A short study on the effects of indoor and outdoor environments on user experience

Assignment 2
Smart Healthy Urban Environments (7ZW5M0)

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Introduction

In this report two topics will be investigated: the environmental effects on a studying experience, and the environmental effects on walkability. The app and program of Senses versus Sensors (SvS) has been made available for the study, and will be used to collect data. It does this on four environmental factors: temperature (-25/100^{o}C), relative humidity (1/99%), Illuminance (1/65000 lux), and sound pressure (38/120 dBA). This data will be gathered in two tests of one hour: one indoor (for study spaces), and one outdoor (for walkability). The device iterates every minute, so a total of 120 data rows are collected.

The selected factors have a significant influence on the performance whilst studying, making the right environment a critical element to successful studying. This study will look into the characteristics in four TU/e buildings: Vertigo, Atlas, Metaform, and Neuron, to discover which has the most optimal conditions. Some elements of studying influenced by the environment include: accuracy and response time, which suffer from uncomfortable temperatures (Li et al., 2022), humidity affects information retention and attention spans (Liu et al., 2020), proper (natural) light is required for alertness (Recalde & Palau, 2020), and sound effects are known to reduce the abilities for logical reasoning (Braat-Eggen, Reinten, Hornikx, & Kohlrausch, 2021).

There are also effects of the selected metrics on walkability and comfort. These include fatigue and discomfort at high- and safety risks at lower temperatures (Dong et al., 2022), sweating at high- and dry skin at low humidity (Kim & Brown, 2022), an (un)safe feeling in darkness (Buratti, Bisegna, & Santoli, 2024), and stress as a result of noise (Tatsumi, Tanaka, Watanabe, & Toda, 2000). The conditions in different parts of the city can be vastly different. The walk depicted in figure 1 crosses through the Centrum of Eindhoven, residential neighbourhoods, along major roads and through a park, all with the goal of collecting as much different data as possible, and painting a complete picture of the walkability situation in Eindhoven.

Figure 1: QGIS map of the walked route

What is Citizen Science?

Golumbic (2024) states that: “Citizen science is a rapidly growing field, defined as the active engagement of non-scientists in scientific research and inquiry”. This collaboration with non-scientists allows for a democratisation of science, which can be crucial in a world where technology has such a significant impact on people’s lives. Public engagement is at the basis of citizen science, with a twofold benefit: it generates more support from a population, and it increases the quality of the process and product. The broader scope and wider reach that is created by the collaboration with many others, allows for a better definition of the challenges ahead and a more extensive pool of concept solutions (Golumbic, 2024).

Where and how the non-scientists can best collaborate with the field experts is open for debate, but a structure has been set up by Haklay (2021). He has created four levels of engagement to define the type of citizen science collaboration. The first one is crowdsourcing. Here the citizens act as ‘sensors’, meaning that they help collect data, but they are not involved with what happens after the first step. This method can be great for gathering loads of raw data, but it does not take the full benefit from so many minds at a researcher's disposal, and it does not give the participants the feeling of meaningful involvement, lessening the public support benefits. The second category is distributed intelligence. This step still has the participants only collect data, but here the data that is collected requires an extra mental step. The participants are able to perform very simple tasks, but without more involvement the benefits are still limited.

From the third step is where citizen science flourishes: participatory science. The knowledge of citizens is used for both the collection of data as well as for the definition of the problem. Here the participants start to add a dimension of knowledge to the project that the scientists otherwise maybe would have missed out on. The greater involvement also means that from this point onwards, social benefits emerge from the collaboration: citizens start to like the project. The fourth step is the most active form of citizen science: extreme citizen science. Here the participants do not stop after collecting data and defining problems, but they also actively participate in data analysis. They are equal partners who are involved in all stages of the process. This category is also where controversies emerge, as some believe that non-scientists are not able to conduct all these tasks as well as the field experts. This last step requires a lot of diligent collaboration, but it may yield the greatest benefits (Hakley et al., 2021).

Setting up your own citizen science project

Our daily lives and experiences reflect the urban planned environment we inhabit. On a personal level, as students in Eindhoven, we experience the city through two central nodes: the Eindhoven University of Technology and the city-centre of Eindhoven. These spaces are critical in shaping our lives in a city known for its innovation and technology-forward mindset. These nodes play pivotal roles for the population of Eindhoven, allowing us to explore how environmental factors can influence a space's comfort, functionality, and livability. Environmental factors shape the physical environment and affect human perceptions and daily experiences. Studies have explored the intersection of planning efforts and environmental factors (e.g., temperature, humidity, light, and sound levels) directly impacting individuals' well-being.

This citizen science project aims to analyze environmental factors in Eindhoven's two central nodes. The data was collected during two one-hour time blocks, one indoors at Eindhoven University of Technology and the other outdoors in the Centrum of Eindhoven. The results will be compared to studies highlighting the optimal conditions for such space interaction in studying and walking to understand if Eindhoven meets peak space performance capabilities standards.

Temperature, Humidity, Light, and Sound Conditions

Temperature, humidity, light, and sound are critical factors that can impact one's studying or walking experiences, comfort, and overall well-being and are important when planning the lived environments. While the factor levels have different effects on the experiences, combined, they contribute to creating conditions for living quality.

Temperature. Multiple studies have found that temperature conditions can negatively affect one's experience. For students studying indoors, Yanxue Li and colleagues found in the case of college students that uncomfortable temperatures can negatively affect accuracy and response times (Li et al., 2022). Thus it shows how temperatures can directly affect a student's physiological and cognitive performance. Studies have shown that the optimal temperature range for studying is 22–25°C. In outdoor settings, uncomfortable temperatures can cause fatigue, discomfort, and even safety risks in extreme conditions (Dong et al., 2022). Studies suggest that optimal outdoor temperatures are between 15–25°C for walks. These numbers set a baseline for comparison.

Humidity. Humidity levels can have both physical and psychological effects. For indoor studying indoors, humidity can play a critical role in information retention and attention spans (Liu et al., 2020). According to this research, the optimal humidity conditions for indoor learning performance are 30–50%. Not surprisingly, extreme humidity levels can cause physical discomfort (Kim & Brown, 2022). This can include sweating in high-humidity environments or dry skin in low-humidity conditions. Humidity levels at both ends of the spectrum can make walking uncomfortable and diminish the overall outdoor experience. The World Health Organization (WHO) has emphasized that walking can create health benefits; therefore, improving an individual's outdoor experience produces tangible benefits (WHO, 2017). The optimal humidity levels for walking lie between 30–50%.

Light. Light levels can significantly affect one's mental state and satisfaction. Studies have shown that natural light is critical for cognitive alertness and efficiency (Recalde & Palau, 2020). From first-hand experience, natural light has notable health benefits and stimulates peak performance. Optimal illuminance levels for studying environments are between 300 and 1000 lux. When walking, natural light also enhances one's mental alertness. Furthermore, studies have further shown that lighting conditions are critically connected to one's perception of safety and comfort. In contrast, walking in the dark produces negative perceptions of safety (Buratti, Bisegna, & Santoli, 2024). Thus, minimum proper illumination levels are between 30–50 lux. In short, adequate lighting is vital to human effectiveness while positively influencing our emotional state indoors and out.

Sound. Sound levels and quality significantly influence indoor and outdoor comfort levels. Studies have shown that loud or distracting sounds can reduce logical capabilities when studying (Braat-Eggen, Reinten, Hornikx, & Kohlrausch, 2021). Excessive noise in study spaces reduces one's ability to focus and affects academic performance. This means that minimal noise levels are ideal in indoor study environments. Likewise, when walking, excessive or unpleasant noise can create stress, increase discomfort, and thus negatively affect the walking experience (Tatsumi, Tanaka, Watanabe, & Toda, 2000). The optimal environment for walking is characterized by minimal noise.

Sustainable Development Goals

Citizen science projects are closely tied to the United Nations Sustainable Development Goals (SDGs), as they contributed significantly to the advancement of many SDGs (Fraisl et al., 2020). To underscore this further, consider SDG 17: *Partnerships for the Goals*. The SDG highlights the benefits of community engagement and collaboration between individuals and researchers, and in doing so bridges the gap between society and science to benefit sustainable environments. In analyzing how temperature, humidity, light, and sound affect studying and walking experiences, the project contributes to several SDGs by seeking to understand and improve living conditions and sustainability. As stated by the WHO, "health-focused urban design" promotes "making cities a bedrock for healthy lifestyles – as well as climate-friendly and resilient" (WHO, 2024). This project supports SDG’s 3, 4, 9, 10, 11, and 13:

- SDG 3, *Good Health and Well-being*, is focused on the interaction between environmental conditions and healthy living (The Global Goals, 2024). Optimizing conditions can improve cognitive abilities, stress levels, and comfort, thus improving well-being. Studies have shown already how optimal temperature and humidity levels contribute to meeting SDG 3 (Niza, Bueno, & Brody, 2023).
- SDG 4, *Quality Education*, relates to ensuring inclusive and quality education, thus promoting education for all (The Global Goals, 2024). It explicitly relates to indoor environments, as data has shown how environmental conditions can affect academic performance and, therefore, the quality of education. Hence, this study advances SDG 4 by studying how optimal temperature, humidity, lighting, and sound conditions can enhance the quality of education, thus directly connecting to SDG 4 (Niza et al., 2023).
- SDG 9, *Industry, Innovation, and Infrastructure/Sustainable Infrastructure*, seeks to promote resilient and sustainable infrastructure and innovation (The Global Goals, 2024). Because the project looks at optimizing environmental conditions relating to urban spaces, creation of innovation, and sustainable infrastructure thus promoting better infrastructure and through that a living environment.
- SDG 10, *Reduced Inequalities*, focuses on reducing inequalities within and among countries (The Global Goals, 2024). Niza et al. explains that improving environmental conditions within urban environments can lead to "mitigate inequalities" (Niza et al., 2023). Thus, by the project goals to improve environmental conditions, it is able to reduce inequalities.
- SDG 11, *Sustainable Cities and Communities*, promotes living areas that are inclusive, safe, resilient, and sustainable (The Global Goals, 2024). This project directly addresses this goal by analyzing environmental factors in the Eindhoven central node. Improved environments for studying and walking make the city healthier, safer, and more livable (Montiel, Mayoral, Pedreño, & Maiques, 2020). Thus, ensuring optional conditions are met improves "the quality of life for residents" and the city's sustainability (King, 2022).
- SDG 13, *Climate Action*, concerns the urgent need for action to address climate change. This project emphasizes the benefits of improving environmental conditions and how to do so through the indoor and urban planned infrastructure. Its goal is to improve life and create a climate friendly environment to help climate change mitigation efforts (Montiel et al., 2020).

In considering these UN SDGs, it is worth noting that the Netherlands occupies a privileged place in the global community. The country is highly developed and deploys an array of innovations and resources to address climate change and sustainable development. To truly address the intent behind the UN SDGs, this small-scale citizen project should investigate conditions far beyond Eindhoven and the Netherlands.

Impact of Citizen’s Engagement

Citizen science projects can critically impact the scientific community and innovation through the project's emphasis on participation. As a whole, Citizen science aims to use the gathered data and insights to identify problems and spark innovation; thus creating diverse information collection and community-driven decision-making. This citizen science project aims to collect data on the environmental factors of temperature, humidity, light, and sound and analyze their influence on the indoor and urban environment. In doing so, we hope to raise awareness of how such factors influence students' lived experiences in two of Eindhoven's central nodes. Through the use of gathered data and insights, we hope to address identified problems and create change. While there is no citizen engagement for determining the current state for this short-term project, this could easily be corrected in future iterations. When considering the level of citizen engagement, it is important to remember Haklay's four levels of engagement (Haklay et. al., 2021):

1) Crowdsourcing: Citizens as sensors.
2) Distributed Intelligence: Citizens as basic interpreters.
3) Participatory Science: Citizen participation in problem definition and data collection.
4) Extreme Citizen Science: Citizen involvement in fully collaborative science—problem definition, data collection, and analysis.

If one were to repeat and extend this project, involvement would ideally occur at Level 3 (Participatory Science) where citizens would be actively involved in problem definition. More importantly, as researchers, it would enable us to distribute the SVS device to many students and allow for more comprehensive data collection on student nodes in Eindhoven. This would permit us to collect more data and gain a more thorough understanding of the environmental conditions that students experience throughout their daily lives. Whilst performing the project at Level 4 might be possible, it would require more structured citizen participation and collaboration. This might not be possible given that we are dealing with students who have busy lifestyles and may have limited long-term interest in improving the Eindhoven environment.

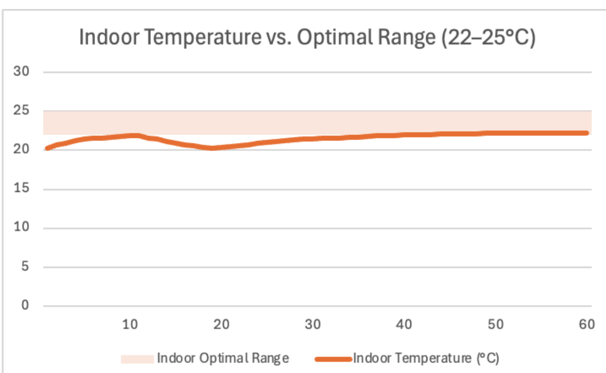
When considering citizen engagement, it is essential to consider how this community participation will occur. There are many ways this can happen. First, it can occur organically; think of protests and citizen movements worldwide. When a concern is heightened, activists and locals often act to drive change. Less dramatically, citizens can be engaged through focus groups and workshops. These would allow citizens to share their grievances about environmental challenges while permitting researchers to educate community members. This could lead to a better definition of the problem to be addressed. It would also permit the distribution of SVS devices to enable these individuals to conduct their own walking tours and collect data. Leveraging digital platforms for easy collaboration and open feedback gathering would also be key. Finally, and probably most applicable to our student demographic group, is the strategic use of incentives. Incentives often increase participation and motivate active engagement. However it is accomplished, engaging our citizens in the study creation would enable a more substantial societal impact and innovation potential.

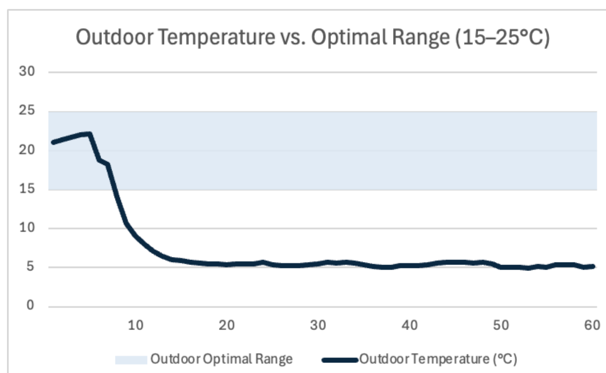
Data Collection and Analysis

The study analyzes environmental factors at Eindhoven's two central nodes. This was accomplished using collected data with SVS devices during two one-hour time blocks, one in study spaces inside university buildings and the other outdoors in Eindhoven’s Centrum. During both observations, there were active walking modes to collect data on an array of settings within each node. Specifically, in the university's buildings, we used increments of ten minutes to go from one study space to another. Then we spent time understanding the environmental factors in each study space. Specifically, we proceeded through the Vertigo, Atlas, Metaform, and Neuron study spaces. This is in comparison to the collection of outdoor data, when we were constantly walking. To capture the data, the devices were either held or placed on a table. The indoor data was captured on December 6th, 2024, between 10:47 and 11:47, and the outdoor data was captured on December 4th, 2024, between 16:25 and 17:25. This resulted in 60 rows of data collected for each time block. Thus, the study aimed to capture a holistic measurement of the two node environments through the constant changing of the environments.

Temperature Measurements

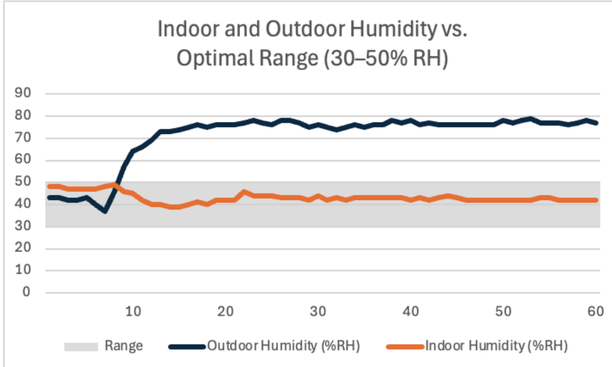
The temperature observation revealed distinct patterns that, at times, reflected the optimal conditions. For indoor study environments, the optimal range is between 22–25°C. The data shows that temperature across Vertigo, Atlas, Metaform, and Neuron averaged 22°C, within the optimal range. Note that the variations in the data at minute 20 can be attributed to the movement through the Eindhoven bridges from one space to another. The stability of temperature conditions corresponds to the ideal learning environments for academic performance. Looking at the outdoor temperature, the recorded average is seven °C; however, setting aside minutes 0 to 10, the average drops to 5°C. The higher temperatures during the first 10 minutes are attributed to initial measurements in a building and in tunnels, as well as the room temperature of the measurement device itself. While the temperatures are well beyond the optimal walkability range, this was not unexpected given the data was collected in late fall. The overall temperature is stable in both environments.





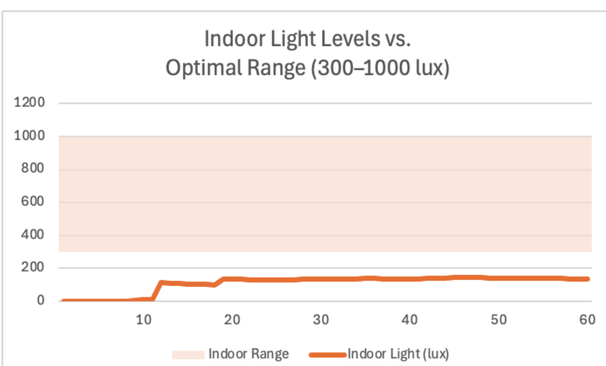
Humidity Measurements

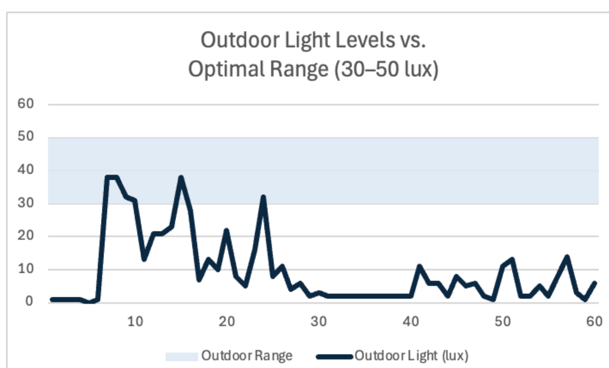
The humidity measurements, specifically for indoor studying settings, reflect the supported standards for peak performance and comfort. As noted above, the optimal humidity range for studying and walking is between 30 and 50% RH. For the indoor environment, the average measured humidity was 43%, which is within the optimal range. All of the measurements taken for the study spaces fell within this range. The stable conditions on campus reflect the prioritization of academic performance and physical comfort. The average outdoor humidity is 70%, and, when the first 10 minutes are excluded, 77%. This data was collected shortly after a rainfall, thus accounting for the relatively high humidity levels at low temperature levels. While the indoor environment did show stable and optimal humidity levels, the outdoor levels exceeded comfort standards and, thus, presumably negatively affected the usability of the space.



Light Measurements

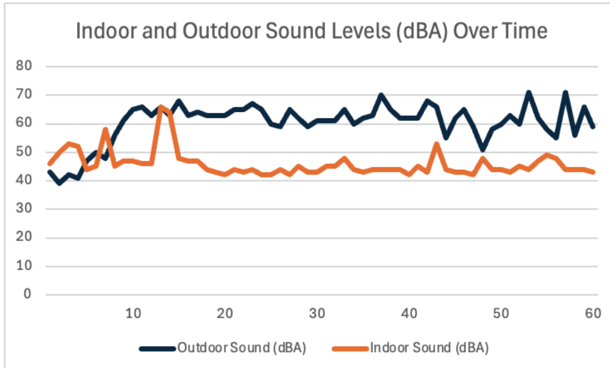
The light measurements contrast sharply between indoor and outdoor environments. While indoor light levels were higher than those outdoors, they were far from optimal. The average light level was 108 lux, and even if one excludes the first 10 minutes spent walking from Vertigo to Atlas, it only reached 129 lux. Thus, Eindhoven's study spaces do not meet cognitive alertness and efficiency standards. It is worth noting that on the day data was collected (December 6th), it was raining outside, thus reducing the natural sunlight in the building. Furthermore, we are unsure if the sensor has been blocked from measuring the actual ambient brightness. Despite careful attention to use the sensor as intended, the low overall indoor measurements seem too low. Indoor lighting levels were steady overall, reflecting the university's control of the indoor environmental conditions. In contrast, outdoor levels were more fluctuating. Even if some points fell within the optimal range, the overall average of 9 lux does not. Again, data was collected late on a rainy late afternoon toward the end of fall, contributing to less natural light. The significant fluctuations in outdoor light levels reflect the considerable differences in the urban environment between a mall, tunnels, shopping streets, and plazas. Regardless, conditions in both settings show that there was not sufficient lighting for the activities in a student's daily life.





Sound Measurements

The measurements during the study revealed similar variations across indoor and outdoor environments. Keep in mind that the ideal noise levels were minimal. Thus, there is no optimal range. For indoor settings, the average noise level was 45 dBA. Note that observations were taken in study areas. Attributes such as human movement and conversations were present, thus disturbing and creating variations in sound levels. Looking at the data, peak noise occurred between Atlas and Metaform. The average outdoor noise level was 60 dBA. Road traffic in Eindhoven was busy, thus creating higher noise levels, given the degree of public activity. Both environments had high noise levels and warrant mitigation strategies, especially in university study spaces.



Conclusions

When comparing the optimal conditions for the two studies, the main differences are found in the temperature requirement (walking can be colder) and lighting (walking requires less light). The optimal humidity and noise levels are the same for both experiments. In the indoor environment the conditions were more fitting to studying, than the outdoor environment was for walking.

The study conditions found in the four selected buildings on the TU/e campus compared similarly to the optimum conditions stated by literature: The temperature was stable, although on the lower side of the recommendation, the humidity was stable and fitting, the amount of light was too low everywhere, and the noise levels were fluctuating. Even though Neuron had the highest noise levels (excluding the first 10 minutes because this was spent walking), and Atlas scored worst on the amount of light, the buildings all performed similar enough to the point where no clear conclusion can be drawn on which building is best to study in. This has to do with the centrally controlled environmental conditions, which hold over the whole campus. Furthermore, we recommend repeating the light measurements to ensure the reliability of the sensor.

When evaluating the outside conditions, it becomes clear that the recorded day was not ideal for walking: it was too cold, too dark, and the fact that it had just rained also made humidity conditions too high. The most meaningful data here concerned the noise levels, which peaked at about 73 dBA: about the noise of a vacuum cleaner. The noise peaks were spread relatively evenly over the walk but were more frequent near the end, when the walk passed by the train tracks. The train tracks running through Eindhoven create sound pollution reducing the environmental quality and walkability.

This citizen science project could be scaled up by iterating this process on level three: participatory science. The participants, students at TU/e, would be able to help define the problems (challenges they face whilst walking or studying), and collect data (by using the sensors in their daily routines). A level four project would require much more coordination and effort, something that would likely not yield significant additional benefits.

Notes on Process of Data Collection

Outside influences contributed to data variations during the data collection. No technical problems were encountered with the SVS device and data recording, however the low readings of the light sensor during the interior measurement made us question the measurements. However, potential limitations in the collection approach resulted from the constant shifting of environmental conditions due to the movement through the two nodes. These variations would have likely been reduced if measurements were taken over time. Several factors contributed to these variations, including level of human activity, weather, time of day/year, etc.. While these variables create variations, they also reflect real-life conditions. Other limitations include the limited scope of the data collection effort, given that it occurred only during two one-hour sessions. More data collection periods would provide a richer understanding of the environmental factors influencing students' experiences in Eindhoven. These might include peak vs. non-peak times, weekdays vs. weekends, and rain vs. sun. Moreover, having study points where no movement happened, i.e., at Vertigo or Metaform only, would capture a more well-rounded condition of the single environment. Likewise, the SVS device had to be held when moving, producing additional variations. Several enhancements could be made to the study. These include capturing data over extended periods, using additional sensors to capture more data on environmental conditions, or capturing visual or geospatial data on the environment itself. Thus, while the project provides valuable insights into the conduct of citizen science projects, a more rigorous approach would leverage community engagement to create a more robust and representative dataset to analyze conditions and generate recommendations to enhance livability and sustainability objectives

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