - 1.244

Table 5. Strength and Significance of the association between the continuous lighting indicators and the mean score. The coefficient represents the strength of association.

The strongest predictor of performance was the window to floor area ratio. The strength of this association persisted in a multivariate linear regression analysis.

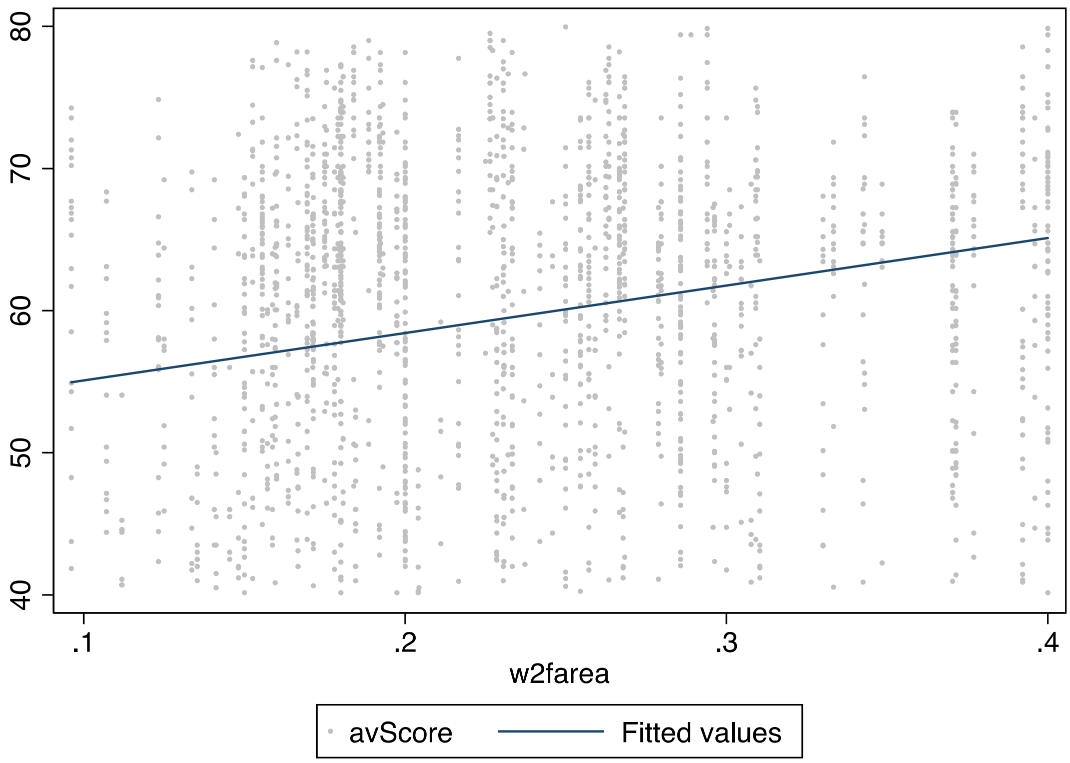

Figure 6. Average Score vs. Window to Floor Area. The blue line shows the resulting fit from a simple linear regression.

We find that average scores were higher during autumn and winter months. There is also a slight but significant effect of of latitude, average scores in northern countries. We find no difference in scores between classrooms, which face urban settings, and those, which face green spaces. There is only a very slight impact from window area alone, but a high significance on the impact of the window to floor area.

Dividing the students into quartiles by their window to floor area score shows that students with a lower window to floor area have lower scores on average than those with a higher window to floor area.

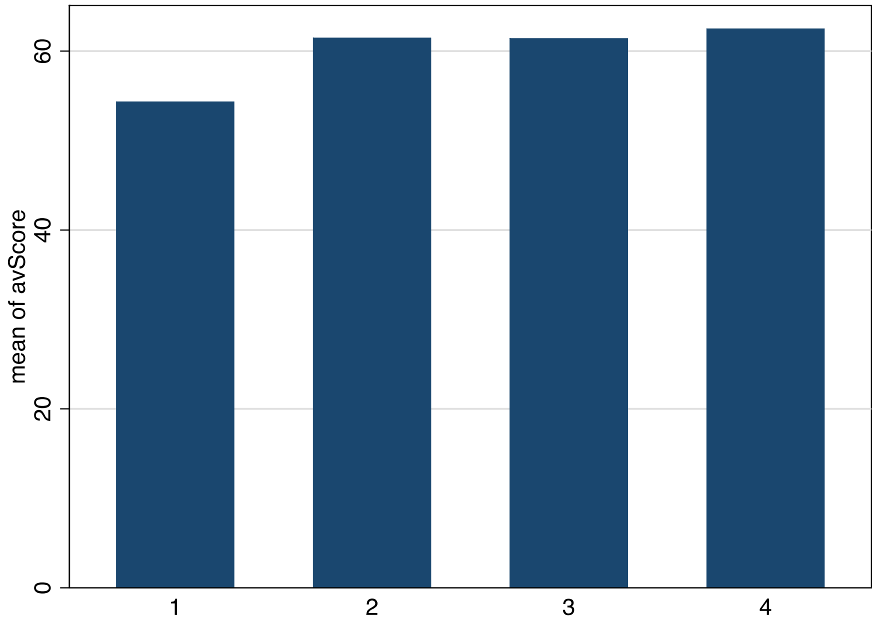

Figure 7. Average scores grouped by window to floor area quartiles. Each group contains roughly the same number of students.

Group	Average W2F	Average Score	% Increase
1	0.1439	54.34	—
2	0.2018	61.48	13%
3	0.2624	61.43	13%
4	0.3759	62.50	14.7%

Table 6. Average scores grouped by window to floor area quartiles. Each group contains roughly the same number of students. The percent increase in scores is from each group in group 1.

For the previously known indicators of student performance, CO_2 and crowding, we see that student performance decreases slightly as CO_2 levels go up, which was expected, and that scores were higher as the number of students in the class increased, which was not expected. From [8] the recommended levels of CO_2 should be between 1,000 – 2,000 ppm, and levels below 1,000 ppm are considered as hygienically unproblematic, while levels above 2,000 ppm are hygienically unacceptable. The graph below illustrates that several classrooms have CO_2 levels above this recommended range. When probed further with a non-linear regression, the resulting fit for crowding was worse than the linear fit and did not explain any detail within the scores as a function of class size.

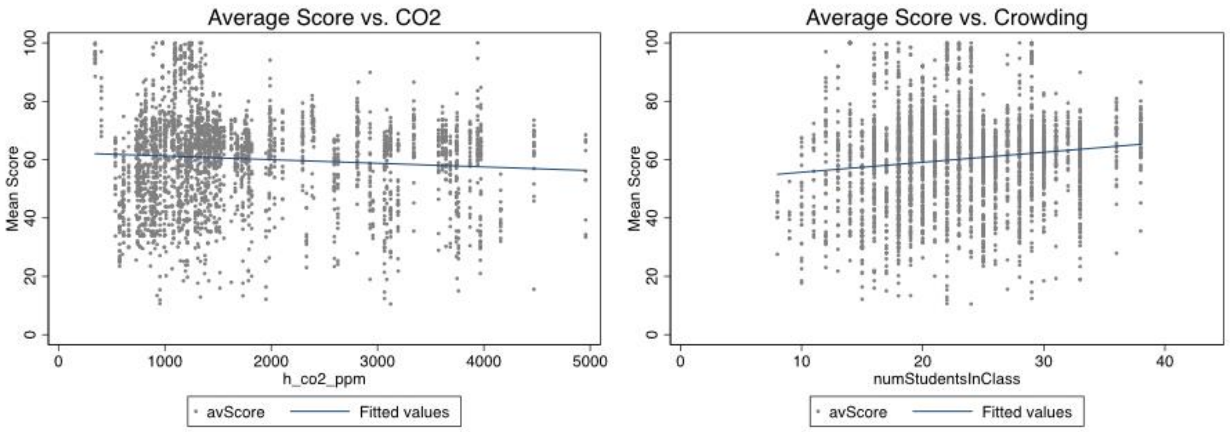

Figure 8. On the left, Average Score vs. CO_2 concentration levels. On the right, Average Score vs. Crowding. The blue lines show the resulting fits from a simple linear regression.

Multivariate Analysis

Variables with significant association in the univariate analysis were then analysed further to understand the overall influence that these indicators have in student performance. Some categorical variables were encoded by a number in order to be used in a linear regression. A stepwise multivariate linear regression was performed on the mean exam score using the indicators listed in Table 6. Variables that were no longer significant at the 0.05 level were excluded, as indicated in Table 6.

Variable	Coefficient	SD	t	P	CI (95%)
Window/ Floor Area Ratio	12.251	2.838	4.32	0.000	6.684 17.82
Type of Shading	3.525	.4131	8.53	0.000	2.715 - 4.335
Latitude	.7903	.0587	13.46	0.000	.6752 - .9055
% South	.0450	.0097	4.67	0.000	.0261- .0640
Daylight Index	-1.238	.1407	-8.80	0.000	-1.514 -.9621
Direct Sunlight	-1.998	.6762	-2.95	0.003	-3.324-.6716
Story Number	Excluded			0.2491	-
Glazing	Excluded			0.4117	-
Ceiling Height	Excluded			0.4486	-
Openable Windows	Excluded			0.4875	-

Table 6. Results from a stepwise multivariate linear regression on the mean exam score.

We find that when all light indicators are included, the positive influence from the window to floor area ratio dominates, followed by the type of shading, the latitude, and finally the percentage of window area facing south. The daylight index shows a negative effect, as does the existence of direct sunlight. Together these indicators explain 22% of the variation between student scores.

Models adjusted for confounders

We adjusted the model detailed above in Table 6 on ethnic group, education of the mother and number of students in the classroom. By including these variables, we were able to explain 25% of the variation between exam scores, an increase of 3%, however the direct sunlight was no longer significant. We also found that the education of the mother and race were not significant indicators of performance. Gender was significant (P = 0.031) and suggested females score 1.45 times better on average. The window to floor area ratio remained the strongest indicator of student performance, with a coefficient of 10.673 (P = 0.001).

4. Conclusions and Discussion

Our data from a pan-European survey suggests that lighting conditions have a significant influence on student performance. In particular, we find a positive association between the window to floor area ratio and student scores and a weaker but significant positive association with the percentage of window area facing south. As the window to floor area ratio is a measure of how large a window is for a given space, we conclude that larger windows can have a positive effect on students. This may be a result of abundant light, but may also be an indication that students who feel less closed in are more relaxed and can concentrate on their schoolwork. We did not have information on the height of the windows, so we are unable to determine if the ability to look outside the classroom is important, and we did not see any difference in scores for classrooms with windows facing green spaces versus those facing urban spaces. This, combined with the small, but positive influence on scores with the percentage of windows facing south indicates that natural light is indeed a factor.

We also find a significant association found between the types of window shading. Classrooms with internal shading, and south side shading had significantly higher average scores than did those with external or no shading, suggesting that it is advantageous to control the amount of sunlight entering the classroom. This would seem obvious, for example, if glare is a problem for some classrooms, as implied by the fact that we see a negative association with direct sunlight. A similar negative association between direct sunlight was seen by [3], which found that students in classrooms with diffuse natural light performed better.

The average national latitude was included in order to understand any differences between students who live with differing amounts of daylight during winter months. As most of the exams were taken during the winter, the amount of sunlight hours varies greatly between our most northern countries, Estonia and Lithuania, and the most southern, Greece and Portugal. The number of daylight hours during regular school hours (from 8:30 – 3:30), however, is roughly the same across Europe. We find that students in the northern countries performed better; however, this might also have been predicted based on PISA ranking [7]. It doesn't suggest that fewer daylight hours impact performance negatively, however, during winter the sun is up during the school day even for the most northern cities in our study. We also observed that students performed better during darker months, based on the negative association with the daylight index. However, this does not necessarily mean winter – mean scores during autumn months were higher than winter months.

Other factors that were significant, when checked directly against the mean exam scores with a univariate model, but did not remain significant when other light indicators were included, are story number, type of glazing, ceiling height and openable windows. We do see a significant difference in average scores between single, double and triple glazed windows, however this may be a signal of an affluent neighborhood rather than due to the glazing itself.

We do not observe an impact on performance from the orientation of the windows, suggesting that performance was not affected by windows that face concrete or green spaces. We should note however, that since window height was not included in the data, we could not determine if the students were able to see out the windows from their seats.

Our results are not comparable with the previous rare studies on the same topic, due to differences in populations and methods, and specifically because we did not have objective light and illumination assessments for classrooms. We also used several variables to assess light and we used European data. In addition, we found high statistical significance in the case of the same variables. However, further studies are necessary to better determine the role that light can have in schools.

To sum up, our European data support the hypothesis that light is important for learning capacities and performance of schoolchildren.

Limitations:

The main limitation of the present study is that light was not originally considered as a stressor in the implementation of the study design protocol. Therefore, no direct assessment of light was performed. Another limitation results from the differences in school systems for different countries. Because of this heterogeneity, comparisons have to be made cautiously. We did have subjective values indicating the Perception of Illumination by students, parents and teachers. However, this variable was excluded from the multivariate analysis on the basis of subjectivity, as well as inconsistencies between the students, parents and teachers. It could, however, be argued that the use of teachers' perception of illumination, which was a significant predictor for performance, is justified as their judgment would be based on a full day's light from an adult, who understands the difference between classrooms and various lighting conditions.

Strengths

The major strength is that our data are representative of the general population at a European level. As a consequence of the fact that light was not one of the research questions in the study, bias towards light assessments is not expected.

Acknowledgments

The authors are indebted to the colleagues of the EU–funded SINPHONIE project (http://www.sinphonie.eu).

References

[1] Haverinen-Shaughnessy, U., D.J. Moschandreas and R.J. Shaughnessy. "Association between substandard classroom ventilation rates and students' academic achievement." Indoor Air. 2011 Apr., 21(2): 121-31.

[2] Meklin, T.H., T. Vepsalainen, A. Vahteristo, M. Koivisto, J. Halla-Aho, J. Hyvarinen, A. Moschandreas and D. Nevalainen, A. "Indoor air microbes and respiratory symptoms of children in moisture damaged and reference schools." Indoor Air. [Research Support, Non-U.S. Gov't]. 2002 Sep., 12(3): 175-83.

[3] Heschong-Mahone Group (1999). Daylight in Schools: An Investigation into the

Relationship between Daylighting and Human Performance. Detailed Report. Fair Oaks, CA: Heschong-Mahone Group

[4] Heschong-Mahone Group (2001). Re-Analysis Report: Daylight in Schools. Fair Oaks, CA: Heschong-Mahone Group

[5] Heschong-Mahone Group (2003). Windows and Classrooms: A Study of Student Performance and the Indoor Environment. Fair Oaks, CA: Heschong-Mahone Group.

[6] P.J.C. Sleegers et al. Lighting affects students' concentration positively: Findings from three Dutch studies. Lighting Res. Technol. 2013; 45: 159–175

[7] OECD, PISA 2012 Database; Tables I.2.1a, I.2.1b, I.2.3a, I.2.3b, I.4.3a, I.4.3b, I.5.3a and I.5.3b

[8] Fraunhofer-Institut für Bauphysik IBP, Impact of the indoor environment on learning in schools in Europe, December 2015