Title

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Impact of Window vs Windowless Exam Rooms on Cognitive Performance:

A Field Study During a University Exam

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ABSTRACT: This study aims to measure the impact of having visual connections to nature through windows on the cognitive performance of university students, as assessed by their final exam scores. To build upon prior research conducted in controlled laboratory and climate chamber settings, which may have a gap between findings and real-world contexts, demonstrating the positive effects of window views on occupants, this study addressed the limitations of lab-based experiments by conducting a field test in university lecture rooms with 121 students enrolled in STEM classes, taking their actual final exam. In the field test, we randomly assigned the students to either of two conditions: one with windows and one without, while monitoring indoor environmental factors. The results revealed no significant difference in cognitive performance—whether measured by scores or cognitive efficiency gauged by the time taken to complete the exam—between students in conditions with and without window views. Given the known small effect size of having windows on cognitive performance and the relatively small number of data points, we recognized that further iterations of the field tests are required to accumulate a more substantial dataset and draw more robust conclusions.
KEYWORDS: Window, View, Cognitive performance, Learning, Field test

1. INTRODUCTION

Creating a visual connection to the natural world outside through windows may bring benefits to the occupants [1]. While consistent findings documented the positive effects of human-nature interaction on cognitive performance [2] and stress recovery [3], Ko et al. (2020) suggested that even providing a visual contact through windows could yield positive outcomes for occupants. The study from Ko, et al. (2020) utilized a randomized crossover study design while maintaining identical indoor environmental quality variables, including temperature, lighting, and air quality, known to significantly affect occupants, controlling the confounding variables. However, it was conducted within a climate chamber. Therefore, it would be valuable to investigate whether the positive effects of a visual connection to nature can be replicated in real-world scenarios. There are several limitations in lab studies, including the unrealistic way of assessing cognitive performance. Ko et al. (2020) utilized cognitive tests from Cambridge Brain Sciences to evaluate participants' cognitive performance. In simulated work and learning conditions, it is difficult to determine whether participants were sufficiently motivated to achieve their highest possible achievements and scores. Additionally, considering that the tests were designed by researchers for specific purpose, a potential gap may exist between these assessments and the actual working tasks. To address these concerns, we conducted a field test to assess the impact of providing window views on cognitive performance by analyzing the final exam scores of students enrolled in a large building science class.

2. METHODS

2.1 Experimental design

We conducted a field experiment within existing university lecture rooms, where students are usually engaged in their typical academic activities, including attending lectures and taking exams.

We used the students' exam scores as a metric for assessing their cognitive performance during the test, given their strong motivation to attain the highest possible scores, which differs from other cognitive tests designed in a laboratory setting where participants may not necessarily exert their maximum effort.

We set two distinct conditions: one with windows (WW) and one without windows (WoW). A total of 121 students were randomly assigned to four lecture rooms, with two rooms designated for each condition. WW1 and WW2 represented the WW rooms, while WoW1 and WoW2 represented WoW. Each room accommodated between 27 to 33 students.

The selected lecture rooms used in the field test were equipped with versatile movable wood panels affixed to the walls, allowing for the transformation of the lecture spaces into exhibition areas. For the WoW condition, these panels remained closed during the exam.

WW1 and WoW1 are located next to each other and they shared similar design contexts and spatial arrangements. WW1 covered an area of 99 m² for 34 students (equating to 2.9 m² per person), while WoW1 had 93 m² for 34 occupants (resulting in 2.7 m² per person). Similarly, WW2 and WoW2 were also located in immediate proximity to each other: WW2 had an area of 93 m² for 30 individuals (3.1 m² per person), and WoW2 spanned 101 m² for 30 occupants (3.3 m² per person).

2.2 Building design, physical and visual attributes of windows, and window view

The building's facade is equipped with an egg crate design, an external shading device featuring both overhangs and vertical fins, across all orientations except the North, ensuring that direct sunlight is blocked from entering the interior spaces year-round, minimizing the potential risks of glare.

For the physical attributes of the windows in both WW1 and WW2, each window had a rectangular design with a fixed width of 1.1 m. However, the windows had different heights depending on the row: 0.9 m for the bottom row, 1.1 m for the middle row, and 1 m for the top row. The window frames were made of metal. These single window units were positioned at fixed intervals of 0.3 m vertically, totalling three windows in height, and repeated horizontally at 0.4 m intervals, totalling six windows across. Consequently, the WW1 wall comprised a total of 18 single windows. The windows are of the operable awning type. During the field test, the windows remained closed. The calculated wall area measures 29.75 m², with a width of 8.5 m and a height of 3.5 m, with 20 m² dedicated to glazing, yielding a WWR of 67%. For their visual attributes, these windows were equipped with single-pane glazing and offered a VLT value of 0.8 when they are clean and new.

There was a difference in finishings between the WW1&WoW1 and WW2&WoW2 conditions. For WW1&WoW1, the horizontal intervals between these windows consisted of wood finishing with a white paint coating. The vertical intervals were constructed from concrete materials with a white paint finish.

For WW2&WoW2, the vertical intervals between these windows consisted of unfinished wood, exposing the material. The horizontal intervals were constructed from concrete materials without a finish. Regarding the window views, for WW1, observers primarily had visual contact with the greenery outside, including trees and grass. For WW2, occupants could have a visual connection with a building featuring a grey facade, which faces the building where the exam is being taken from a distance. At a closer range, the view content seen included land covered with grass.

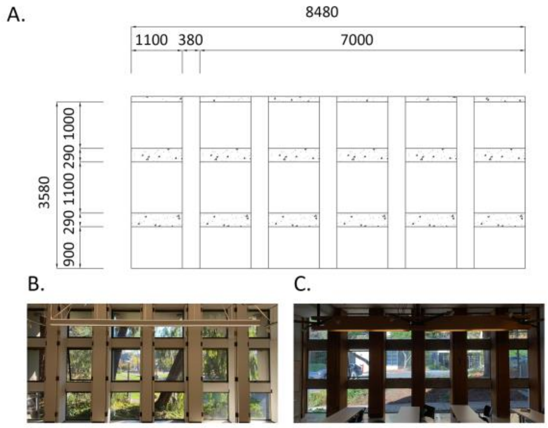

Figure 1. A. Section of walls and windows for both WW1 and WW2; B. The window view as seen in the room, With Window #1; C. The window view as seen in the room, With Window #2.

2.3 Environmental conditions: Pre-measurement

We monitored the temperature, relative humidity, and carbon dioxide concentration (CO_2), and light intensity by employing data loggers (Model MX1102, Onset HOBO, USA) and light meter (T-1H, KONICAMINOLTA, Japan and Ds-2000, Sylvania, Hungary). These measurements were taken due to the potential of these variables to act as confounding factors. In addition, in the middle of the semester, we conducted a continuous, week-long pre-measurement for temperature, relative humidity, and CO_2. The resulting median and Interquartile range (IQR) values for temperature, RH, and CO_2 are as follows:

WW1: 20 °C (IQR=1), 40% (IQR=9), 350 ppm (IQR=30)
WW2: 20 °C (IQR=2), 40% (IQR=6), 430 ppm (IQR=50)
WoW1:21 °C (IQR=1), 40% (IQR=8), 450 ppm (IQR=40)
WoW2:20 °C (IQR=1), 40% (IQR=7), 375 ppm (IQR=50)

We found that the indoor conditions were consistent and meeting guidelines. To measure light intensity, sensors were placed in five different locations within each room, and the mean values were calculated. The results indicated that for WW1 and WoW1, the recorded values were 800 lux and 900 lux, respectively, while for WW2 and WoW2, the values were 300 lux and 350 lux.

2.4 Final exam details

The final exam, having a total of 100 points, comprised a combination of 62 assigned points for conceptual questions, true/false and multiple-choice, and 37 points for calculation questions. 1 point was given to all for acknowledging the school's honor code. To ensure a comprehensive assessment that challenges both theoretical understanding and calculation skills, we meticulously structured our exam. It encompasses conceptual inquiries into several fundamental concepts of building science, including climate analysis, heat transfer, building energy, solar geometry, daylighting, indoor air quality, acoustics, and HVAC. For instance, we ask questions like: How bright is the brightest part of the overcast sky compared to the darkest part? These questions aim to evaluate students' understanding of well-established knowledge covered in the class and required readings, rather than requiring them to generate their own ideas. In the calculation questions, students are tasked with deriving specific values by correctly selecting and applying the appropriate formulas and input parameters.

2.5 Statistical analysis

We first conducted the Shapiro-Wilk normality test to assess whether the students' final exam scores followed a normal distribution [4]. Following this, we investigated the influence of two experimental conditions, WW and WoW, on students' cognitive performance during the exam using the Mann-Whitney U Test [5]. The Mann-Whitney test, a non-parametric method, was employed, eliminating the need for specific assumptions about normal distribution. Within this test, data from the WW and WoW groups were pooled, ranked in ascending order, and then the sum of ranks for each data point was calculated, resulting in having the U value. When comparing the U values between the two groups (WW and WoW), if one is significantly smaller or larger (two-sided) than the other, it indicates a meaningful difference in final exam scores between the groups.

We used the z-score method and t-test to assess whether there was a significant difference in individual students' relative grade positions before (pre-exam) and after (post-exam) the exam by the conditions. Our hypothesis was that having a visual connection to the outside through windows would increase cognitive performance. Consequently, we expected that students in WW would demonstrate an improved post-exam ranking compared to their pre-exam ranking, and vice versa. To test this, we computed z-scores for each student before and after the exam, calculating the difference between these two z-scores for each student. We then applied a t-test to analyze these difference values by the conditions.

To assess their pre-final exam performance, we aggregated the scores from six in-class quizzes. These quizzes were proctored by the instructor team, similar to the actual exam format and excluding any potential for collaborative work or cheating. The post-exam Z-score for each student was determined using their final exam score. We computed the effect size using Cohen's d, denoted as "r."

We assessed statistical power using GPower. For the effect size, we adopted a value of .2 based on prior literature (Ko et al., 2019), which suggested small effect sizes for cognitive performance—.31 for "Working memory" and .26 for "Concentration." Given that this is our initial field test, we intentionally chose a relatively small effect size. We established a significance level (alpha error probability) as .05, and the sample size for both groups was set at 60. Consequently, our calculated statistical power was .19. We used R as a statistical analysis software to run Mann-Whitney U Test, Shapiro-Wilk Test, standarized score, and t-test.

3. RESULTS

3.1 Environmental conditions

The field test took place on in mid-May, 2023 from 8:00 am to 11:00 am. We monitored several indoor environmental quality factors, including temperature, relative humidity, CO_2 levels, lighting, and acoustic conditions, to ensure similarity across four distinct rooms: WW1, WoW1, WW2, and WoW2. To gather this data, we used two sensors—MX1102 (Onset HOBO, USA) for temperature, relative humidty, and CO2 measurement and MX1104 (Onset HOBO, USA), for measuring temperature and relative humidity while also measuring light data. As a result, the temperature difference between WoW1 and WW1 was found to be $Median_{windowless-window\_1}$ = 1 °C, with an $IQR_{windowless-window\_1}$ of .5 °C. Similarly, WoW2 and WW2 showed a temperature difference of $M_{windowless-window\_2}$ = 1 °C, accompanied by an $IQR_{windowless-window\_1}$ of .7 °C.

For the lighting conditions at WW1 and WW2, we measured horizontal illuminance levels to assess the lighting condition of two spaces during the test. This was because there might be a potential dynamic influence of direct sunlight and diffuse light on the desk-level illuminance (target illuminance), affecting students taking exams when the movable panels remained open. To ensure consistent data collection, we positioned both sensors on stools at the same height as the desks where students took exams. In WW1, the light intensity increased by ~200 lux compared to the pre-measurement, rising from ~800 to ~1000 lux. Meanwhile, in WW2, the light intensity decreased by ~100 lux, dropping from ~300 to ~200 lux. We conducted two separate acoustic level measurements: the first at 8:30 and the second at 9:00. The resulting average acoustic levels for each room were as follows: 47 dB for WW1, 50 dB for WoW1, 49 dB for WW2, and 44 dB for WoW2.

Table 1: Environmental conditions during the field test

Condition	WW1	WoW1	WW2	WoW2
Temp °C	22 (0.5)	23 (0.3)	21 (1)	22 (1)
RH %	50 (2)	45 (3)	50 (2)	50 (1)
CO_2 ppm	480 (120)	580 (150)	490 (55)	410 (63)
Light lux	1,000	n/a	200	n/a
Acoustics	47 dB	50 dB	49 dB	44 dB

Figure 2. Field experimental conditions: two spaces with windows (left column) and two spaces without windows (right column)

3.2 Cognitive performance by overall, conceptual and calculation question scores

There were no significant differences in students' performance between the condition with and without view (*p-value*>.8, r < .1, a negligible effect). The same was found regardless of question types, whether they were conceptual, calculation, or the sum of the two.

Table 2: Exam score results based on question type and room type.

Type	Conceptual (62 points)	Calculation (37 points)	Overall (99 points)
Entire Class	Mean=43.8 SD=7.5	Median=30 IQR=9	Median=74.5 IQR=17.5
WW	Mean=44.1 SD=7.5	Median=30 IQR=9.5	Median=74.2 IQR=17.6
WoW	Mean=43.52 SD=7.5	Median=30 IQR=7	Median=75 IQR=20
Normally Distributed?	Y (*p-value* >.07)	N (*p-value* <.01)	N (*p-value* <.01)

Since the scores from conceptual questions followed a normal distribution, we employed a t-test. However, when comparing the scores representing the sum of conceptual questions between the two conditions, our analysis did not provide any significant evidence of a difference in means (*p-value* > .9, r < .1, a negligible effect).

Similarly, we did not find that scores obtained from calculation questions from students in the WW condition were higher than those of the students who took the exam in the WoW condition (*p-value*>.7, r<.1, a negligible effect).

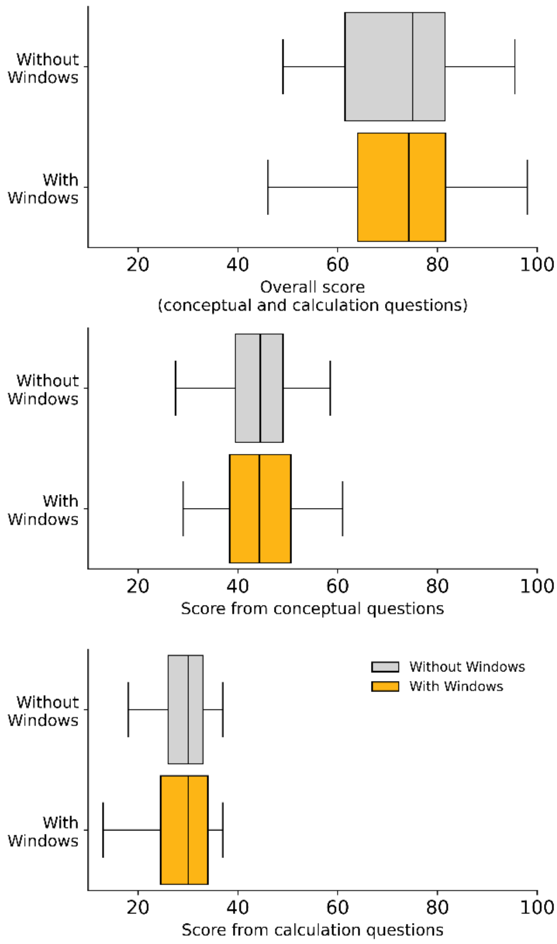

Figure 3. Comparing students' overall scores, their scores on conceptual and calculation questions, depending on the students took the exam in the rooms with or without windows.

3.3 Cognitive performance by pre-and post-exam performance

We observed that the difference between pre-exam and post-exam Z-scores followed a normal distribution, as tested by applying a Shapiro test with a significance level of .05 and a *p-value* of .388. Since students are randomly assigned to either WW or WoW and are independent of each other, we conducted a t-test, which revealed that there was no significant difference in the mean values of Z-score differences between the conditions (significance level = .05, *p-value* = .485, t = .700, effect size < .2, a negligible effect).

3.4 Cognitive efficiency measured by taken exam time

We analyzed the data in terms of cognitive efficiency. This analysis was based on the assumption that if the students who stayed in the WW condition finished their exam earlier, we could infer higher efficiency, as the outcomes were similar between the conditions. We excluded two students from the WoW1 condition as they arrived late for the exam. Therefore, 119 data points were used for the analysis. The exam time had median and IQR values of 111 min and 40.5 min, respectively, for the overall class. For the students in the WW condition, the time taken to finish the exam was 114.5 min and 42.5 min for the median and IQR, respectively. For the students in the WoW condition, the time taken to finish the exam was 106 min and 34 min for the median and IQR, respectively. Because the time taken for the exam was not normally distributed (significance level = .05, *p-value* < .01), we utilized the Mann-Whitney U test. There was no significant difference in the time taken for the exam between the conditions (U=1528.5, significance level=.05, *p-value*=.200, effect size=.23, indicating a small effect).

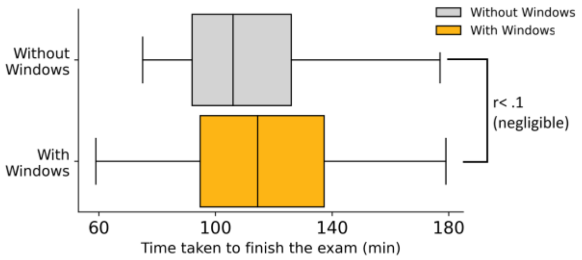

Figure 4. Comparing students' time taken to finish the exam, depending on the condition where students took the exam, the rooms with or without windows.

4. CONCLUSION

We investigated the impact of having a visual connection to the outside via windows on performance of students during their university final exams.

We plan to replicate this study over several years to accumulate a sufficient sample size. Based on our literature review, we expected a .25 effect size in people's enhanced exam performance when they have a visual connection to the outside. To achieve a statistical power of .8 with a significance level of .05, we need 265 data points for both the with window and windowless conditions, which may require up to four years of field experiments.

In this study, we could not find a significant difference in students' performance whether they had a window view out or not. At this stage, it is difficult to explain why our results were inconsistent with previous findings in controlled laboratory experiments. It is unclear whether this gap is due to an insufficient sample size or if the effects of having windows are not substantial enough to boost performance in the real-world contexts. Further research is needed to better understand these outcomes.

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