The influence of indoor air quality in classrooms on the short-term academic performance of students in higher education; a field study during a regular academic course

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ABSTRACT

The indoor air quality (IAQ) in classrooms in higher education can influence in-class activities positively. In this context, the actual IAQ and students' perceived IAQ (PIAQ), perceived cognitive performance (PCP), and short-term academic performance (SAP) were examined in two identical classrooms during regular academic courses. During the lecture, key performance indicators (KPI) for the IAQ, i.e. carbon dioxide concentration, particulate matter 2.5, and total volatile organic compounds, were measured. After the lecture, responses of 163 students were collected with a validated self-composed questionnaire and a cognitive test, which covered topics discussed during the lecture. A significant association between the IAQ KPI and the PIAQ was found ($p < .000$). The PIAQ significantly predicted the PCP ($p < .05$) and the PCP significantly predicted the SAP score ($p < .01$). These results indicate that the IAQ in classrooms is associated with the PIAQ and PCP, and therefore is associated with students' SAP.

INTRODUCTION

In this study, we explore the influence of the indoor air quality (IAQ) on the academic performance of students in higher education. In this context, we define higher education as a college or university (Wæraas & Solbakk, 2009). Students' academic performance is one of three main student outcomes, besides behavioural and psychological outcomes (Wang & Degol, 2016). Cohen, McCabe, Michelli, & Pickeral (2009) have argued that it is the primary goal of schools to create a sustainable and positive school climate, and by doing so, the academic performance of both students and teachers is positively influenced.

This study focusses on the impact of IAQ on students' short-term academic performance. Earlier research by Wargocki and Wyon (2017) revealed how thermal conditions and IAQ influences humans' cognitive performance. However, individuals may react differently to the same IAQ. Cultural, climatical, social, and contextual factors can moderate students' response to the experienced IAQ (De Dear & Brager, 1998). Furthermore, overall satisfaction with the IAQ depends, among other things, on a person's demographic characteristics, such as gender and age (Frontczak & Wargocki, 2011). Mendell and Heath (2005) analysed the direct relationships between the thermal environment (TE) and IAQ and the performance and attendance of students. Although they reported that little direct scientific evidence of high quality was available, they also state that certain indoor environmental conditions have adverse effects on students' cognitive performance and attendance.

Poor IAQ conditions may also affect teachers' and students' health and cause different physical health symptoms. For example, poor IAQ conditions may cause ocular symptoms (i.e., dry eyes), respiratory symptoms (i.e., nasal or throat symptoms), skin symptoms (i.e., dry skin), and general health symptoms (i.e., headache, fatigue, shivering, sweating, nausea) (Sahlberg, Wieslander, & Norbäck, 2010). Furthermore, the chance to develop rhinitis is significantly higher when humans are exposed to air with high carbon dioxide concentrations (CO_2) over a long period, as a proxy for a poor IAQ (Sarigiannis, 2013; Simoni et al., 2010).

These individual responses to the IAQ influence in-class activities, such as teaching and learning, and might affect students' ability to pay attention and to be alert (Wargocki & Wyon, 2017), which are indicators for the PCP. Subsequently, when we focus on the specific educational goals of a lecture, the IAQ can influence students' short-term academic performance (Dawson & Parker, 1998). Table 1 presents the assumed hypotheses and associations between the independent (x) and dependent (y) variables, which are explored in this study.

Table 1. Assumed hypotheses and associations between independent (x) and dependent (y) variables and explanation of used abbreviations. See footnote to Table and Table 2 for explanation of symbols used

x	y	Hypothesis	Association
CO_2	PIAQ	An increase in all KPI will lead to a deterioration in the perceived indoor air quality (PIAQ)	-
PM2.5			
TVOC			
PIAQ	PCP	An increase in PIAQ will lead to an increase of the perceived cognitive performance (PCP)	+
PIAQ	PHC	An increase in PIAQ will lead to a decrease of the perceived health complaints (PHC)	-
PIAQ	SAP	An increase in PIAQ will lead to an increase of the students' academic performance (SAP)	+
PCP	SAP	An increase in PCP will lead to an increase of the SAP	+

- = negative correlation; + = positive correlation

METHODS

In this study, freshman of the Hanze University of Applied Sciences (UAS) School of Business Management participated during one week in February 2020, while following their normal educational program. This group of students was selected for this study, because they were lay persons and not versed in building physics. The study was performed in two heated and natural ventilated classrooms located in the city Groningen, the Netherlands. The capacity of these two classrooms, to accommodate this group of students, was sufficient to facilitate the 12 two-hour lectures and an additional 20 minutes for research participation under similar conditions. Furthermore, these classrooms were identical in size, height, orientation, daylight entry, and artificial lighting and were both equipped with a full recirculation system to achieve a set air temperature (T_a). Fresh air could enter the classrooms though vents, which were located above the double glazing. Table 2 presents the IAQ key performance indicators (KPI) measured, using two VLK-60W multi-sensors, including measurement accuracy.

Table 2. Specifications ATAL VLK-60W multi sensor device

Performance indicator	Symbol	Description
Indoor air temperature at desktop height	T_a	Air temperature in degrees Celcius (°C), accuracy ±0.5 °C @ 0 to +50 °C
Indoor relative humidity	RH_i	Indoor relative humidity in percentage (%), accuracy ±0.3 % RH_i @ 5 to 99 % RH_i
Carbon dioxide concentration	CO_2	Parts per million carbon dioxide concentration (ppm CO_2) accuracy ±75 ppm + 10% of the actual reading
Particulate matter 2.5	$PM_{2.5}$	Particulate matter, accuracy < ±15% @ 0 to 1,000 μg/m^3
Total volatile organic compounds	TVOC	Total volatile organic compounds, accuracy ± 0.02 mg (or 10%) @ 0 to 3.5mg/m^3

The air temperature (T_a) and relative humidity (RH_i) in the two classrooms were logged and assessed for confounding the results. The logged data of these devices was exported to EXCEL to determine the condition at the start of the lecture (C_s), to calculate the average condition (C_a) during the lecture, and to determine the condition in which the students answered the questionnaire and performed tests (C_t).

During the study, four teachers gave a two-hour lecture, as part of a regular academic course. Each teacher gave the same number of lectures in classrooms A and B. The lectures were given on each weekday, except for Monday. After the lecture, the researcher asked the students present to participate in the study. The degree of participation was high, reaching approximately 90% of all students present. All participants answered a self-composed online questionnaire to obtain the variables perceived IAQ (PIAQ), perceived physical health complaints (PHC), and perceived cognitive performance (PCP). The protocol, from which this questionnaire is derived, is described in a manuscript entitled: "Towards a framework studying the influence of the indoor environment quality on academic performance in higher education; evidence-based on literature and field studies" (Brink, Loomans, Mobach & Kort, submitted 2021). To measure students' academic performance (SAP), students made a test. After the lecture and a short break of approximately ten minutes, the students answered first the questions in the online questionnaire. Then, after approximately 15 minutes, they made the academic performance test. This test covered topics that were discussed during the lecture and consisted of ten questions and it took the students approximately 5 minutes to complete this test. Figure 1 visualises the study design.

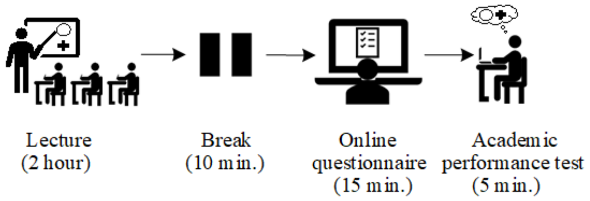

Figure 1. Visualisation of study design

To assess the internal validity of the statements which addressed the PIAQ and the PCP, all negative formulated statements were recoded, a Cronbach's alpha analyses of these composed perception scales was performed. Due to the application of a five-point Likert scale, the lowest perception score for the categories PIAQ and PCP is one, which can be interpreted as very poor, and the maximum score is five, which can be interpreted as very good.

Linear regression analyses were performed to analyse all bivariate and multivariate associations between independent and dependent variables. The output of the regression analyses was only used when it met the following assumptions for all associations: First, the number of outliers in the data is limited. To determine if there were any outliers, standard residuals and Cook's distance were computed. Standard residuals' value must be between -3 and +3 and Cook's distance should not be larger than 1 (Cohen, Jacob, Cohen, West, & Aiken, 2013, p. 404). Third, the assumption of normality is met. To determine normal distribution of the data, a normal P-P plot of the regression standardized residual was computed. When this normal probability plot of the residuals appeared to be approximately linear, the assumption of normal distribution was met. When the outcome appeared not to be linear, the distribution of the standardized residuals and unstandardized residuals was analysed with the Shapiro-Wilk test (Ghasemi & Zahediasl, 2012). When the significance level of this test is >.05, the assumption for normality is met. For multivariate associations also the tolerance values should be .10 or higher to rule out multicollinearity (Cohen et al., 2013) p.424). The missing values in all linear regression models were excluded pairwise. When the assumption for regression is not met, the Spearman's rho was used to assess the association. For all tests, the confidence interval (CI) was set at 95%. All statistical analyses were performed with SPSS version 25.0 (SPSS Inc. Chicago, IL,USA).

RESULTS

In this study, 163 first-year students (19.3 years, SD 1.6, 39% female) participated, The average number of students, who attended the lecture, was 14 (SD 3). In the study week, a total of 12 lectures were given by the four teachers. The T_a was regulated by the installed heating system and varied slightly at 23°C (SD 0.4). Table 3 presents all measurements of the IAQ and TE KPI, during the lectures.

Table 3. Observations of the indoor air quality en thermal environment key performance indicators

(Table 3 is presented below the References section)

Of the 163 students, 52 students reported one or more physical health complaints (PHC), which will disappear according to the students when they leave the classroom, as presented in Figure 2. Figure 3 presents the type of health complaints, which were reported by more than two students.

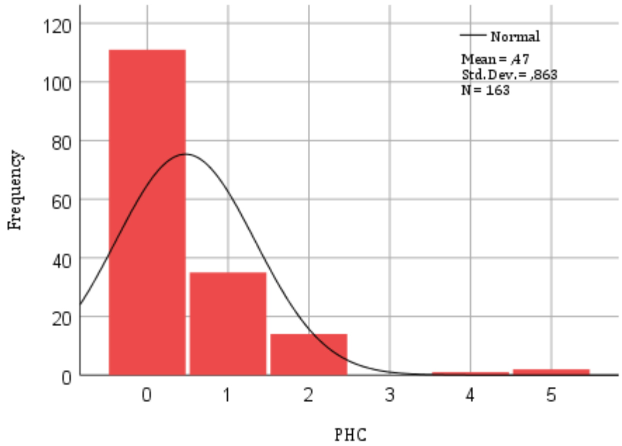

Figure 2. Distribution of number of reported physical health complaints (PHC)

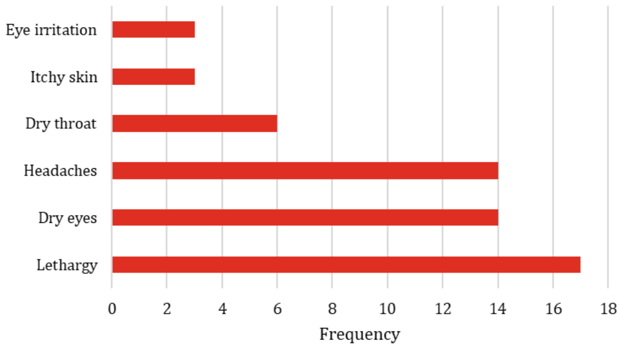

Figure 3. Health complaints which were reported by more than two students

To assess the internal validity of perception scales PIAQ and PCP the Cronbach's Alpha for these scales were calculated. All items contribute to the internal validity of the scales. Figure 4 presents students' scores on the individual statements.

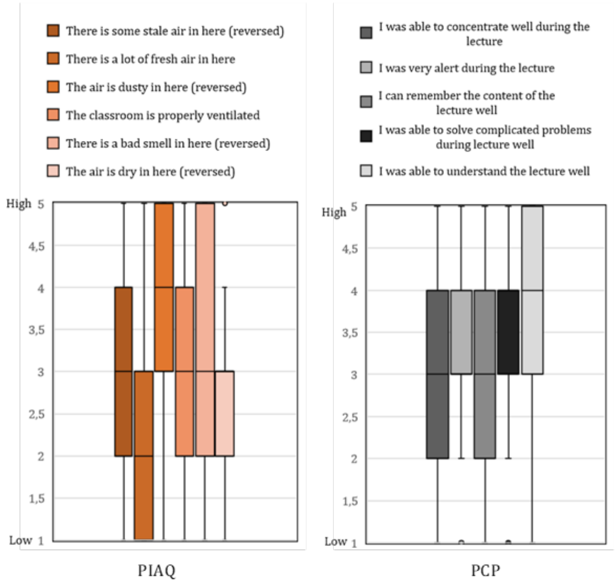

Figure 4. Box-plots of students' score on individual statements addressing the perceived indoor air quality (PIAQ) and perceived cognitive performance (PCP)

The alpha value for the PIAQ and PCP was 0.82 and 0.87, showing that these scales have considerable reliability; therefore, average perception scores were used for further analyses. Figure 5 presents the PIAQ, PCP and the SAP scores.

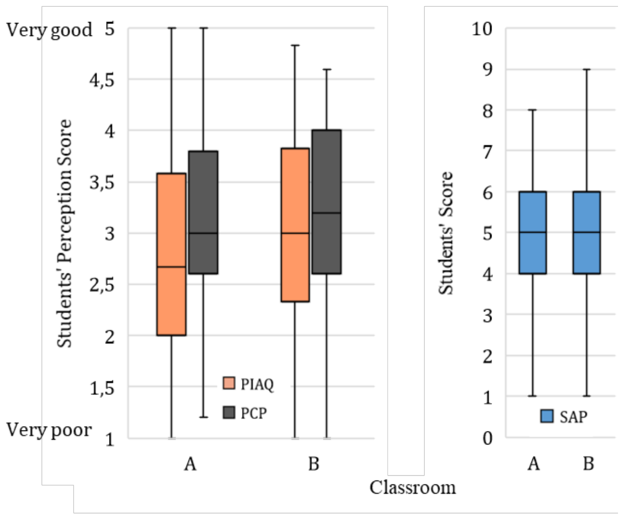

Figure 5. Students' mean perceived indoor air quality (PIAQ), perceived cognitive performance (PCP), and academic performance test (SAP) score in classroom A and B

Direct associations were analysed between the PIAQ and dependent variables PCP and PHC. Although the dependent variables PCP and PHC did not pass the Shapiro-Wilk test, a Q-Q plot of the PCP did not reveal large deviation from normality. However, the histogram of the PHC revealed a skewed distribution of data, indicating that this variable is not normally distributed, as presented in Figure 2.

To assess possible associations between the PIAQ, PCP, PHC, and SAP bivariate regression was conducted to examine how well the independent variable (*x*) could predict the level of the dependent variable (*y*). Table 4 presents the outcome of all analyses.

Table 4. Outcome of data analyses

x	y	β	R^2_{adj}	F-value	df1	df2
CO_2	PIAQ	-.157*	.019	4.060	1	160
PM2.5		-.255**	.059	11.170	1	160
TVOC		-.283**	.074	13.903	1	160
PIAQ	PCP	.163*	.021	4.377	1	160
PIAQ	PHC	-.366**1)				
PIAQ	SAP	.080	.006	.994	1	156
PCP	SAP	.269**	.067	12.185	1	156

x=independent variable; *y*=dependent variable; β= standardized coefficient beta; R^2_{adj}=squared regression coefficient; df=degrees of freedom; *=correlation is significant at the 0.05 level (1-tailed); **=correlation is significant at the 0.01 level (1-tailed); 1=Spearman's rho correlation coefficient

The multiple regression model of the IAQ KPI CO_2, PM2.5, and TVOC as independent factors and PIAQ as dependent variable was significant ($F(3,158)=7.409$, $p < .000$), with an R^2 of .12. However, in this model only PM2.5 and TVOC were significant predictors ($p < .05$) of PIAQ. Inclusion of the RH_i in this model contributed positively to the explained variance, with an R^2 of .18. In addition, it was found that PIAQ significantly predicted the PCP ($\beta = .16$, $p < .05$). Although no significant association was found between the PIAQ and the SAP score, it was found that the PCP significantly predicted the SAP score ($\beta = .27$, $p < .01$). Figure 6 presents the significant ($p < .05$) linear regression bivariate standardized coefficients.

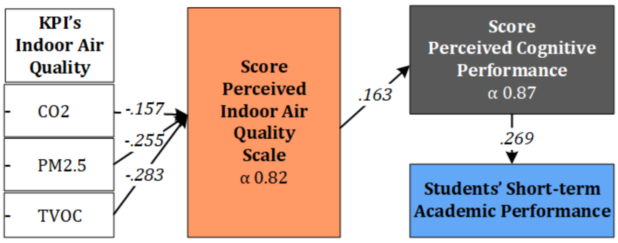

Figure 6. Significant (p < .05) linear regression bivariate standardized coefficients

DISCUSSION

During this field study, the IAQ of two identical classrooms, in which this study was conducted, was not manipulated, resulting in similar conditions in the two classrooms and limited variations of the IAQ and TE KPI in these classrooms. These limited variations may explain why the observed bivariate and multivariate standardized coefficients are relatively small.

GPOWER (Erdfelder, Faul, & Buchner, 1996) was used to determine the statistical power. The achieved power (1- β) for a bivariate normal model (one-tailed) is sufficient (> .80) to evaluate the assumed associations, given a relative small expected effect of 0.2, an α of .05, and a sample size of 163.

This study does reveal to a certain extend the associations between the actual indoor air conditions, students' perceptions and responses to these conditions and their short-term academic performance. The recorded CO_2 concentrations, even at the start of the lecture, were relatively high during all lectures and exceeded Dutch regulations for classrooms (RVO, 2015) and might explain the relatively small effect size of CO_2 on PIAQ. However, despite these small variations, all IAQ KPI were significantly associated with the PIAQ. No associations between the IAQ KPI and other perception scales and SAP were examined. These relations were not assumed because humans may react differently to the same IAQ due to personal differences, as addressed in the introduction part.

A significant association was observed between the PIAQ and the PHC, which addresses self-reported health issues that are related to the conditions in the classroom. Of these issues, the most reported issues were lethargy, dry eyes, and headaches. Research of Jaber Ahmed, Mumovic, & Ucci (2017) showed that reported symptoms of headache, dizziness, heaviness on head, confusion, difficulty thinking, difficulty concentrating and fatigue have a negative effect on the performance of students. This effect is also confirmed by Lee, Mui, Wong, Chan, Lee & Cheung (2012), thus emphasising the importance of ensuring a healthy IAQ to improve students actual and perceived short-term academic performance.

The reported CO_2 concentrations in this study should be considered as a proxy for air quality and ventilation adequacy. As mentioned before, high concentrations of CO_2 were observed, even at the beginning of the lecture. This impaired IAQ can be related to human bio-effluents, but also to material emissions, chemicals used indoors, as well as other indoor sources of pollutants. The elevated concentrations of bio-effluents, but not pure CO_2, and other constituents have a negative effect on students' cognitive performance (Zhang, Wargocki, Lian, & Thyregod, 2017). High CO_2 concentrations of 1800 ppm might affect cognitive performance with 24% (Jaber Ahmed et al., 2017). The limited variation and the on average high CO_2 concentrations observed during the study can explain the absence of an association between the PIAQ and SAP.

A significant association between the PCP and PIAQ was observed in this study. This association is also confirmed by previous studies (Mendell & Heath, 2005). Furthermore, the assumed association between the PCP and SAP was confirmed, highlighting the indirect relation between classrooms IAQ conditions and students' short-term academic performance.

CONCLUSIONS

This study confirmed associations between the IAQ and the PIAQ. Furthermore, this study revealed associations between the PIAQ and students' PCP and their physical health. An association between students' PCP and their short-term academic performance is confirmed. These associations emphasizes the importance of providing optimal IAQ conditions in classrooms for higher education.

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Table 3. Observations of the indoor air quality en thermal environment key performance indicators. See Table 2 and footnote to Table for the explanation of all variables and symbols used

		CO_2 [ppm]			$PM_{2.5}$ [μg/m³]			TVOC [mg/m³]			T_a [°C]			RH_i [%]		
CLR		C_s	C_a	C_t	C_s	C_a	C_t	C_s	C_a	C_t	C_s	C_a	C_t	C_s	C_a	C_t
A	Mean	1291	1775	1956	1.5	1.5	1.7	0.178	0.238	0.265	22.1	22.9	23.0	46	47	47
	SD	436	347	294	0.4	0.5	0.4	0.028	0.065	0.050	0.9	0.5	0.3	6	5	5
B	Mean	1037	1487	1662	1.7	1.8	1.8	0.164	0.290	0.277	21.7	22.5	22.9	46	47	47
	SD	209	244	276	0.6	0.4	0.6	0.043	0.129	0.106	0.7	0.3	0.3	7	7	7

CLR = classroom, SD = standard deviation, C_s = condition at the start of the lecture, C_a = average condition during lecture, C_t = condition at the moment students filled in the questionnaire and performed the test