

# A BREATH OF FRESH AIR: TOWARDS OPTIMAL INDOOR AIR QUALITY

## INVESTIGATING INTERVENTION STRATEGIES FOR ENHANCING OCCUPANTS AWARENESS, COMFORT AND HEALTH

SUBMITTED IN PARTIAL FULFILLMENT FOR THE DEGREE OF MASTER OF SCIENCE

DANNY DE VRIES  
14495643

MASTER INFORMATION STUDIES  
INFORMATION SYSTEMS  
FACULTY OF SCIENCE  
UNIVERSITY OF AMSTERDAM

SUBMITTED ON 30.06.2024



	<b>UvA Supervisor</b>
<b>Title, Name</b>	Dr. H. (Hamed) Seied Alavi PhD
<b>Affiliation</b>	University of Amsterdam
<b>Email</b>	<a href="mailto:h.alavi@uva.nl">h.alavi@uva.nl</a>



## ABSTRACT

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Fusce ac massa nec lorem porta tincidunt id non enim. Aliquam lobortis lacinia ultricies. Etiam arcu urna, auctor non convallis aliquam, blandit et nibh. Donec dignissim, enim vitae fringilla finibus, mauris enim bibendum eros, et mollis ipsum nulla a nunc. Vestibulum blandit ornare neque, nec porttitor lorem sodales id. Pellentesque scelerisque sem dui, vitae mattis nulla fringilla sit amet. Fusce tristique turpis id libero condimentum, sed malesuada nulla dapibus. Sed suscipit varius est non molestie. In pretium maximus tortor ac molestie. Duis lectus nibh, auctor at condimentum eu, ultrices sit amet risus. Cras in vulputate tellus, id vulputate dui. Vestibulum rhoncus odio in tincidunt pretium. Aenean finibus sapien non leo condimentum venenatis. Nulla tincidunt nulla sollicitudin elit porta, laoreet imperdiet metus fermentum. Suspendisse consequat in ipsum nec efficitur.

## KEYWORDS

Human-Building interaction, Indoor air quality, Living Lab, Data physicalization, Smart buildings, User-centered design.

## 1 INTRODUCTION

Globally, it is estimated that people spend approximately 90% of their time indoors [18, 28] and breath 11.000 liters of air per day [8]. Suboptimal indoor air quality (IAQ) conditions affect building occupants' experiences of comfort and insufficient ventilation in indoor spaces is proven to play significant roles in occupants' well-being, health and cognitive functions [16, 33].

The research into the influence of Indoor Environmental Quality (IEQ) [19] on occupants', including acoustic, thermal and visual conditions, is gaining more attention especially the field of indoor ventilation. One core aspect of air quality is its invisibility to occupants [29], polluted air is not easily detected by smell or sight. Additionally, mechanical ventilation systems in buildings operate discreetly, contributing to occupants' perceived lack of control since these systems are typically automated and cannot be directly regulated or controlled by occupants themselves. This creates an interplay between occupants' effects on health and comfort, architecture and built environments, and computing technologies (see Figure 1).

This thesis focuses on understanding occupants' needs through in-the-wild studies measuring indoor air quality in specific spaces (e.g. meeting rooms) and arprototyping various persuasive technologies and data physicalization devices to visualize indoor air quality and evaluating their effectiveness with the overall goal of gathering insights into occupants' comfort levels and helping them to take preventive action against poor indoor air quality.

Researching occupants' subjective needs, experiences, and behavior, coupled with a human-centric design approach, has the potential to improve occupants' well-being and create indoor environments with good indoor air quality. Furthermore, it provides valuable insights to faculty staff in making decisions in setting up ventilation systems, arranging indoor spaces, and informing architecture and interior design studios on making decisions about

structuring spaces and integrating computing technologies within built environments.

While research on defining comfort within indoor buildings, gathering and analyzing sensory indoor climate data, and the effects of poor air quality are prevalent, there is a gap in understanding occupants' behavior and their subjective needs, along with limited research on how design solutions visualize environmental data and computing installations can empower occupants, particularly within the field of physically visualizing data to convey IAQ to building occupants in real-time.

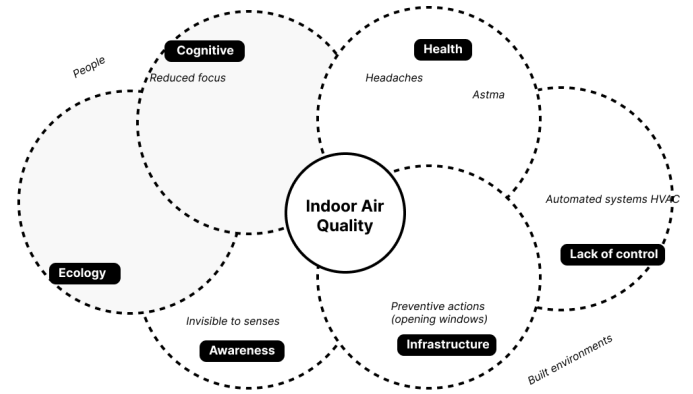


Figure 1: Complexity diagram providing an overview of the effects of IAQ and needs of occupants [16, 28, 33]

### 1.1 Research questions

In order to research intervention strategies for improving indoor air quality, the following main research question is formulated:

**RQ:** *How can real-time sensory measurements and future predictions of air quality be physically visualised in specific indoor spaces integrating both environmental information and elements that increase awareness among occupants facilitating their adoption of preventive measures against poor air quality?*

To effectively answer this main research question, this research is guided by the following supporting sub-questions that also serve as objectives to delineate the necessary knowledge:

- **SRQ1:** *How can environmental information related to air quality, such as pollutant concentrations and ventilation rates, be incorporated into the visual representations?*
- **SRQ2:** *How do different types of physical visualizations impact occupants' understanding of air quality and their willingness to adopt preventive measures?*
- **SRQ3:** *How do occupants' perceptions and behaviors regarding indoor air quality change over time, from pre to post-installation of the physical representation of poor air quality?*

## 2 RELATED WORK

This section provides an overview of studies conducted on the involvement of Human-Computer Interaction (HCI) in studying Built Environments. It begins by introducing the overarching concept of Human-Building Interaction (HBI) and subsequently narrows its focus to Indoor Air Quality (IAQ) and Post-occupancy Evaluation (POE) for the scope of this research. Finally, it presents key findings from previous approaches to mapping and encoding sensory data in a new area of research called Data Physicalization.

### 2.1 Human-Building Interaction

Buildings increasingly incorporate new forms of digital interaction [21, 23], which means new inherent connections between 'people', 'built environments', and 'computing' research in an area called Human-Building Interaction (HBI) [1, 31]. This research area is dedicated to exploring the design of built environments that may incorporate computing to varying degrees [30]. A logical extension where indoor spaces are increasingly refitted with sensing devices [ ]. Understanding how people use different spaces in a building through computing can inform design interventions aimed at improving the utility of the space and well-being of occupants. [32].

Current research into architecture and built environments indicate that a significant portion of the data collected by these computing devices are not necessarily transparent or comprehensible to occupants [27], and indoor spaces are designed without much thought of placing of computing devices integrated within the environment [15, 17] leaving users with a perceived lack of control over their indoor comfort.

### 2.2 Comfort within buildings

Comfort is achieved in interaction with the environment and is represented in four respective dimensions; thermal, respiratory, visual, and acoustic [2]. Indoor Environmental Quality (IEQ) [19] indexes serve as metrics for assessing the aforementioned properties of comfort with Post-Occupancy Evaluation (POE) [10] being employed to gauge occupants' perceived comfort [7].

Previous studies focussed mostly on the static IEQ conditions based on the buildings' physical characteristics, on which various recommended standards have emerged such as ASHREA 62.1, ISO 16814 and LEED v5 but recently studies are more focussed on the active role occupants play within the built environment and their behavior considering the activity within the building as a 'living ecology' itself [20].

IK VIND DEZE NOG NIET COMPLEET, HIER MAG NOG WEL ERGENS EEN ALINIEA BIJ. MAAR OOK SHORTCOMINGS WATER NU ZIJN WAT IK OOK BIJ DE ANDERE SECTIES DOE. MISSCHIEN IEQ UITBREIDEN (WAT HET IS etc.) EN MISSCHIEN POE UITBREIDEN

### 2.3 Indoor Air Quality

A suboptimal indoor environment has reportedly been associated with health-related problems such as headaches, asthma and feeling dizzy [18] as well as a decrease in cognitive functions such as tiredness, decreased productivity and a lack of focus [33] [9]. A phenomenon often referred to as the Sick Building Syndrome (SBS) [12, 22]. Most of these symptoms are predominantly associated

with respiratory comfort and thus the Indoor Air Quality (IAQ) [16].

Indications of poor air quality are gathered by measuring using sensors to measure common pollutants with a focus on molds and allergens (humidity), volatile organic compounds (VOC) and carbon dioxide (CO<sub>2</sub>) where occupant behaviour and the number of occupants within indoor space have a specific negative effect on CO<sub>2</sub> levels [11]. These indoor climate factors are related to the building occupants' behaviors and need special attention to be considered in assessing the IEQ conditions and determining if adequate ventilation is present [9]. When occupants experience symptoms this means that a suboptimal air quality situation has already occurred.

The existing literature on indoor air quality provides quantifiable and tested methods to measure indoor air quality using sensory data, stresses the complications associated with IAQ and the importance of creating solutions to providing adequate ventilation to occupants.

### 2.4 Data Physicalization

The research domain known as data physicalization [3] has emerged as a notable area of study, emphasizing the creation of physical data visualizations making the invisible tangible and interactable by encoding data in physical artifacts [24]. This shift from focusing on individual artifacts to a broader environmental context facilitates the physical embodiment of computing. Data physicalization has the potential to positively influence the perception and exploration of data [14], presenting distinct advantages over traditional 'screen-focused' data representations, such as 2D canvas displays (dashboards). [13] especially with the focus on IAQ where a 'physical data visualization' is a fitting metaphor for visualizing 'invisible indoor air'.

These tangible artefacts usually come in the form of a ubiquitous computing (ubiquitous computing) [6] device that seamlessly blends into the environment, essentially making the computing devices 'disappear' [34]. These devices are frequently employed as persuasive technology, strategically designed to gently nudge individuals towards behavior change leveraging the emerging notion of pervasive sensing to subtly enhance users' awareness regarding the impacts of their decisions [4, 25]. This method of persuasive design serves as a powerful tool in calmly extending users' awareness, helping users understand gathered data, the consequences of their actions, and gaining insight into their behavior [5]. Numerous approaches to study computing devices within indoor spaces and interactivity with occupants have been explored in prior research [26] to nudge occupants to a desired behaviour but limited design solutions have been developed and explored to focus specifically on IAQ awareness.

This framework of data physicalization and persuasive technology establishes the theoretical foundation for the creation (prototyping) and the evaluation (usability testing) of the design solution within this research.

## 3 METHODOLOGY

Write about your methodology here. Focus on your own contribution. Indicate exactly how you will assess your work in terms of evaluation.



The goal of the prototype is to recognize the role of humans as active users of a indoor environment and helping them prevent these situations before they occur with minimal interruption cost.

## 4 RESULTS

Write about your results here. Good captions to tables and/or figures are key.

## 5 DISCUSSION

Write your discussion here. Do not forget to use sub-sections. Normally, the discussion starts with comparing your results to other studies as precisely as possible. The limitations should be reflected upon in terms such as reproducibility, scalability, generalizability, reliability and validity. It is also important to mention ethical concerns.

## 6 CONCLUSION

Write your conclusion here. Be sure that the relation between the research gap and your contribution is clear. Be honest about how limitations in the study qualify the answer on the research question.

## REFERENCES

- [1] Hamed S. Alavi, Elizabeth F. Churchill, Mikael Wiberg, Denis Lalanne, Peter Dalsgaard, Ava Fatah gen Schieck, and Yvonne Rogers. 2019. Introduction to Human-Building Interaction (HBI): Interfacing HCI with Architecture and Urban Design. *ACM Transactions on Computer-Human Interaction* 26, 2 (March 2019), 6:1–6:10. <https://doi.org/10.1145/3309714>
- [2] Hamed S. Alavi, Himanshu Verma, Michael Papinutto, and Denis Lalanne. 2017. Comfort: A Coordinate of User Experience in Interactive Built Environments. In *Human-Computer Interaction – INTERACT 2017 (Lecture Notes in Computer Science)*, Regina Bernhaupt, Girish Dalvi, Anirudha Joshi, Devanuj K. Balkrishnan, Jacki O'Neill, and Marco Winckler (Eds.). Springer International Publishing, Cham, 247–257. [https://doi.org/10.1007/978-3-319-67687-6\\_16](https://doi.org/10.1007/978-3-319-67687-6_16)
- [3] Jason Alexander, Petra Isenberg, Yvonne Jansen, Bernice E. Rogowitz, and Andrew Vande Moere. 2019. Data Physicalization. *Dagstuhl Reports* 8, 10 (April 2019), 127. <https://doi.org/10.4230/DagRep.8.10.127>
- [4] Patrick Bader, Alexandra Voit, Huy Viet Le, Paweł W. Woźniak, Niels Henze, and Albrecht Schmidt. 2019. WindowWall: Towards Adaptive Buildings with Interactive Windows as Ubiquitous Displays. *ACM Transactions on Computer-Human Interaction* 26, 2 (March 2019), 11:1–11:42. <https://doi.org/10.1145/3310275>
- [5] S. Sandra Bae, Clement Zheng, Mary Etta West, Ellen Yi-Luen Do, Samuel Huron, and Danielle Albers Szafrir. 2022. Making Data Tangible: A Cross-disciplinary Design Space for Data Physicalization. <https://doi.org/10.48550/arXiv.2202.10520> [cs].
- [6] Genevieve Bell and Paul Dourish. 2007. Yesterday's tomorrows: notes on ubiquitous computing's dominant vision. *Personal and Ubiquitous Computing* 11, 2 (Jan. 2007), 133–143. <https://doi.org/10.1007/s00779-006-0071-x>
- [7] Alexandra Boissonneault and Terri Peters. 2023. Concepts of performance in post-occupancy evaluation post-probe: a literature review. *Building Research & Information* 51, 4 (May 2023), 369–391. <https://doi.org/10.1080/09613218.2022.2132906> Publisher: Routledge \_eprint: <https://doi.org/10.1080/09613218.2022.2132906>
- [8] R. V. Corlan, R. M. Balogh, I. Ionel, and St Kilyeny. 2021. The importance of indoor air quality (IAC) monitoring. *Journal of Physics: Conference Series* 1781, 1 (Feb. 2021), 012062. <https://doi.org/10.1088/1742-6596/1781/1/012062> Publisher: IOP Publishing.
- [9] Bowen Du, Marlie C. Tandoc, Michael L. Mack, and Jeffrey A. Siegel. 2020. Indoor CO2 concentrations and cognitive function: A critical review. *Indoor Air* 30, 6 (2020), 1067–1082. <https://doi.org/10.1111/ina.12706> \_eprint: <https://onlinelibrary.wiley.com/doi/pdf/10.1111/ina.12706>
- [10] Mohamed Elsayed, Sofie Pelsmakers, Lorenza Pistore, Raúl Castaño-Rosa, and Piercarlo Romagnoni. 2023. Post-occupancy evaluation in residential buildings: A systematic literature review of current practices in the EU. *Building and Environment* 236 (May 2023), 110307. <https://doi.org/10.1016/j.buildenv.2023.110307>
- [11] Hermann Fromme. 2023. Indoor Environment: Background Information. In *Indoor Air Quality: Occurrence and Health Effects of Contaminants*, Hermann Fromme (Ed.). Springer Nature Switzerland, Cham, 1–36. [https://doi.org/10.1007/978-3-031-40078-0\\_1](https://doi.org/10.1007/978-3-031-40078-0_1)
- [12] Sonal Gawande, Rajnarayan Tiwari, Prakash Narayanan, and Ashwin Bhadri. 2020. Indoor air quality and sick building syndrome: Are green buildings better than conventional buildings? *Indian Journal of Occupational and Environmental Medicine* 24, 1 (Jan. 2020), 30–30. <https://go-gale-com.proxy.uba.uva.nl/ps/i.do?p=AONE&sw=w&issn=09732284&v=2.1&it=r&id=GALE%7CA618547062&sid=googleScholar&linkaccess=abs> Publisher: Indian Association of Occupational Health.
- [13] Eva Hornecker, Trevor Hogan, Uta Hinrichs, and Rosa Van Koningsbruggen. 2023. A Design Vocabulary for Data Physicalization. *ACM Transactions on Computer-Human Interaction* 31, 1 (Nov. 2023), 2:1–2:62. <https://doi.org/10.1145/3617366>
- [14] Yvonne Jansen, Pierre Dragicevic, Petra Isenberg, Jason Alexander, Abhijit Karnik, Johan Kildal, Sriram Subramanian, and Kasper Hornbæk. 2015. Opportunities and Challenges for Data Physicalization. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. Association for Computing Machinery, New York, NY, USA, 3227–3236. <https://doi.org/10.1145/2702123.2702180>
- [15] Stine Schmiege Johansen, Jesper Kjeldskov, and Mikael B. Skov. 2019. Temporal Constraints in Human–Building Interaction. *ACM Transactions on Computer-Human Interaction* 26, 2 (April 2019), 8:1–8:29. <https://doi.org/10.1145/3301424>
- [16] Jimin Kim, Tachoon Hong, Minhyun Lee, and Kwangbok Jeong. 2019. Analyzing the real-time indoor environmental quality factors considering the influence of the building occupants' behaviors and the ventilation. *Building and Environment* 156 (June 2019), 99–109. <https://doi.org/10.1016/j.buildenv.2019.04.003>
- [17] David Kirsh. 2019. Do Architects and Designers Think about Interactivity Differently? *ACM Transactions on Computer-Human Interaction* 26, 2 (April 2019), 7:1–7:43. <https://doi.org/10.1145/3301425>
- [18] Neil E. Klepeis, William C. Nelson, Wayne R. Ott, John P. Robinson, Andy M. Tsang, Paul Switzer, Joseph V. Behar, Stephen C. Hern, and William H. Engelmann. 2001. The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. *Journal of Exposure Science & Environmental Epidemiology* 11, 3 (July 2001), 231–252. <https://doi.org/10.1038/sj.jea.7500165> Publisher: Nature Publishing Group.
- [19] Priyanka Kulshreshtha, Sumanth Chinthala, Prashant Kumar, and Barun Aggarwal (Eds.). 2024. *Indoor Environmental Quality: Select Proceedings of ACIEQ 2023*. Lecture Notes in Civil Engineering, Vol. 380. Springer Nature, Singapore. <https://doi.org/10.1007/978-981-99-4681-5>
- [20] Jared Langevin, Jin Wen, and Patrick L. Gurian. 2016. Quantifying the human–building interaction: Considering the active, adaptive occupant in building performance simulation. *Energy and Buildings* 117 (April 2016), 372–386. <https://doi.org/10.1016/j.enbuild.2015.09.026>
- [21] Eleni Margariti, Vasilis Vlachokyriakos, and David Kirk. 2023. Understanding occupants' experiences in quantified buildings: results from a series of exploratory studies.. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23)*. Association for Computing Machinery, New York, NY, USA, 1–15. <https://doi.org/10.1145/3544548.3581256>
- [22] Giuseppe Ryan Passarelli. 2009. Sick building syndrome: An overview to raise awareness. *Journal of Building Appraisal* 5, 1 (July 2009), 55–66. <https://doi.org/10.1057/jba.2009.20>
- [23] Andrew Pulsipher and Michail Giannakos. 2023. Towards a Taxonomy of Human-Building Interactions. In *Adjunct Proceedings of the 2023 ACM International Joint Conference on Pervasive and Ubiquitous Computing & the 2023 ACM International Symposium on Wearable Computing (UbiComp/ISWC '23 Adjunct)*. Association for Computing Machinery, New York, NY, USA, 411–416. <https://doi.org/10.1145/3594739.3610730>
- [24] Champika Ranasinghe and Auriol Degbelo. 2023. Encoding Variables, Evaluation Criteria, and Evaluation Methods for Data Physicalisations: A Review. *Multimodal Technologies and Interaction* 7, 7 (July 2023), 73. <https://doi.org/10.3390/mti7070073> Number: 7 Publisher: Multidisciplinary Digital Publishing Institute.
- [25] Yvonne Rogers, William R. Hazlewood, Paul Marshall, Nick Dalton, and Susanna Hertrich. 2010. Ambient influence: can twinkly lights lure and abstract representations trigger behavioral change?. In *Proceedings of the 12th ACM international conference on Ubiquitous computing (UbiComp '10)*. Association for Computing Machinery, New York, NY, USA, 261–270. <https://doi.org/10.1145/1864349.1864372>
- [26] Kim Sauvé, Miriam Sturdee, and Steven Houben. 2022. Physecology: A Conceptual Framework to Describe Data Physicalizations in their Real-World Context. *ACM Transactions on Computer-Human Interaction* 29, 3 (Jan. 2022), 27:1–27:33. <https://doi.org/10.1145/3505590>
- [27] Holger Schnädelbach, Nils Jäger, and Lachlan Urquhart. 2019. Adaptive Architecture and Personal Data. *ACM Transactions on Computer-Human Interaction* 26, 2 (March 2019), 12:1–12:31. <https://doi.org/10.1145/3301426>
- [28] Christian Schweizer, Rufus David Edwards, Lucy Bayer-Oglesby, William James Gauderman, Vito Ilaqua, Matti Juhani Jantunen, Hak Kan Lai, Mark Nieuwenhuijsen, and Nino Künzli. 2007. Indoor time-microenvironment-activity patterns in seven regions of Europe. *Journal of Exposure Science & Environmental Epidemiology* 17, 2 (March 2007), 170–181. <https://doi.org/10.1038/sj.jes.7500490>
- [29] Young Joo Son, Zachary C. Pope, and Jovan Pantelic. 2023. Perceived air quality and satisfaction during implementation of an automated indoor air quality monitoring and control system. *Building and Environment* 243 (Sept. 2023), 110713.

- <https://doi.org/10.1016/j.buildenv.2023.110713>
- [30] Holly Sowles and Laura Huisinga. 2021. Introducing Intelligent Interior Design Framework (IIDF) and the Overlap with Human Building Interaction (HBI). In *Advances in Artificial Intelligence, Software and Systems Engineering (Advances in Intelligent Systems and Computing)*, Tareq Ahram (Ed.). Springer International Publishing, Cham, 483–489. [https://doi.org/10.1007/978-3-030-51328-3\\_66](https://doi.org/10.1007/978-3-030-51328-3_66)
  - [31] Roohollah Taherkhani and Mohamadmahdi Aziminezhad. 2023. Human-building interaction: A bibliometric review. *Building and Environment* 242 (Aug. 2023), 110493. <https://doi.org/10.1016/j.buildenv.2023.110493>
  - [32] Himanshu Verma, Hamed S. Alavi, and Denis Lalanne. 2017. Studying Space Use: Bringing HCI Tools to Architectural Projects. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. Association for Computing Machinery, New York, NY, USA, 3856–3866. <https://doi.org/10.1145/3025453.3026055>
  - [33] Chao Wang, Fan Zhang, Julian Wang, James K. Doyle, Peter A. Hancock, Cheuk Ming Mak, and Shichao Liu. 2021. How indoor environmental quality affects occupants' cognitive functions: A systematic review. *Building and Environment* 193 (April 2021), 107647. <https://doi.org/10.1016/j.buildenv.2021.107647>
  - [34] Mark Weiser. 1999. The computer for the 21<sup>st</sup> century. *ACM SIGMOBILE Mobile Computing and Communications Review* 3, 3 (July 1999), 3–11. <https://doi.org/10.1145/329124.329126>

## **Appendix A ACKNOWLEDGEMENTS**

My sincere gratitude to all the participants who generously contributed to this study by dedicating their time to respond to the surveys and questionnaires voluntarily, as well as those who willingly tested and interacted with the prototype. Special appreciation goes to everyone who supported me in data analysis, provided hardware for the prototypes, and reviewed and tested the code for the hardware devices.

A thank you to supervisor, Dr. H. Seïed Alavi (University of Amsterdam), for his invaluable guidance, though-provoking questions, and overall assistance throughout the project and Dr. Shruti Rao (University of Amsterdam) for her constructive feedback and suggestions, which further expanded this research. Also, my sincere appreciation to all the reviewers of this research for their insightful comments and contributions.

## **Appendix B ETHICAL CONSIDERATIONS**

Before user studies were conducted, an application to the Ethics Committee for Information Sciences (ECIS) <sup>1</sup> about the methodology of this research, how data is being gathered and stored was made. Advice from the committee is still pending.

Prior to conducting the questionnaire survey and evaluation procedure, a domain expert from the Informatics Institute at the University of Amsterdam reviewed the methodologies involved. All individuals participating in the survey and evaluation process were obliged to confirm their voluntary involvement by carefully reading and signing a letter of consent, with the assurance that they retained the right to withdraw from participation at any point without the need for explanation. To uphold confidentiality and privacy, survey participation occurred anonymously, and all evaluation data underwent anonymization following the conclusion of the evaluation sessions.

Interacting with occupants within the building and interacting with participants of the usability tests of the prototype adhered to the principles outlined in the UvA code of conduct <sup>2</sup>.

## **Appendix C DATA STORAGE AND ARCHIVAL**

Take some parts of the ethical application to describe data storage and archival of the devices etc.

## **Appendix D SOURCE CODE**

In the spirit of open research, to support reproducibility and enable future work in this problem space the datasets, research notebooks, and prototypes in this work are publicly available on a GitHub organization with the working title 'vizslab' <sup>3</sup> using the MIT License. Several code repositories for different parts of the research can be accessed. The readme.md of the repository described the contents and how to perform the technical set-up:

- (1) **Prototype.** Code and models for the physical prototype.  
<https://github.com/vizslab/prototype>
- (2) **Datasets.** Code and models for the physical prototype.  
<https://github.com/vizslab/prototype>

A one-page website was created for shareability of this research. It's an online website which gives an overview of the research, allows for viewing the source coded of the prototype and allows for downloading of this paper. A live version is deployed on:

- (1) **One-pager.** Code and models for the physical prototype.  
<https://vizslab.github.io/>

<sup>1</sup><https://ivi.uva.nl/research/ethical-code/ethical-code.html>

<sup>2</sup><https://www.uva.nl/en/about-the-uva/policy-and-regulations/>

<sup>3</sup><https://github.com/vizslab>

## Appendix E FLOORPLAN AND LAB SET-UP

A diagram indicating where the sensors were installed. This shows the lab set-up in the two meeting rooms.

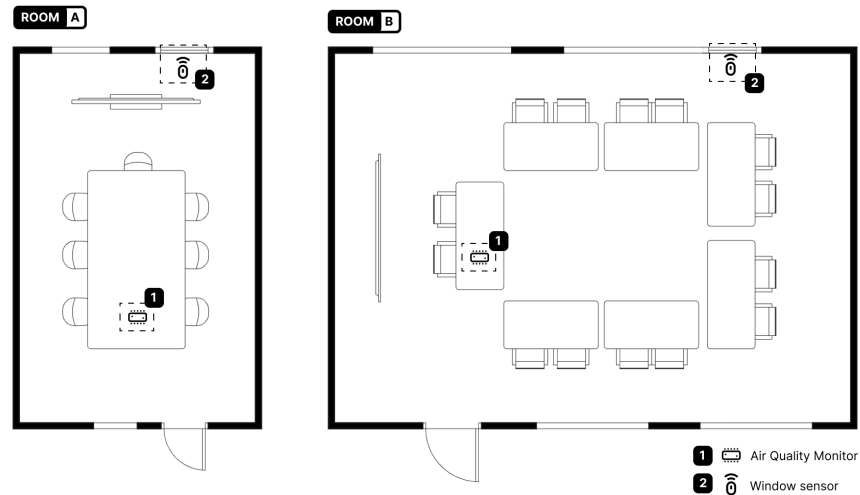


Figure 2: Diagram of the floorplan with sensors installed

## Appendix F IOT ARCHITECTURE OF THE PROTOTYPE

System diagram which shows the IoT architecture of the prototype.

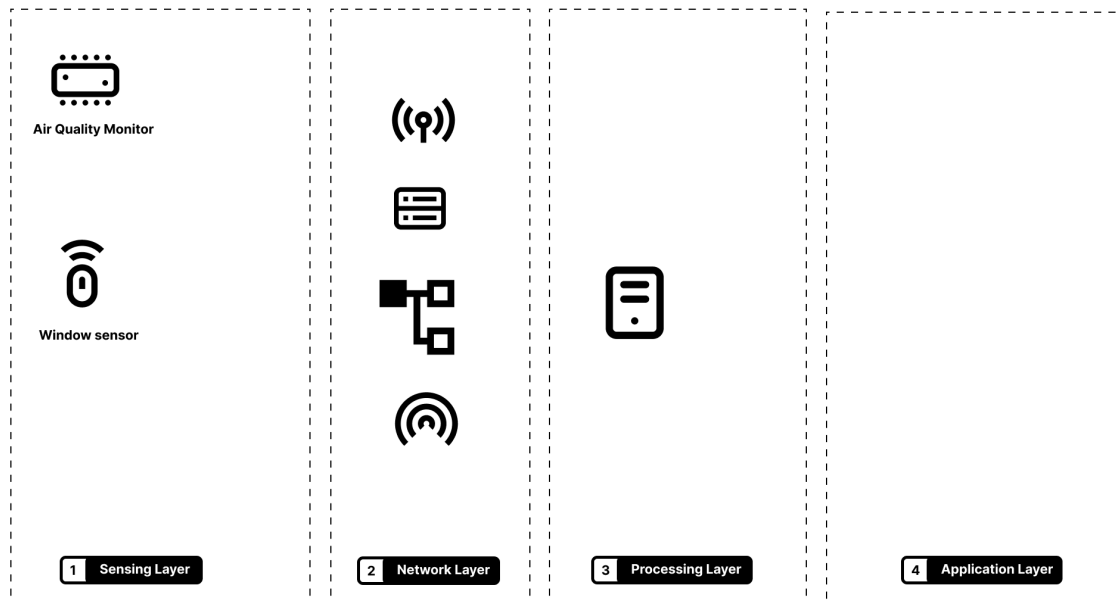


Figure 3: System diagram that shows the technical set-up of the prototype

## Appendix G MEETING ROOM IMPRESSIONS



Figure 4: System diagram that shows the



Figure 5: System diagram that shows the

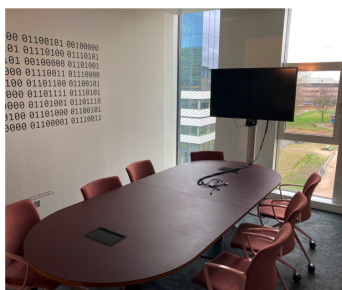
## Appendix H LAB SETTING IMPRESSIONS



(a) first



(b) second



(c) third



(d) fourth

Figure 6: caption



Figure 7: System diagram that shows the



## Appendix I PROTOTYPE IMPRESSIONS



Figure 8: System diagram that shows the



(a) first

(b) second



(c) third



(d) fourth

Figure 9: caption

## Appendix J WEEKLY SCHEDULE

Horizontal boxplot that indicates an average week of booking in the meeting rooms scheduled.

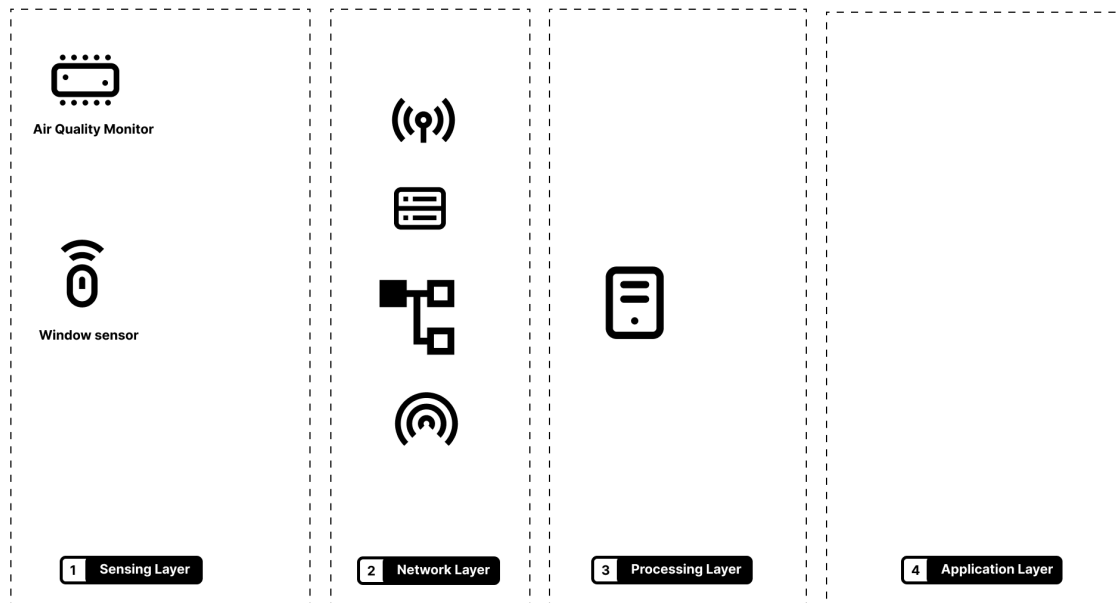


Figure 10: System diagram that shows the technical set-up of the prototype

## **Appendix K AIR QUALITY MONITORS SAMPLE DATA**