

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.



SCHOOL
OF BUILT
ENVIRONMENT

**MONITORING THE EFFECT OF INDOOR ENVIRONMENT
QUALITY ON OCCUPANTS' COMFORT AND SATISFACTION**

The Case of Two Renovated Houses.

Kris Wang

November 2023

**MONITORING THE EFFECT OF INDOOR ENVIRONMENT QUALITY ON
OCCUPANTS' COMFORT AND SATISFACTION**

The Case of Two Renovated Houses.

A research thesis presented in partial fulfilment of the requirements for the degree of
Master of Construction

Massey University, Albany Auckland New Zealand, 2023

Kris Wang

November 2023

Declaration

Name of candidate: Kris Wang

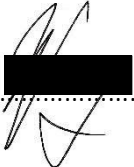
This 90-credit thesis, entitled: **Monitoring the Effect of Indoor Environment Quality on Occupants' Comfort and Satisfaction: The Case of Two Renovated Houses** is submitted in partial fulfilment for the requirements for Massey University, Albany Auckland for the degree of Master of Construction.

Candidate's Declaration

I confirm that:

- This thesis represents my own work.
- The contribution of supervisors and other to this work was consistent with the Massey University and Policies.
- Research for this work has been conducted in accordance with the Massey University Research Ethics Committee Policy and Procedures and has fulfilled any requirements set for this project by the Massey University Research Ethics Committee.

Research Ethics Committee Approval Number: 4000026290

Candidate Signature:

Date: 08 Novembre 2023

Abstract

The well-being and satisfaction of occupants in buildings are greatly affected by indoor environmental quality (IEQ). This research project is aimed at monitoring and comprehensively analysing the effect of IEQ on the occupants' perception, comfort, and satisfaction during their daily activities in their homes, with a specific focus on the winter season when indoor environments face unique challenges due to heating, ventilation, and insulation factors.

The project has two main objectives: Firstly, it aims to analyse the subjective experiences and perceptions of individuals in their homes at different times of the day. It is achieved by collecting data on occupant activities, environmental conditions, and subjective feedback to understand how different IEQ factors affect occupant comfort and satisfaction. These factors include temperature, humidity, air quality, and illuminance.

Secondly, the study intends to explore the importance of maintaining a 'good' IEQ in residential buildings for occupants' overall health and well-being. By examining the correlation between IEQ parameters and occupant well-being, the study provided insights into the optimal conditions required for occupants to feel comfortable and satisfied in their living spaces. This information can inform building design, renovation, and maintenance practices to create healthier and more conducive indoor environments.

The research project employed quantitative and qualitative methods to achieve these objectives. Data was collected through surveys, interviews, and objective measurements of IEQ parameters using advanced sensors and monitoring systems. Statistical analysis techniques are applied to identify patterns, correlations, and potential influencing factors.

The findings of this research project are expected to contribute significantly to the existing knowledge base on IEQ and its impact on occupant well-being and satisfaction. Building designers, managers, and policymakers can use the information and insights from this study to enhance IEQ standards and promote healthier living environments. Ultimately, the goal is to create indoor spaces that meet or exceed energy efficiency standards and prioritise the comfort, well-being, and satisfaction of those who occupy them.

In summary, this research project aims to provide valuable insights and recommendations for creating healthier, more comfortable, and sustainable living spaces by monitoring and analysing the effect of IEQ on occupant well-being and satisfaction during the winter season. This research project will analyse and show the differences between two refurbished buildings. Each building has been renovated according to the New Zealand Standard (MBIE, 2022) regarding Indoor Air Quality (IAQ) and energy use.

Internal environmental monitoring takes the tangible evidence of how the external and internal environment with human behaviour acts on interior air quality, temperature, humidity, illuminance, and concentration of CO₂, influencing occupants' perception, comfort, and well-being. Harvested data will be crucial to understanding the optimum performance in two rental setups with the occupants in a building at different times of the week (weekends) and the year (seasons).

Acknowledgements

I would like to express my sincere gratitude and appreciation to my thesis supervisor, Dr Eziaku O. Rasheed, from the School of Built Environment at Massey University. I am grateful for her constant guidance, support, passion, motivation, patience, enthusiasm, and immense knowledge. With her help, I was able to focus adequately on my thesis research and writing. I would also like to thank all the School of Built Environment staff, especially Dr Ruggiero (Rino) Lovreglio, for their technical support and guidance. Additionally, I am grateful to Chris Chitty for his assistance in organising the instruments required for my research. Finally, I express my gratitude to Tether Limited for providing the sensors, software, and technical support.

Dedication

I would like to express my gratitude and dedicate this thesis to my beloved Family. Firstly, to my mother, Czeslawa, who has been my strongest supporter and believer throughout my entire life. Secondly, I thank my wife, Dongmei (Mikki), and our daughter, Patricia, for their unwavering sacrifice, dedication, and remarkable support and understanding. Lastly, I would also like to thank my research participants, who are also my tenants. From the deepest place in my heart, I thank all of you for making this achievement possible.

Table of Contents

Declaration	3
Abstract	4
Acknowledgements	6
Dedication	7
Table of Contents	8
List of Figures	12
List of Tables.....	15
List of Appendices	16
Chapter 1	17
Introduction	17
1.1 Overview	17
1.2 Background.....	17
1.3 Statement of Research Problem	18
1.4 Research Aim.....	20
1.5 Research Questions.....	20
1.6 Scope and Limitations	21
1.7 Benefits Envisaged of the Research Findings	21
1.8 Structure of the Thesis	22
<i>Chapter 1 – Introduction:</i>	22
<i>Chapter 2 – Literature Review:</i>	22
<i>Chapter 3 – Research Methodology:</i>	22
<i>Chapter 4 – Results:</i>	22
<i>Chapter 5 – Discussion:</i>	22
<i>Chapter 6 – Conclusion and Recommendations:</i>	22
1.9 Timeline	22
Chapter 2	23
Literature Review	23
2.1 Indoor Environment Quality (IEQ)	23
2.2 IEQ Related Health and Performance.....	25
2.3 Wellbeing and Perception of Renters.....	27

2.4 Historical Buildings	27
2.5 A Healthy Indoor Environment.....	28
2.6 Impacts of IEQ on Homeowners and Renters	29
2.7 IEQ and Behaviour of Occupants Energy	30
2.7.1 <i>Four Key Factors in IAQ</i>	30
<i>Thermal Comfort and Factors</i>	30
<i>Indoor Air Quality</i>	31
<i>Visual Comfort</i>	31
<i>Acoustic Comfort</i>	31
Chapter 3	32
Research Methodology	32
3.1 Introduction.....	32
3.2 Research Design	33
3.2.1 <i>Quantitative Method</i>	33
3.2.2 <i>Qualitative Method</i>	35
3.2.3 <i>Integration of Quantitative and Qualitative Methods</i>	35
3.2.4 <i>Ethical Considerations</i>	36
3.3 Validation of the Sensors.....	36
3.3.1 <i>Tether EnviroQ</i>	36
3.3.2 <i>Testo872 Thermal Imager</i>	37
3.3.3 <i>Tether Hot Drop</i>	37
3.3.4 <i>Personalised Weather Station (PWS)</i>	38
3.4 Data Collection	38
3.4.1 <i>Placement of the Sensors</i>	38
3.4.2 <i>Sampling of Sensors Data</i>	39
3.4.3 <i>Qualitative Sampling</i>	40
3.5 Data Analysis	40
3.5.1 <i>Quantitative Analysis</i>	40
3.5.2 <i>Thematic Analysis</i>	42
3.5.3 <i>Architectural Floor Plans</i>	42
3.5.4 <i>Pilot Project</i>	42

Chapter 4	44
Findings and Analysis	44
4.1 Introduction.....	44
4.2 Analysis of Findings	44
4.3 Qualitative Analysis	44
4.3.1 <i>HotDrop Findings</i>	44
4.3.2 <i>Personal Weather Station (PWS) Findings</i>	48
4.3.3 <i>Tether Sensors Findings</i>	51
4.3.4 <i>Testo 872 Thermal Imaging Findings</i>	62
4.4 Quantitative Analysis.....	75
4.4.1 <i>Graphical Interpretations (Survey 1)</i>	75
4.4.2 <i>Graphical Representation (Survey 2)</i>	81
4.4.3 <i>Insights and Data Trends</i>	86
4.4.4 <i>Data Preparation and Testing for Analysis</i>	87
4.4.5 <i>Facts about mould</i>	89
Chapter 5	91
Discussion	91
5.1 Factors.....	93
5.1.1 <i>Indoor environmental quality</i>	93
5.1.2 <i>Building layout and functionality</i>	94
5.1.3 <i>Amenities and facilities</i>	94
5.1.4 <i>Building maintenance</i>	94
5.1.5 <i>Safety and security measures</i>	94
5.1.6 <i>Integration with natural environment</i>	94
5.1.7 <i>Energy efficiency and sustainability</i>	95
5.1.8 <i>Factors related to the landlord and owners</i>	95
5.1.9 <i>Factors related to the architects and designers</i>	95
5.1.10 <i>Factors related to the contractors</i>	96
5.1.11 <i>Factors related to Regulatory Authorities</i>	96
5.1.12 <i>Factors related to consultants – (Tether, Tech. support Massey)</i>	96

Chapter 6	97
Conclusion and Recommendations	97
6.1 Conclusion.....	97
6.2 Recommendations.....	99
<i>6.2.2 Recommendations for Regulatory Authorities</i>	99
<i>6.2.3 Recommendations for contractors, architects, and designers</i>	100
<i>6.2.4 Recommendations for consultants</i>	100
6.3 Critical challenges and limitations.....	100
6.4 Future research work.....	101
References.....	102
Appendices.....	114
Appendix A.....	114
Appendix B.....	117
Appendix C.....	118
Appendix D.....	120
<i>Appendices' - abbreviation</i>	121
Appendix E.....	122
Appendix F.....	124
Appendix G.....	126
Appendix H.....	127

List of Figures

Figure 1. Thermal Comfort and IEQ vs Virus Risk	24
Figure 2. Contribution of IEQ and Health Effect	26
Figure 3. Tether Q specifications	33
Figure 4. Testo872 Thermal Imager - technical specifications	34
Figure 5. Tether HotDrop - technical specifications	34
Figure 6. La Crosse Sensor - technical specifications.....	34
Figure 7. Questionnaires throughout iWatch	41
Figure 8. Temperature vs power performance - Building 318.....	45
Figure 9. Temperature vs Power performance - Building 320.....	46
Figure 10. Monthly summary from the Personal Weather Station (PWS) - outdoor.....	50
Figure 11. Tether monthly report, Bathroom – temperature.....	51
Figure 12. Tether monthly report, Bathroom - relative humidity and CO2	51
Figure 13. Tether monthly report, Bedroom1 - temperature and relative humidity.....	52
Figure 14. Tether monthly report, Bedroom1 - CO2	52
Figure 15. Tether monthly report, Bedroom2 - temperature and relative humidity.....	53
Figure 16. Tether monthly report, Bedroom2 - CO2	53
Figure 17. Tether monthly report, Office - temperature and relative humidity.....	54
Figure 18. Tether monthly report, Office - CO2.....	54
Figure 19. Tether monthly report, Open Plan Living Room - temperature and relative humidity.....	55
Figure 20. Tether monthly report, Open Plan Living Room – CO2	55
Figure 21. Tether monthly report, Outdoor Pergola - temperature and relative humidity	56
Figure 22. Tether monthly report, Outdoor Pergola – CO2.....	56
Figure 23. Tether monthly report, Bathroom – temperature.....	57
Figure 24. Tether monthly report, Bathroom - relative humidity and CO2	57
Figure 25. Tether monthly report, Kitchen - temperature and relative humidity	58
Figure 26. Tether monthly report, Kitchen – CO2	58
Figure 27. Tether monthly report, Living Room - temperature and relative humidity	59
Figure 28. Tether monthly report, Living Room – CO2.....	59
Figure 29. Tether monthly report, Main Bedroom - temperature and relative humidity.....	60
Figure 30. Tether monthly report, Main Bedroom – CO2	60

Figure 31. Tether monthly report, Mid Bedroom2 - temperature and relative humidity	61
Figure 32. Tether monthly report, Mid Bedroom2 – CO2	61
Figure 33. Tether monthly report, Mid Bedroom2 – CO2	62
Figure 34. A non-insulated entrance door, heat escape from the side of the door and glass panel	63
Figure 35. A view of the same door from outside	64
Figure 36. A view of the door handle and locker	65
Figure 37. The doorsill from inside, ingress of the cold air	66
Figure 38. A heat escape from the uPVC double-glazed window frame (uneven surface of the frame or faulty seals)	67
Figure 39. HRV ducting system shows evidence of blowing cold and dumping air into a living room ..	68
Figure 40. The bathroom's extractor also extracts (evidently) heat from the ambient.....	69
Figure 41. A heat escape from the ventilation grills (view from outdoor) that is installed under the floor structure close to the insulation between the joists.....	70
Figure 42. Deficiency of insulation on the ceiling roof space	71
Figure 43. Deficiency of insulation on the ceiling roof space-support rafter penetration.....	72
Figure 44. The ceiling roof space has gaps alongside the beam due to a lack of insulation	73
Figure 45. Thermal bridging was created by the corner of the building that has not been insulated (common defect even with ‘modern’ builds). Source: Author’s contribution	74
Figure 46. Date / Time - Building 318/320.....	75
Figure 47. Demographics Building 318/320	75
Figure 48. Demographics - single level building	76
Figure 49. Demographics – rooms.....	76
Figure 50. Demographics - configuration	77
Figure 51. Demographics - configuration2	77
Figure 52. Demographics - configuration3	78
Figure 53. Demographics.....	78
Figure 54. Demographics2.....	79
Figure 55. Heating sources	79
Figure 56. Ventilation	80
Figure 57. Passive ventilation	80
Figure 58. Personal preferences.....	81
Figure 59. Date	82
Figure 60. Buildings	82
Figure 61. Time frame	82

Figure 62. Location during the survey	83
Figure 63. Well-being in relation to the IEQ.....	83
Figure 64. IEQ.....	84
Figure 65. Personal preferences.....	84
Figure 66. Light preferences.....	85
Figure 67. Air preferences	85
Figure 68. Clothing preferences	86
Figure 69. Connected two pictures to give a full participation date from 4 to 11 of October 2022.....	86
Figure 70. Typical black mould grows with restricted ventilation and elevated humidity due to the condensation and temperature.	89
Figure 71. Aspergillus fungus, coloured scanning electron micrograph (SEM). Magnification: x240 at 5x7cm size.	90
Figure 72. The function of the relative humidity (RH) and temperature as mould germination growth.	90

List of Tables

Table 1. Project Schedule	43
Table 2. Timeframe completed survey answers	81
Table 3. Correlation output	87
Table 4. Regression output.....	87
Table 5. ANOVA 1	87
Table 6. ANOVA 2	88

List of Appendices

Appendix A: Information Sheet and Participation Consent Forms.....	112, 113, 114
Appendix B: Satellite Aerial View - Buildings 318, and 320.....	115
Appendix C: Floor Layout Building 318, and Placement of the Sensors.....	116, 117
Appendix D: Floor Layout Building 320, and Placement of the Sensors.....	118, 119
Appendices' – Abbreviation.....	119
Appendix E: Questionnaires A.....	120, 121
Appendix F: Questionnaires B.....	122, 123
Appendix G: Equipment Notification and Serial Number.....	124
Appendix H: Clause H1 Minimum Requirement of the R-value	125

Chapter 1

Introduction

1.1 Overview

New Zealand is a country that has had a tradition of building and renovating houses, with a significant number of refurbished and reconditioned old buildings. Rentals are increasing in New Zealand and represent 582,000 households (Stocktake of New Zealand's Housing, 2021). New Zealand's Building Code concerning housing has continuously developed due to climatic changes, human behaviours, and lifestyle (MBIE, 2019).

This research project analyses and shows the differences between two refurbished buildings. Each building has been renovated according to the New Zealand Standard (MBIE, 2022) regarding heating, insulation, ventilation, and moisture ingress. All collected data from two adjacent buildings situated on the same property will show in real time how the buildings perform based on the influence and interaction of the occupants.

Internal environmental monitoring: It is taking the tangible evidence of how the external and internal environment with human behaviour act on interior air quality, temperature, humidity, illuminance, and concentration of CO₂, influencing occupants' perception, comfort, and well-being. Harvested data will be crucial to understanding the optimum performance in two rental setups with the occupants in a building at different times of the week (weekends) and the year (seasons).

1.2 Background

BRANZ publications offer a wealth of insightful resources for those seeking a solid grasp of building construction and effective moisture management. These materials delve into the various sources of moisture and how excessive dampness can infiltrate walls, gaps, and other imperfections caused by subpar workmanship, insufficient insulation, external moisture, or thermal bridging. Additionally, selecting high-quality joinery for doors and windows is crucial in New Zealand to prevent drafts and heat loss, as is required by the new H1 standard (Build Magazine187, 2022). Nevertheless, while internal moisture is a concern, it is not the sole factor

to consider. We must consider how individuals utilise and occupy buildings to comprehend the issue truly. By closely monitoring and analysing such behaviours, we can strive towards creating more ideal living conditions for the contemporary "indoor generation" (Aspiredil, 2022).

Indoor air quality (IAQ) significantly impacts the comfort and satisfaction of residents, as poor indoor quality affects the health of occupants. To improve indoor air quality, the ventilation rate is increased, which helps reduce the pollutants or germs in the indoor air. Another way of improving indoor air quality is by preventing or limiting the entrance of pollution within the building, which helps reduce the entrance of pollutants (Andargie & Azar, 2019). The quality of indoor air is affected by temperature, physical conditions, humidity, and chemical and biological pollution, which are the major causes of poor indoor air quality. The occupants' satisfaction and comfort are affected due to the irritation in their throat, headache, nose, and eyes (Abdulaali et al., 2020).

The indoor environment is also associated with the building's thermal condition. *Thermal condition* is defined as the humidity, temperature, and airflow rate present within the building. It also refers to the things that transfer the heat or radiation. Poor or unsatisfactory thermal conditions affect the occupant's satisfaction level. It has been observed that if eighty per cent of occupants are satisfied with the thermal conditions of the buildings, then the thermal condition is satisfactory (El-Salamouny et al., 2019).

1.3 Statement of Research Problem

In New Zealand, building renovations can negatively affect indoor air quality, leading to discomfort and dissatisfaction among occupants. In comparison, extensive research has been conducted on the relationship between indoor air quality (IAQ) and health and well-being (Bluyssen, 2020; Megahed & Ghoneim, 2021; Altomonte et al., 2020). However, more information is needed on its impact on occupant satisfaction and comfort. This study examines the indoor air quality of two residential buildings and observes their occupants' satisfaction and comfort levels. Given the prevalence of building renovations in New Zealand, it is crucial to understand how neglecting essential factors such as air quality and thermal efficiency impacts occupant satisfaction and comfort. While previous studies have primarily focused on the impact on health and well-being, this research aims to observe and understand these

factors in two identified residential buildings. However, due to the limited number of occupants in these buildings, future research will require more participants to better understand IAQ and occupant satisfaction with their living conditions.

In addition, New Zealand buildings are majorly responsible for greenhouse gas emissions due to their energy consumption. It has also been found that the negative impact of building energy conservation measures indoor air quality (IAQ), which is considered a rising concern (Domínguez-Amarillo et al., 2020). Additionally, occupants' lifestyles and indoor exposure are specific concerns as most of the time is spent indoors in residences. Hence, it is imperative to understand how energy-saving techniques influence indoor air quality and the health and comfort of the occupants. Fisk et al. (2020) have discussed the energy impact of retrofits from dwellings on indoor air quality, which is relatively limited. The enhanced thermal conditions and health indicators were also found after the installation of standard insulation in New Zealand. In addition, Ala-Kotila, Vainio, and Laamanen (2020) highlighted that the comprehensive energy in California retrofits combined systems with improved mechanical ventilation and air cleaners that result in enhanced indoor environmental conditions. Also, the positive effects of energy retrofit on indoor occupant satisfaction and environmental quality are demonstrated in residential buildings that are mechanically ventilated (Ortiz et al., 2020). Hence, with the higher exchange rates of air provided by mechanical ventilation, satisfaction with the buildings' indoor air quality was acquired in the study as reported.

Energy-saving measures have started getting greater attention in New Zealand, but indoor air quality has yet to receive much attention or consideration in terms of satisfaction. Adopting standards for new buildings with a primary focus on energy conservation is feared to compromise indoor air quality. The WHO (World Health Organization) resolution on the health and environment has highlighted the policies to secure public health from significant environmental hazards that arise from housing and climate change. Consequently, Energy Performance of Building Directive (EPBD), have established the targets for reducing energy consumption. Existing and new residential buildings promote and target nearly zero-energy buildings and energy retrofits.

To overcome the issues with energy efficiency and reduction of energy, the techniques for building renovation procedure result in both improved indoor comfort and climate for

residents and enhanced energy efficiency. However, the rebound effects have also been an example of enhanced noise levels because of the suitable installation of mechanical ventilation systems and enhanced exposure to indoor pollutants (Critical Care Practitioner, 2023). Remarkably, people spend more than 60% of their time at home and the rest of their time at work, which results in 90% of the time indoors (Bluyssen, 2020). In most buildings, people are exposed to an indoor environment that can cause adverse health effects. Furthermore, by enhancing energy efficiency and addressing the consequences of climate change, we can further amplify their positive effects.

According to Naegler et al. (2021), many of the residential buildings predicted to be energy-neutral by 2050 have already been constructed. This is because the rate of construction for new builds is less than 1% annually. To achieve energy efficiency in the residential sector, the focus is on renovating existing houses. Most of these renovated houses are fitted with mechanical ventilation, renewable energy systems, and relevant distribution systems. Initiatives have been taken in the past to improve indoor air quality, and the initial steps to reduce energy consumption were taken in response to an energy crisis in the 1970s (Ortiz et al., 2020). However, improvements in thermal insulation and air tightness have led to problems with mould, dampness, and poor indoor air quality.

1.4 Research Aim

The research aims to monitor the effect of Indoor Environment Quality (IEQ) on the well-being and satisfaction of the occupants.

1.5 Research Questions

Analysing the perception of the persons (building occupier) during their activities at different times of the day during the seasons at their home.

- What is the people's comfort and perception in the occupied space area in a specific situation exposed to the differences in temperature, humidity, air quality, or illuminance?
- How important is it to keep up with a 'good' refurbishment of the old buildings for the health of the occupants?
- How and what are the best solutions we can provide to meet or exceed the H1/AS1 Energy Efficiency for the internal occupants' comfort and well-being?

1.6 Scope and Limitations

This research study evaluates the effect of indoor environment quality (IEQ) on occupant well-being and satisfaction in a specific context. The study examines a sample of residential buildings in Auckland, New Zealand, during the winter season.

The research project considers various IEQ variables, including ventilation, insulation, heating, humidity, and lighting. By evaluating these variables, the study aims to provide comprehensive insights into the impact of IEQ on occupants' perception and comfort.

Regarding building systems and design aspects, the research project covers natural and mechanical ventilation systems, insulation materials and techniques, heating systems, dehumidification systems, and lighting fixtures.

While this research project strives to provide valuable insights, it is essential to acknowledge certain limitations that may have influenced the outcomes. These limitations include a relatively small sample size of the two examined residential buildings in which may limit the generalizability of the findings to other regions or building types. Additionally, external factors such as weather conditions and occupant behaviour can influence the measured IEQ variables and consequently impact the study's results.

The duration of this study was limited due to the number of the occupants (by the tenants), and consented time to collect the data. However, efforts were made to minimize these limitations and conduct a rigorous analysis to present meaningful conclusions.

Overall, this research study contributes to understanding the relationship between IEQ and occupant well-being and provides practical recommendations for building constructors and occupants to enhance the indoor environment.

1.7 Benefits Envisaged of the Research Findings

The research study's discoveries would spur the development of better-ventilated buildings in New Zealand, featuring lower thermal conditions, insulation, and reduced humidity. Additionally, these findings are advantageous for builders and construction companies,

allowing them to tailor their designs to the preferences and needs of both occupants and residents and the country's weather patterns.

1.8 Structure of the Thesis

This thesis is a summary of the six chapters, which are defined below:

Chapter 1 – Introduction:

Overview of the research project, the research problem and appointed research aim, and objective followed by the scope of this study with conceive benefits of the research findings.

Chapter 2 – Literature Review:

It is an overview of previously published research articles that helps build an understanding of the research topic and helps determine the expected outcomes of the research.

Chapter 3 – Research Methodology:

This chapter provides a detailed explanation of the research methods utilised in this study. It covers the data collection process, research strategy, sources of data, timeframes for data collection, data analysis methods, survey questionnaires, and ethical considerations.

Chapter 4 – Results:

In this chapter, we summarise and discuss the gathered and analysed data. The results are presented in the following order: data preparation, missing value handling, analysis tests, and reliability/validity.

Chapter 5 – Discussion:

A discussion of the analysed results has been conducted in this chapter, relating them to previous research articles to support their authenticity.

Chapter 6 – Conclusion and Recommendations:

In this chapter, we provide an overview of the entire research study. We redefined the research purpose and developed it based on our conclusions. Additionally, we provide recommendations for future research.

1.9 Timeline

As part of the Thesis 90 credits for the 2022/2023 academic years, there are two components: the research project and data collection. During this period, the assigned activities will collect data from two living-occupied spaces on the same property starting in winter 2022.

Chapter 2

Literature Review

The quality of the indoor environment is a critical factor to consider when designing buildings, as it significantly impacts the health, comfort, and satisfaction of its occupants. There is a growing interest in exploring how different elements of the indoor environment, such as lighting, temperature, and air quality, can affect the well-being of those who use the space. Through an in-depth review of existing literature and analysis of various studies, this research aims to understand the connection between indoor environment quality and occupant well-being.

Internal Environmental Quality (IEQ)

Indoor Environmental Quality (IEQ) encompasses numerous facets of the indoor environment, including thermal comfort, air quality, lighting, acoustics, and ergonomics. The National Institute for Occupational Safety and Health (NIOSH) of the U.S. Department of Health and Human Services defines IEQ as "the quality of the indoor environment that impacts the health, comfort, and performance of the building occupants" (NIOSH, 2019). This encompasses elements such as air quality, thermal conditions, lighting, and noise.

Thermal Comfort

Thermal comfort is a crucial aspect of Indoor Environmental Quality (IEQ), which refers to indoor environment quality. It is defined as the state of mind that indicates satisfaction with the thermal environment (Čulić et al., 2022). Several factors influence thermal comfort, including air temperature, radiant temperature, humidity, and air velocity. Studies have demonstrated that it considerably impacts the well-being, productivity, and satisfaction of occupants. For instance, a study by Heschong Mahone Group (2003) discovered that maintaining a comfortable thermal environment can boost workers' productivity and satisfaction by 10-15%.

2.1 Indoor Environment Quality (IEQ)

Recently, there has been a growing interest in IEQ (Indoor Environmental Quality) issues due to the belief that the indoor environment significantly impacts productivity and performance. IEQ is affected by various factors, such as physical, toxicological, and microbiological systems, including building structure and living conditions. Kim & Carswell (2022) also noted that these

factors interact in complex ways, making it difficult to isolate one specific factor as the cause of poor air quality indoors. However, outdoor pollutants can also contribute to indoor air pollution. Previous studies have found a strong correlation between indoor air quality and outdoor air conditions and the presence of outdoor particles.

Indoor air pollution is strongly linked to components such as tobacco smoke odour, dry air, and mould. According to a study by Yock (2021), renters are more sensitive to indoor air quality than homeowners, reporting lower odour perception. The quality of housing is also a mediator for health, as it not only represents the financial constraints of renters but also directly affects their well-being, particularly for lower-income families and those with disabilities. Renters are also four times more likely than homeowners to experience risky situations at home, which can lead to mental health problems such as anxiety and depression (Rosen et al., 2021).

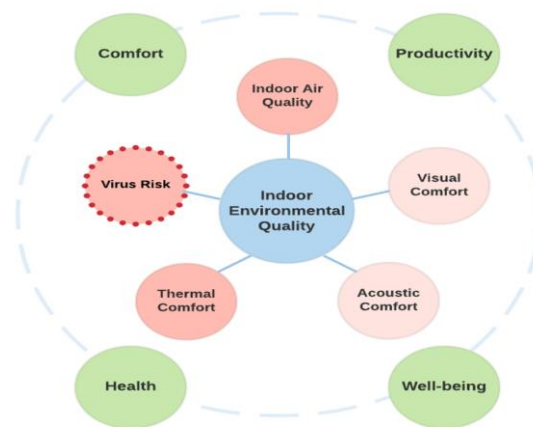


Figure 1. Thermal Comfort and IEQ vs Virus Risk

Source: (Research Gate). “A Review of Field Measurement Studies on Thermal Comfort, Indoor Air Quality and Virus Risk.”

https://www.researchgate.net/figure/Typical-influencing-factors-of-the-IEQ_fig1_358122387

Due to significant changes in pollution sources, indoor pollutants are becoming more chemically diverse than ever before. As a result, new building designs and techniques are being developed to save energy efficiently, which can lead to airtight indoor spaces with inadequate ventilation (O'Donovan & O'Sullivan, 2023). Additionally, the constant increase in the number of compounds found indoors is due to improvements in sampling strategies and more advanced analytical instruments. Research has identified significant sources of indoor air

pollution, including outdoor pollutants penetrating indoors, endogenous contamination, and indoor environment reaction products (Kelly & Fussell, 2019).

Studies have shown that indoor pollutants include emissions from “Do It Yourself” (DIY), and building materials, personal and cleaning products, environmental tobacco smoke, cooking, human metabolism, and other biological sources such as house dust mites, pets, and moulds. Furthermore, primary pollutants from indoor sources are complex and largely uncharacterised, as they undergo chemical transformations indoors, which can degrade ambient pollutants.

2.2 IEQ Related Health and Performance

The quality of the indoor environment (IEQ) is linked to various health issues like sick building syndrome, respiratory illness, sick leaves, and productivity losses. According to Anand, Cheong, and Sekhar (2022), the cost of poor IEQ could exceed the expenses of energy needed for ventilation and space conditioning. However, several cost-effective measures can be taken to improve IEQ indoors, resulting in monetary savings and better productivity and health. Studies indicate that the indoor environment significantly impacts health and performance. Building professionals are keen on quantifying these effects. Moreover, ventilation is crucial for residents as it significantly impacts short-term sick leaves caused by infectious diseases (Sadrizadeh et al., 2022).

There are many residential buildings where the temperature could be better controlled due to various factors such as inadequate thermal zones, insufficient heating, or cooling capacity, high internal or external loads, and improper control system operation or design. Furthermore, these thermal conditions can vary significantly over time, such as changes in indoor and outdoor temperatures. While the impact of temperature on comfort has been widely recognised, less attention has been paid to its effect on worker productivity. To address this, several studies have been conducted to determine how temperature affects performance so that these effects can be considered in building operations and design cost-benefit calculations. Additionally, air temperature can directly impact productivity by affecting air quality satisfaction or causing symptoms, but existing information can be used for cost-benefit calculations.

In recent decades, it has become increasingly evident that humans are polluting the Earth to the point where natural systems can no longer function smoothly, resulting in progressive

changes in climate. Sustainable buildings have been identified as a significant step in reducing these impacts (Amerio et al., 2020). The built environment is responsible for approximately 40% of annual global energy consumption and significantly impacts health, mental well-being, and behaviour.

Studies have shown that indoor thermal discomfort and air pollution have diverse impacts on the well-being and productivity of building occupants (Kakoulli et al., 2022). These concerns are increasing since people spend a significant amount of time indoors in tightly sealed buildings. Furthermore, anxiety and depression account for 55% of all work-related illnesses, resulting in lost working days. Indoor environments are crucial in people's psychological well-being, and indoor air quality and physical space design are the key factors. The indoor space design can be manipulated in various ways to have a significant impact. In addition, indoor plants have been found to benefit both the psychological and physical well-being of building occupants, resulting in reduced health complaints and sick leaves.



Figure 2. Contribution of IEQ and Health Effect

Source: (Medium) "Indoor Environmental Quality Parameters."

<https://medium.com/@ieqandwellbeing/indoor-environmental-quality-parameter-56aab5cffd8>

Improving indoor air quality can be challenging and expensive when using mechanical ventilation systems to control carbon dioxide concentration and relative humidity. However, studies have shown that the presence of plants can improve indoor air quality and thermal comfort, even if there are no actual changes in air quality conditions. The adverse health effects of poor indoor air quality have become a widespread concern for public health professionals and policymakers worldwide. Harmful substances, such as ketones and volatile organic compounds, found in indoor environments can significantly impact an individual's health.

2.3 Wellbeing and Perception of Renters

The study found that poor indoor air quality has a more substantial negative impact on renters' health than homeowners. This is because unequal environmental conditions can trigger respiratory problems, diabetes, obesity, and other serious illnesses. Argarwal, Gao, and Garner (2023) noted that lower-rent dwellings typically consist of older buildings and are more prevalent in areas with lower-income populations. However, the supply of rental housing has been steadily increasing since the Great Recession due to rising labour and construction costs. On the other hand, homeowners experience less of a cost burden for housing, while approximately half of renter's struggle with high expenses.

2.4 Historical Buildings

Historic buildings each possess unique qualities and reasons that make them valuable for restoration and preservation. However, restoring such buildings can be lengthy and often depends on a country's financial resources (Taher Tolou Del, Saleh Sedghpour & Kamali Tabrizi, 2020). Restoring old buildings primarily aims to safeguard a country's cultural heritage. This process can take months or even years to complete, requiring significant time and financial investment. Moreover, refurbishing old buildings is also crucial and can have a significant impact. An indoor environmental quality survey was conducted in Singapore, across seven buildings, with 666 responses received. The survey revealed that 30% of respondents were dissatisfied with weak air movement caused by temperature fluctuations, while 42% were bothered by noise from other people. 86% of respondents were satisfied with the overall environment and dress codes (Cheung et al., 2020).

In the conducted survey 30% of the occupants were dissatisfied with the weak air movement due to temperature fluctuations in the building, whereas 42% were dissatisfied because of the noises from people. Although, overall, 86% of the respondents were satisfied with the overall environment and dress codes.

One reason to restore old buildings is the intrinsic value and admiration it can garner from the public. Cultural landmarks hold a special place in people's hearts and are often seen as iconic symbols of a country. This is true for many nations around the world.

Old buildings have not only cultural value but also educational value. However, it is essential to note that prolonged refurbishment of these old buildings may result in health concerns for the occupants. A successful refurbishment of old buildings can significantly improve the overall health and well-being of the occupants. Several factors contribute to the successful refurbishment of old buildings, including refurbishment strategies, environmental performance of the buildings, and decision-making strategies.

2.5 A Healthy Indoor Environment

Some older buildings may require additional indoor environments due to outdated infrastructure, which can result in higher levels of microorganisms. The thermal conditions and indoor air quality of a building can also significantly impact the health of its occupants. Studies indicate that proper window operation is essential for maintaining a comfortable indoor environment, increasing ventilation, and reducing carbon dioxide levels. These actions can improve indoor air quality and energy efficiency. However, opening windows can also impact energy consumption by allowing outside air to enter and alter the temperature inside the building. It is essential to consider heating costs, often positively correlated with lower air quality. Improving air quality can come at the cost of decreased thermal comfort.

Studies have shown that indoor mould can be responsible for causing health issues in 30 to 50% of living spaces (Ortiz et al., 2020). There is a clear correlation between these adverse health conditions and the presence of mould, especially in children. The term "Bad Indoor Environment" refers to a range of factors that can negatively impact the health and well-being of occupants, such as poor thermal acoustics, lighting quality, indoor air quality, and high concentrations of CO₂ during heating seasons. Additionally, everyday activities like cooking, cleaning, laundry, showering, and improper ventilation can exacerbate these conditions. It is important to note that even during building refurbishments, occupants may experience respiratory issues and breathing difficulties (Ortiz et al., 2020).

2.6 Impacts of IEQ on Homeowners and Renters

The quality of the indoor environment can significantly impact human health and productivity. If the indoor environment is unsuitable, it can lead to health concerns caused by design or technical faults. Various factors, such as building structures like schools, offices, and homes, can impact human health. Studies have shown that the quality of the indoor environment significantly affects productivity, learning ability, and work quality. Residents' feedback has been collected directly to redefine and improve buildings and their characteristics: temperature, light intensity, airflow, pressure, and humidity all impact indoor environment quality. Several approaches have been carried out to analyse the relationship between Indoor Environment Quality (IEQ) and occupants. According to Elsayed et al. (2023), the post-occupancy model (POE) is the most effective way to obtain feedback about the experience and performance of a building from its inhabitants. The objective of POE is to ask the users of the building about their needs and experiences in the built environment. This model helps identify design lapses, construction management issues, misuse, and improvements that should be made. The POE method collects quantitative and qualitative data through questionnaires, interviews, and direct visits to these spaces, involving the residents directly.

Furthermore, evaluating the environments involves functional, technical, and behavioural analyses. However, the study's primary goal is to ascertain the definition of "overall comfort" from the occupants' perspective. This includes comparing occupant comfort to factors such as IEQ, building performance, safety standards, satisfaction-productivity ratio, POE's role in building design and maintenance, and the impact on occupant behaviour.

The versatility of POE has been established as it can be employed in various contexts. This study focused on different building types and found that involving users through social media is the most widely used method to assess building performance. However, certain factors, such as thermal comfort, air quality, lighting, humidity and pressure, and non-physical aspects like privacy, cleanliness, facilities, and views from the building, are challenging to measure using tools (Alfalah et al., 2022). In contrast, a complex IEQ assessment model developed by Zambrano et al. (2021) can determine stressor patterns for different scenarios. The author suggests a more detailed, situation-based model that considers all stressor factors, environmental indicators, indoor environment quality, building labelling, and components,

considering different spaces such as schools, homes, and offices and their potential issues and interactions with people. The study revealed that prolonged indoor stays can harm health even if indoor environment quality standards are met. Therefore, it is crucial to understand the indoor environment of spaces and its impact on occupants, as everyone has unique needs.

2.7 IEQ and Behaviour of Occupants Energy

Studies have identified four key parameters that broadly categorise indoor environmental quality (IEQ): visual comfort, acoustic comfort, indoor air quality (IAQ), and thermal comfort (Weerasinghe et al., 2020).

2.7.1 Four Key Factors in IAQ

Thermal Comfort and Factors

According to the ISO, thermal comfort refers to the mental state of satisfaction with the surrounding thermal conditions. Environmental factors, such as air velocity, relative humidity, mean radiant temperature, air temperature, clothing, and metabolic rate, contribute to an occupant's thermal sensation. In naturally ventilated buildings, occupants can adjust doors and windows to regulate the room temperature and air exchange. However, in mechanically ventilated buildings, occupants must either accept the system's settings or adjust their clothing and metabolic rate to adapt to the indoor environment.

To achieve optimal thermal comfort, occupants may need to adjust fans, heaters, and thermostats to their preferences. Since thermal comfort varies from person to person, buildings should allow occupants to personalise their preferred conditions to reduce discomfort. Previous studies have shown that personalised ventilation systems, such as ceiling fans and individual airflow rates, are preferred by many occupants over HVAC systems, regardless of ambient air temperature. However, occupants should maintain the building's energy savings when modulating their thermal preferences. Setting the cooling set point below 24°C is an energy-wasting behaviour that occupants should avoid.

Indoor Air Quality

Indoor air quality is a crucial factor that impacts the comfort and health of occupants within buildings and structures. Poor IAQ can cause Sick Building Syndrome and lead to respiratory health problems among office and residential occupants due to indoor air pollutants. Residents with respiratory diseases are particularly concerned about IAQ, while those with symptoms such as sore throat are less satisfied with the IAQ in their homes. Numerous factors impact IAQ, including humidity, crowding, odour, and carbon dioxide concentration.

Occupancy-controlled ventilation can help achieve energy savings by reducing the average ventilation rate while maintaining better control of indoor pollutant concentrations and indoor climate. Additionally, there is a relationship between building energy and behavioural pattern management systems. By connecting behavioural patterns to building energy and comfort management systems, sensor-based modelling can predict user behaviours and indicate a potential for up to 30% energy savings without sacrificing indoor air quality.

Visual Comfort

Visual comfort within a building is determined by an individual's subjective impression of lighting quantity, quality, and distribution. This ensures that occupants are not subjected to uncomfortable levels of glare or contrast in brightness. Moreover, light intensity significantly impacts psychological, physical, and physiological human responses.

Acoustic Comfort

Acoustic comfort refers to maintaining background noise levels within an acceptable range. It is recommended that workers are not exposed to noise levels exceeding 85 dBA for eight hours to prevent occupational noise-induced hearing loss.

Chapter 3

Research Methodology

3.1 Introduction

The study examined the impact of indoor environment quality on occupants' comfort and satisfaction in two upgraded buildings in Auckland, New Zealand. The researcher used a mixed methodology incorporating both quantitative and qualitative data. To collect the quantitative data, indoor environment quality (IEQ) sensors were employed, including the Tether EnviroQ device, the Testo 872 model for thermal imaging, and the Tether Hot Drop for transmitting data via LoRaWAN IoT protocol directly to the Tether Platform for easy measurement comparisons.

Between August 4 and 11, 2022, the Tether EnviroQ device collected temperature, humidity, carbon dioxide, light, and pressure data (Kallio et al., 2020). The Testo Thermal imager was used to monitor thermal images of both buildings' heat escapes and insulation deficiencies. At the same time, the Tether Hot Drop tracked the energy consumption used in each building through two separate HotDrop sensors with two separate main power meter boxes.

The researcher also implemented a personalised weather station (PWS) V40A-PROv2, with La Cross remote sensors to measure the temperature and humidity of the external environment, the roof space attic, ducting ventilation, and extractors.

Quantitative methods were used to analyse the sensor data, including descriptive and inferential statistics, correlation, and regression analysis. In addition to analysing sensor data, a qualitative method was employed to gather data on user perceptions of indoor environmental quality in two refurbished buildings. This involved interviewing occupants using an open-ended questionnaire for eight days (Winter 4-11 August 2022) to understand better their comfort and satisfaction levels in specific areas with varying environmental conditions, such as temperature, humidity, illuminance, pressure, and air quality.

The thematic analysis of the collected data identified key themes and patterns in occupants' perceptions of indoor environmental quality to understand its effects on their comfort and satisfaction levels. The data collected would help identify areas for improvement and determine the best possible solutions to align with H1/AS1 energy efficiency goals. It would also provide insights into the best key performance indicators (KPIs) for enhancing occupants'

comfort and well-being, including appropriate temperature, energy consumption, humidity levels, and other determinants.

3.2 Research Design

3.2.1 Quantitative Method

The researcher will use a quantitative method to capture data on the indoor environment quality (IEQ) of two houses: House 1, 318 and House 2, 320. This will be done using the EnviroQ IEQ measuring device, Testo Thermal Imager, and Tether Hot Drop energy consumption monitor. The Tether EnviroQ device will collect data on temperature, humidity, carbon dioxide, pressure levels in the two buildings, and light levels. The Testo Thermal Imager will capture thermal images of the houses to measure temperature variations. The Tether HotDrop will measure total energy consumption for maintaining a quality indoor environment, while a personalised weather station will monitor external temperature and humidity. The sensors used are illustrated in Fig. 4, 5, 6, and 7.

The data collected from these devices will be analysed and interpreted using various quantitative methods, including descriptive and inferential statistics and regression and correlation analysis. Descriptive statistics will be used to summarise and present the data gathered from the sensors over eight days (4-11 August 2022). This will involve identifying each variable's mean, median, mode, and standard deviation, such as air quality, temperature, humidity, or daily energy consumption. The outcomes of this analysis will provide a clear picture of different determinants contributing to the quality environment of the two houses.

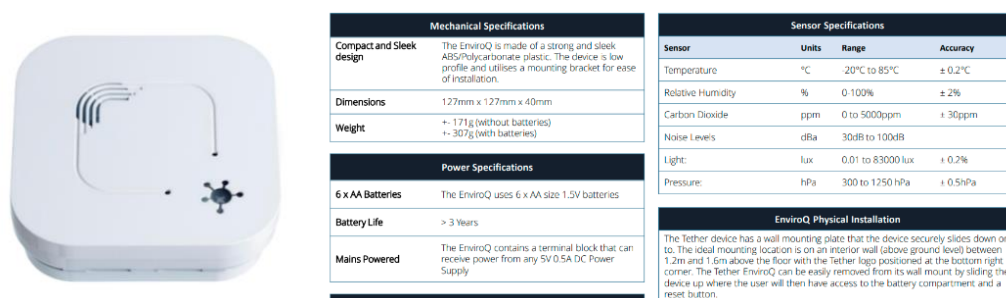


Figure 3. Tether Q specifications

testo 872

testo 872 thermal imager with integrated testo SuperResolution technology, radio module BT/WLAN, USB cable, mains unit, lithium-ion rechargeable battery, professional software (free download), 3 x testo ε-markers, commissioning instructions, calibration protocol and case

Order no. 0560 8721



Technical data

Infrared image output		Imager features	
Infrared resolution	320 x 240 pixels	Digital camera	✓
Thermal sensitivity (NETD)	<0.05 °C (50 mK)	Lens	42° x 30°
Field of view/min. focusing distance	42° x 30° / < 0.5 m	Laser ¹⁾	Laser class 2
Geometric resolution (IFOV)	2.3 mrad	Video streaming	via USB
testo SuperResolution (pixels/IFOV)	640 x 480 pixels	Storage as .JPG	✓
Image refresh rate	9 Hz	Fullscreen mode	✓
Focus	Fixed focus	Image storage	
Spectral range	7.5 to 14 µm	File format	bmt and .jpg; export options in .bmp, .jpg, .png, .csv, .xls
Visual image output		Memory	Internal memory (2.8 GB)
Image size / min. focusing distance	5 MP / min. 0.5 m	Power supply	
Image presentation		Battery type	Lithium ion rechargeable battery exchangeable on site
Image display	8.9 cm (3.5") TFT, QVGA (320 x 240 pixels)	Operating time	4 hours
Digital zoom	2x, 4x	Charging options	In instrument/in charging station (optional)
Display options	IR image / real image	Main operation	✓
Colour palettes	Iron, rainbow, rainbow HC, cold-hot, blue-red, grey, inverted grey, sepia, Testo, Iron HT	Ambient conditions	
Data interface		Operating temperature range	-15 to +50 °C
WLAN Connectivity	Communication with the testo Thermography App	Storage temperature range	-30 to +60 °C
Bluetooth ²⁾	Measurement value transfer from thermohygrometer testo 855i, clamp meter testo 770-3 (optional)	Air humidity	20 to 80 %RH, non-condensing
		Housing protection class (IEC 60529)	IP54
		Vibration (IEC 60068-2-6)	2G

Figure 4. Testo872 Thermal Imager - technical specifications



The Core is the brain and transmitter of any meter that it connects to. The Core can be swapped between various devices built to measure utilities such as electricity, water and gas.

The Core is Portable, Versatile, Durable, Secure and Reliable.

The Core Specifications	
PHYSICAL	
Size	15.90 x 30.80 x 35.0 mm
Weight	42.5g – 227g (Varies by model)
Power Supply	5 VDC 10mA Pogo interface or micro USB
COMMUNICATION	
Sampling Rate	Up to 6,000 samples per second
Data Reporting Rate	1/min (standard), 15-min (optional)
ISM Radio	LoRaWAN: 868 MHz - 928 MHz
Bluetooth	Bluetooth: BLE 5.0; 2.4 GHz
Security	Triple cipher AES rotating encryption
ENVIRONMENT	
Enclosure	Indoor rated. Outdoor weatherproof models available.
Operating Temperature	-40 to +85 degrees Celsius

Figure 5. Tether HotDrop - technical specifications

Description

LTV-TH3 Thermo-Hygro Sensor for use with La Crosse View Connected range series of weather stations.

Features:

- Indoor or Outdoor Temperature Sensor
- Indoor or Outdoor Humidity Sensor
- Swiss Precision Sensor for Greater Accuracy
- LCD Screen - Fahrenheit/Celsius Select-able
- Integrated Mounting Hole
- Ergonomic Base for Free Standing
- Easy Access Battery Compartment
- Over 2 Year Battery Life
- Weather Resistant

Specifications:

- Temperature range: -40c to 60c
- Humidity range: 10% to 99% RH
- Transmission Range: Up to 121 meters in the open air
- Power requirements: 2 AA Alkaline batteries (not included)
- Dimensions: 5cm L x 1.91cm W x 14.55cm H



Figure 6. La Crosse Sensor - technical specifications

Using inferential statistics makes testing hypotheses and generating predictions based on sensor-collected data possible. The aim is to determine whether there are notable differences in indoor environmental quality between two refurbished buildings or at different times of day

or year (Abbass & Hamdy, 2021). For example, the study may investigate whether there is a significant temperature difference between the two refurbished buildings during the winter. Inferential statistics can reveal any trends or patterns in indoor environmental quality over a specific period (Zhang et al., 2022). Regression analysis will establish the link between different variables and indoor environmental quality (Lee et al., 2019). For instance, the analysis may explore how temperature or humidity affects occupant comfort and satisfaction. The regression analysis results may uncover significant correlations between various variables and indoor environmental quality.

3.2.2 Qualitative Method

A qualitative method will be utilised to gather information on occupants' perceptions of indoor environmental quality. This will involve an open-ended questionnaire survey that will be conducted over eight days, with the participation of occupants in two renovated buildings. The survey will aim to gain insight into how comfortable occupants feel and their perception of the occupied space in various situations involving temperature, humidity, air quality, and illuminance. The collected qualitative data will undergo thematic analysis to identify prominent themes and patterns in occupants' perceptions of indoor environmental quality. This analysis involves coding and categorising responses into themes, which will help identify areas for improvement and better understand how occupants assess indoor environmental quality.

3.2.3 Integration of Quantitative and Qualitative Methods

To gain a comprehensive understanding of how indoor environment quality affects occupant comfort and satisfaction in houses 318 and 320, Kinnebrew et al. (2021) utilised both qualitative and quantitative methods. The involved comparing data collected from chosen sensors, such as Tether EnviroQ, HotDrop, and Testo Thermal imager, with insights gained from occupant interviews. By analysing the themes and patterns identified in the interviews, the researchers could determine whether there were any discrepancies between the objective measurements gathered through the sensors and the subjective perceptions of the occupants.

3.2.4 Ethical Considerations

The researcher followed universal ethical principles and Treaty of Waitangi obligations in their selected research method, as the National Ethics Advisory Committee outlined in 2019. Participant privacy and confidentiality were paramount, with consent obtained before interviews or data collection, as noted by DeJonckheere & Vaughn in 2019. The researcher also considered low risks and reported findings in the Annual Report of the Massey University Human Ethics Committee.

To ensure compliance with ethical standards, a comprehensive analysis was conducted, including contingency measures to address any potential risks. The results of the analysis were discussed extensively with the supervisor. Prior to the commencement of the study, ethical approval was obtained from Massey University and can be found in Appendix A, along with the Ethics Notification Number 400026290.

This study employs a mixed research method combining qualitative and quantitative approaches to explore the impact of indoor environment quality on occupant comfort and satisfaction in two refurbished buildings in New Zealand, as detailed by Hou et al. in 2023. Quantitative data will be collected using indoor environment quality sensors. In contrast, qualitative data will be gathered through open-ended interviews with occupants to identify emerging themes and patterns, as described by Li et al. in 2018. Utilising these methods will achieve a thorough understanding of the relationship between indoor environment quality and occupant comfort.

3.3 Validation of the Sensors

3.3.1 Tether EnviroQ

The Tether EnviroQ indoor environment quality device has undergone validation testing, which has confirmed its accuracy in measuring temperature, humidity, carbon dioxide levels, light intensity, and pressure (Ade & Rehm, 2021). The testing has shown that the device is reliable and accurate when measuring indoor environmental quality. This device aligns with the study's research objectives, as it will be used for data collection on the indoor environmental quality of two renovated buildings in West Auckland. The data collected through the Tether EnviroQ

device will be crucial in assessing the impact of indoor environmental quality on occupants' comfort and satisfaction. By monitoring temperature, humidity levels, luminance, CO2 concentration, and interior air quality, the device can provide concrete data demonstrating how the external and internal environment affects human behaviour and influences occupants' perception of comfort and well-being.

3.3.2 Testo872 Thermal Imager

The Testo 872 thermal imager is a reliable tool to detect temperature differences, potential leaks, and humidity caused by water infiltration. It identifies areas with insufficient insulation through dark spots indicating lower temperatures, as well as escaping warm or hot air due to unsealed doors or windows, single-pane windows, non-insulated entrance doors, non-insulated ceiling or attic openings, ducts that pump in cold and damp air, extractors that suck up hot air, and ventilation grills around basement-piled houses (Zuhaib et al., 2018). This device ensures accurate temperature readings and helps to locate areas with air leaks and moisture problems that can impact occupant comfort and health. The Testo thermal imager can assess people's comfort and perception in occupied areas exposed to temperature and humidity variations. This information is essential for providing solutions that meet or exceed the H1/AS1 Energy Efficiency standard for internal occupant comfort and well-being. It is crucial to maintain a "good" renovation of old buildings to promote the health and wellness of their occupants.

3.3.3 Tether Hot Drop

The validation of the Tether Hot Drop sensors is critical for the research, as it is responsible for the accuracy of the energy data collected from the buildings. This innovative device utilises state-of-the-art wireless CT with data collection technology requiring neither wires nor batteries. The sensors are installed in less than 20 seconds. Using its cutting-edge wireless transmitter, it can send signals across 10 km with direct visibility. In the challenging of conditions, it supplies convenient, live energy metrics. HotDrop's minimal physical design allows it to slot into the most confined areas. The instantaneous information guarantees exact setups. This platform has been designed to support expansion and incorporates encrypted messaging to ensure utmost confidentiality and protection.

Furthermore, it also possesses a wireless setup for adjusting and upgrading in diverse surroundings, mobile device synchronisation for quick setup, and three-phase wireless cooperation for industrial and utility-grade deployments. This product is offered in different energy rating options. This technology tackles even the tiniest and most complex problems related to energy tracking. Hence, providing critical insights into the energy consumption data in the two houses utilised to maintain the IEQ will be crucial.

3.3.4 Personalised Weather Station (PWS)

To ensure precise and consistent temperature and humidity readings, the PWS V40A-PROv2 is crucial in this research. The Personal Weather Station sources data from trustworthy weather monitoring sources or stations nearby. This helps maintain the accuracy and consistency of the PWS data. By establishing the correlation and reliability of the PWS readings with external references, researchers can confidently rely on the PWS data. This enhances the credibility of the research outcomes by ensuring that the temperature and humidity data used in the study are reliable and representative of the designated region.

3.4 Data Collection

3.4.1 Placement of the Sensors

Strategically placed sensors within specific buildings were crucial to reliably track the quality of the indoor environment and understand how it affects the comfort and satisfaction of its occupants (Dong et al., 2019). For House 2 at location number 320, Tether EnviroQ sensors have been installed in the living room, kitchen, main bedroom, mid bedroom, and bathroom to collect temperature, humidity, carbon dioxide concentrations, luminosity, and pressure data. Meanwhile, Tether Hot Drop and La Crosse sensors have been placed in the main power box, outdoor (north), and indoor air vent ducts to monitor energy consumption for each house with independent main power.

The La Cross remote sensors in the attic space have been installed in Building 1 at 318 and Building 2 at 320. To monitor the indoor environmental quality (IEQ), Tether EnviroQ sensors have been placed in various locations, including the office, bedroom 1, bedroom 2, bathroom/laundry, and open plan living room/kitchen. The Tether HotDrop sensors have been strategically placed in multiple grids to monitor energy consumption effectively. Temperature

and humidity levels are observed through Personal Weather Station (PWS) sensors strategically located outside and within both buildings.

The placement of sensors has been determined by identifying areas where occupants frequently reside, as outlined in Weston et al. 2019. For instance, in Building 2, sensors have been positioned in areas such as the living room, kitchen, bathroom, and bedroom spaces that experience high occupancy. The positioning of sensors has also been influenced by the need to collect data from different zones within the facility for a comprehensive assessment of IEQ. For this reason, Tether EnviroQ sensors have been placed in various rooms in both House 1 and 2, allowing for data collection from diverse locations within the building. Appendix C and D.

The strategic placement of sensors is crucial for accurately monitoring IEQ, which can enhance occupants' comfort and satisfaction. Quantitative and qualitative approaches will be employed to analyse the data collected from these sensors. This will allow for a detailed examination of IEQ and its influence on occupants.

3.4.2 Sampling of Sensors Data

From August 4th to 11th, 2022, sensors strategically placed in various buildings will gather data on indoor environment quality (IEQ) and energy consumption. The Tether EnviroQ sensors, positioned in ventilation ducts, extractors, and attics, will obtain information on temperature, humidity level, carbon dioxide concentration, light intensity, and pressure. The Tether HotDrop sensors will also track energy consumption, while the PWS La Crosse remote sensors will monitor temperature and humidity levels.

For House 2, 320, the temperature recorded by the Tether EnviroQ sensors will range from -5 to 40 degrees Celsius. House 1, 318, will experience a temperature range of -5 to 45 degrees Celsius, with humidity ranging from 20% to 70%. The Tether HotDrop sensors will capture energy usage data from Building 1 and 2, up to 1200kWh.

The PWS sensors will record data on temperature and humidity levels, encompassing temperatures between -5 and 25 degrees Celsius in both houses, along with humidity levels ranging from 20% to 70%. Through quantitative and qualitative methods, the collected data will undergo analysis to extract crucial insights into how IEQ impacts occupants' comfort and

satisfaction. The findings from this analysis can then be used to pinpoint areas that require enhancement.

3.4.3 Qualitative Sampling

The research involved utilising open-ended questionnaires administered through Survey Monkey via text messages on smart watches or Apple Watch with the occupants of selected buildings to gather qualitative data on their perception of indoor environment quality (IEQ) (Wagner et al., 2018). The survey comprised four participants, with two occupants from each building participating. The questionnaire included questions about the well-being and satisfaction of the residents in particular areas of the buildings that experienced different environmental conditions such as temperature, humidity, and air quality. The qualitative data collected will be examined through thematic analysis to identify significant themes and patterns in how occupants perceive IEQ (Calleja, 2018). The combination of numerical and descriptive data helps to develop a comprehensive understanding of how IEQ impacts the comfort and satisfaction of occupants. By using the internet portal Survey Monkey a self-report questionnaire was created for the first part of the survey dedicated to; Survey1 Winter August 2022 Buildings; 318/320 Monitoring the effect of Indoor Environmental Quality (IEQ) on occupant's comfort and satisfaction (<https://www.surveymonkey.com/r/CMKVJWM>).

The second part of the survey dedicated to; One-off Survey – 2022 Occupancy Characteristics Buildings; 318/320 Monitoring the effect of Indoor Environmental Quality (IEQ) on occupant's comfort and satisfaction (<https://www.surveymonkey.com/r/Z6JQ528>). A full copy of the questionnaires is in Appendix E, and F.

3.5 Data Analysis

3.5.1 Quantitative Analysis

To achieve our research objectives, we collected data from sensors and utilized various quantitative techniques as described in our methodology. Our analysis involved using SPSS, a Statistical Package for the Social Sciences and included descriptive statistics, inferential statistics, correlation analysis, and regression analysis to thoroughly examine the data (Türkeş et al., 2019). Descriptive statistics were utilised to display the information collected from sensors between August 4-11, 2022. All variables, including temperature, humidity, CO2 levels, lux level, and energy consumption, will be separately calculated for their mean, median, mode,

and standard deviation. These statistics offer valuable insights into the indoor environment quality of the two houses, as demonstrated by Zuhaib et al. in 2018.

Using inferential statistics, hypotheses were tested, and predictions were generated using the gathered sensor data. Significant variations in indoor environmental quality were explored between the two refurbished buildings and at different moments throughout a day or year. For instance, notable disparities in temperature between the two edifices in winter were examined. Inferential statistics revealed trends and patterns in indoor environmental quality over a specific timeframe (White et al., 2018).

An investigation into the relationships between variables and indoor environmental quality is set to be conducted through a correlation analysis. This will involve a careful assessment of how factors such as temperature and humidity impact the comfort and satisfaction of occupants. A thorough correlation analysis will uncover essential connections between various variables and indoor environmental quality, revealing the key factors contributing to occupant well-being (Tang et al., 2020). Furthermore, this analysis will offer valuable insights into how to optimise indoor environmental conditions and enhance occupant satisfaction.

The quantitative methods employed in this study hold great significance as they provide empirical evidence and statistical analysis on the relationship between indoor environmental quality and occupant comfort and satisfaction. Through rigorous analysis of the collected data, researchers can identify areas for improvement and propose practical measures aligned with energy efficiency goals (Savacgal et al., 2018). Moreover, to comprehensively analyse the impact of indoor environment quality on occupants, quantitative analysis will be complemented by qualitative data gathered through open-ended survey questionnaires administered via the Survey Monkey-Text on the Apple Watch or smartwatch. This integration of quantitative and qualitative data will contribute to enhancing comfort and well-being in refurbished buildings.



*Figure 7. Questionnaires throughout iWatch
Source: Author's contribution*

3.5.2 Thematic Analysis

The study delved deeply into the occupants' perspectives by analysing the data collected from open-ended questionnaire surveys presented in Appendix E & F. A thematic analysis approach was employed to identify recurring themes, patterns, and meanings within the interview transcripts (Bennett et al., 2019).

The responses were then thoroughly analysed to pinpoint emerging themes from the gathered data. These themes offered valuable insights into the occupants' attitudes, experiences, and perceptions of indoor environment quality in the remodelled buildings. The study fully understood how the indoor environment impacted their overall well-being and satisfaction by exploring the subjective aspects of occupant comfort and satisfaction through thematic analysis (Villeneuve & O'Brien, 2020).

3.5.3 Architectural Floor Plans

The performances and discrepancies between the two buildings were further understood through aerial satellite photographs and simplified architectural floor plans, as presented in Appendix B, C, and D (Kamali et al., 2018). These floor plans visually depicted the building's layout, showcasing room sizes, window and door locations, and air conditioning and ventilation system placement by carefully analysing the floor plans of both buildings, potential variations in the arrangement of spaces and architectural characteristics that could impact indoor environment quality were identified. This analysis was crucial in comprehending the impact of building design and layout on occupant comfort and satisfaction, providing valuable insights that can inform improvements to indoor environments in future refurbishment projects (Lee, 2019).

3.5.4 Pilot Project

The purpose of the pilot project was to assess the efficacy of the research methodology, validate data-gathering methods, and identify any potential issues or opportunities for improvement before embarking on the primary research initiative. By optimising sensor placement and refining interview techniques, the accuracy and legitimacy of the data were ensured (Malmqvist et al., 2019). The pilot project played a critical role in minimising errors, enhancing data quality, and boosting the overall efficiency of the primary research project.

During the pilot project, adjustments were made to improve data collection and ensure that the research methodology was robust. The insights gained from the pilot project informed the refinement of protocols and procedures for the primary research effort, resulting in a more streamlined and effective data collection process.

The schedule for the pilot project is outlined below:

3.5.4.1. Pilot Project Schedule:

NAME	DURATION	START	FINISH
Research Scope & Identification Research Problem	10	28/1/2022	06/2/2022
Literature review to establish knowledge gap	31	10/3/2022	09/4/2022
Establishing Objectives	2	26/3/2022	27/3/2022
Selection of the Buildings	1	01/4/2022	01/4/2022
Collection of the Tether sensors, HotDrop & Thermal Imaging Camera	2	19/7/2022	20/7/2022
Sensor' calibration & uploading into a software	4	19/7/2022	22/7/2022
Locating & Installation of the Sensors	1	19/7/2022	19/7/2022
Technical consultation- additional installation of the hardware LoRaWAN to gain the signal??	3	20/7/2022	22/7/2022
Additional installation of the Personal Weather Station (PWS) & remote sensors La Crosse	1	25/7/2022	25/7/2022
Floor plan drawing with location of the sensors	4	07/6/2022	10/6/2022
Initial testing of the sensors & software	2	13/7/2022	14/7/2022
Initiating tracking sensors data	21	22/7/2022	11/8/2022
Creating questionnaires & supervisor consultation	3	23/7/2022	25/7/2022
Ethical consent approval & signing with participant's consent	4	03/7/2022	06/7/2022
Test sending questionnaires & initial answers	1	02/8/2022	02/8/2022
5 days pilot project- Test	5	28/7/2022	01/8/2022
Recording Measurements and images from Testo 872 thermal imaging camera	6	06/8/2022	11/8/2022
Initiating survey with questionnaires	8	04/8/2022	11/8/2022
Data collection & Occupant's responses	8	04/8/2022	11/8/2022
Data Analysis	1	24/8/2022	24/8/2022
Supervisor consultation	1	24/8/2022	24/8/2022
Thesis write up and Submission	649	28/1/2022	8/11/2022

Table 1. Project Schedule

Chapter 4

Findings and Analysis

4.1 Introduction

This project aims to delve into the intricacies of how both external and internal environments and human conduct can impact the ease and welfare of inhabitants. Our data analysis aims to ascertain the ideal living parameters for occupied spaces. Our primary focus will be pinpointing crucial factors, such as CO₂ concentration and humidity levels, as they can significantly influence our mental well-being, contentment, and physical health, particularly concerning respiratory issues.

"If you are sharing air, the lower the CO₂, the lower risk of infection", (Jose-Luis Jimenez).

Jose-Luis Jimenez, an aerosol scientist at the University of Colorado Boulder, has emphasised that maintaining lower carbon dioxide (CO₂) levels in indoor environments can significantly reduce the risk of COVID-19 transmission. According to him, when individuals share air in a closed space, the concentration of exhaled CO₂ increases and indicates poor ventilation and a higher likelihood of infectious aerosol accumulation. Hence, reducing CO₂ levels by improving ventilation or increasing the air exchange rate can be an effective measure to mitigate the spread of the virus.

4.2 Analysis of Findings

The research used a mixed-method approach, utilising both qualitative and quantitative data. This section analyses and discusses the data collected from the indoor environment quality (IEQ) sensors and the Survey Monkey survey.

4.3 Qualitative Analysis

The combination of sensor data and survey responses allowed for a comprehensive indoor environment quality assessment, providing objective measurements and subjective perceptions. This qualitative analysis offers valuable insights for facility managers, designers, and occupants to make informed decisions for improving IEQ in the future.

4.3.1 HotDrop Findings

Leveraging the data acquired from HotDrop wireless sensors that gauge the energy consumption of occupants and combining it with qualitative analysis, researchers and

stakeholders can extract valuable insights into the Indoor Environmental Quality (IEQ) of indoor spaces. This comprehensive approach provides an in-depth understanding of energy consumption patterns, enabling targeted interventions and environmental improvements that enhance occupant well-being, health, and comfort.

4.3.1.1 Building 318, HotDrop 4-11/8/2022 Period.

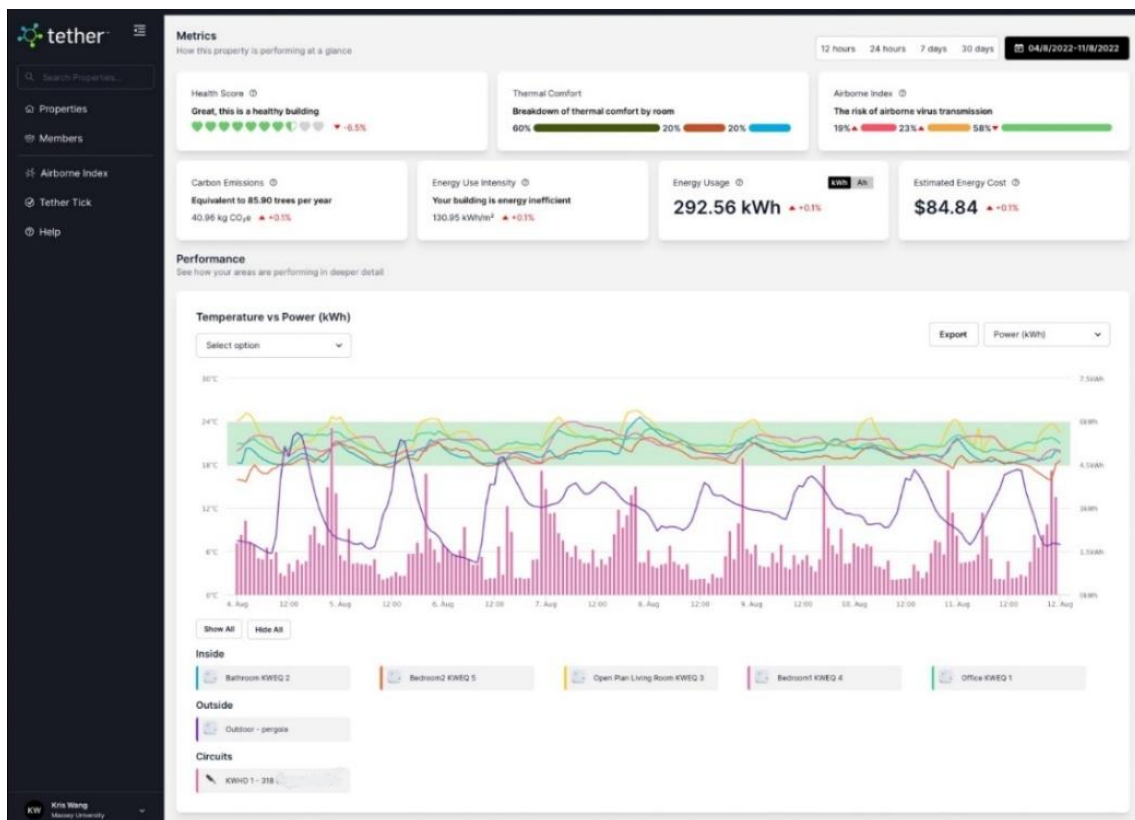


Figure 8. Temperature vs power performance - Building 318

The analysis of metrics depicted in the graph revealed that the sensors measure crucial parameters that hold significant technical importance. Some of these parameters include:

- **Health Score:** The property has a health score of "Great, this is a healthy building" with an 8.5% increase.
- **Thermal Comfort:** It displays the thermal comfort breakdown by room. 60% of rooms are comfortable, 20% are uncomfortable, and 20% are neutral.
- **Airborne Index:** This metric shows the risk of airborne virus transmission. The risk level is green (which is typically considered safe), with 233 IAQ (Indoor Air Quality) and a 58% improvement.
- **Carbon Emissions:** The property has an emission equivalent to 850 trees per year and has decreased its carbon footprint by 0.01%.

- **Energy Use Intensity (EUI):** The building is considered "inefficient" with a reading of 130.95 kWh/m², which has increased by 0.01%.
- **Energy Usage:** The property has used 292.56 kWh of energy.
- **Estimated Energy Cost:** The estimated cost for the energy consumed is \$84.84, with a 0.01% decrease.

The study conducted on performance analysis included an examination of the relationship between temperature and power consumption (kWh). The analysis was conducted by studying the correlation between temperature and power consumption over time, as demonstrated in the graph. The graph shows the colourful area lines that depict the temperature in different rooms, including the bathroom, bedroom, open-plan living room, and office. The jagged purple line represents the power consumption, and it shows how the temperature fluctuates throughout the days, along with power usage spikes at various times.

4.3.1.2 Building 320, HotDrop 4-11/08/2022 Period

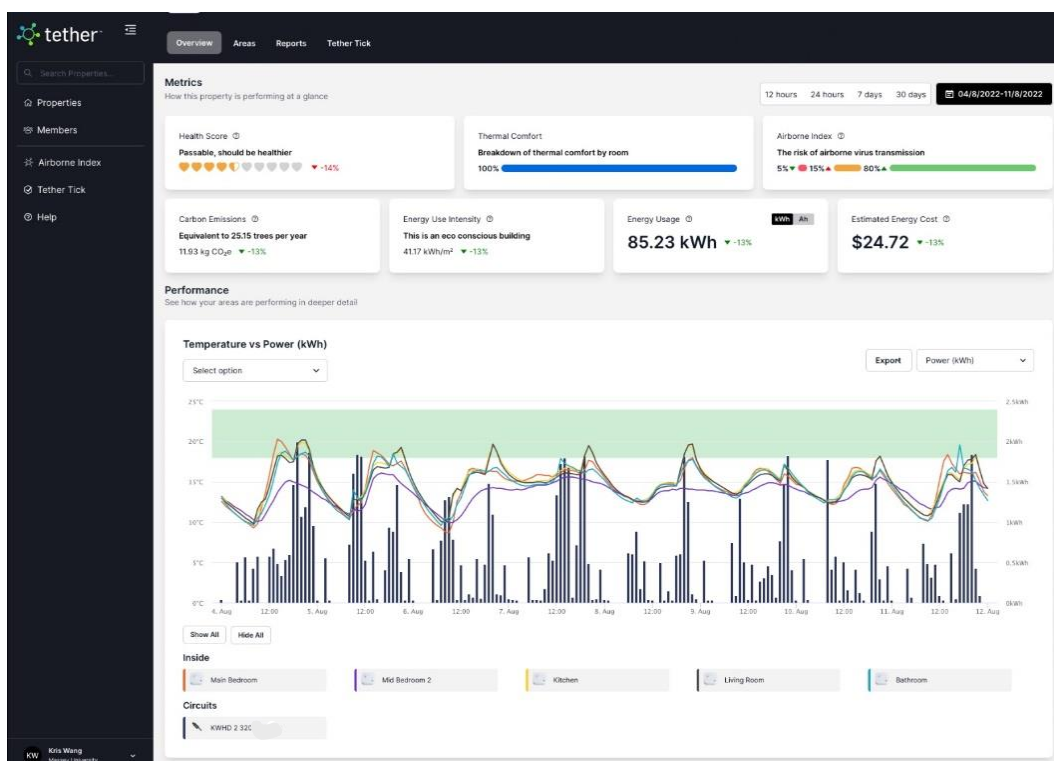


Figure 9. Temperature vs Power performance - Building 320

Based on the results of the investigation, the graphical metrics reveal that:

- **Health Score:** The property is rated as "Passable should be healthier," with a decrease of 14% in its health score.
- **Thermal Comfort:** The property boasts a 100% thermal comfort across all rooms.
- **Airborne Index:** This metric assesses the risk of airborne virus transmission. The property exhibits a green risk level, which generally denotes a safe range. The index value is 515 IAQ (Indoor Air Quality), reflecting an 8% improvement.
- **Carbon Emissions:** The property's emissions are equivalent to 255 trees per year, which has increased by 13%.
- **Energy Use Intensity (EUI):** The property is designated as "an eco-conscious building," with a EUI of 41.17 kWh/m², marking a 13% decrease.
- **Energy Usage:** Energy consumption stands at 85.23 kWh.
- **Estimated Energy Cost:** The energy costs are calculated at \$24.72, reflecting a 13% decrease.

The study's findings on the correlation between indoor temperatures and energy consumption over time were presented through a Temperature vs. Power (kWh) graph. The graph displayed the temperatures of different areas, such as the Main Bedroom, Bedroom 2, Kitchen, Living Room, and Bathroom, through various colourful lines. The jagged blue bars indicated the power consumption and showed distinct spikes during specific times, which could be associated with specific activities or appliances.

In the case of circuits, the analysis includes specific information on power consumption for circuits, such as "KW02 - 3D" steps. The property strives to be eco-conscious, as shown by the energy use intensity and cost reduction. A thermal comfort level of 100% indicates that all rooms in the property maintain a comfortable temperature. The improved airborne index suggests measures have been taken to enhance indoor air quality.

4.3.2 Personal Weather Station (PWS) Findings

August 1, 2022 – August 31, 2022 (4-11 August 2022) Period

In August 2022, the personal weather station at location "IAUCKLB47" recorded a range of temperatures from cold to mild, with intermittent rainfall, particularly on the 7th and 19th. Wind speeds fluctuated throughout the month, and a few gusty days were observed. The atmospheric pressure remained relatively stable. The study highlighted the analysis of some critical parameters.

Summary (August 1, 2022 - August 31, 2022)

- Temperature:
 - High: 22.2°C
 - Low: 2.3°C
 - Average: 12.1°C
- Dew Point:
 - High: 18.4°C
 - Low: -0.1°C
 - Average: 9.9°C
- Humidity:
 - High: 96%
 - Average: 88%
 - Low: 45%
- Precipitation:
 - Total: 138.68 mm
- Wind:
 - Speed:
 - High: 27.0 km/h
 - Average: 2.0 km/h
 - Low: 0.0 km/h
 - Gust:
 - High: 28.0 km/h

-
- Direction:
 - Average: Northwest
- Pressure:
- High: 1,033.9 hPa
 - Low: 1,009.14 hPa

Graphs:

- Temperature and Dew Point:
- The red line represents temperature changes throughout the month.
 - The green line represents the dew point.
 - It is noticeable that both curves follow a similar pattern with temperatures peaking mid-month and then gradually decreasing.
- Wind Speed and Wind Gust:
- The blue dots showcase wind speed.
 - The orange dots depict wind gust speeds.
 - There are periodic spikes in wind gusts, indicating occasional gusty days.
- Wind Direction:
- Blue dots represent the direction of the wind.
 - From the vertical axis labels, it can be inferred that W stands for West, S for South, E for East, and N for North.
- Precipitation:
- The green bars show the accumulated precipitation for each day.
 - The dark line highlights the precipitation rate.
 - There is noticeable rainfall around the 7th and the 19th of August.
- Pressure:
- The black line highlights atmospheric pressure changes.
- Humidity:
- Humidity indicates from the 1st of August 2022 to the 31st of August 2022, 99% High, 45% Low, 88% Everage.

A relatively steady pattern can be observed, with minor fluctuations throughout the month as demonstrated below:

Weather History for IAUCKL847

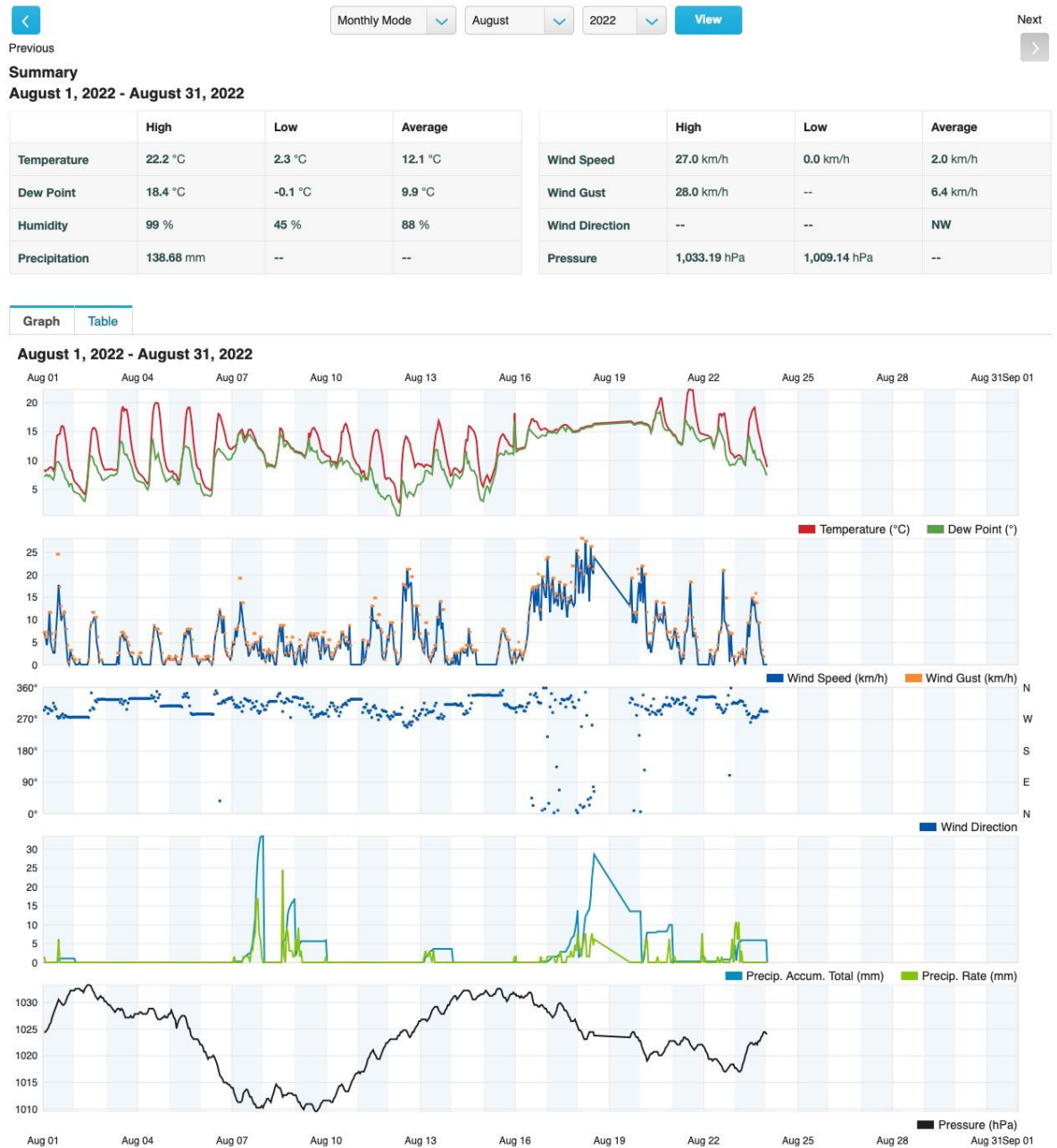


Figure 10. Monthly summary from the Personal Weather Station (PWS) - outdoor

4.3.3 Tether Sensors Findings

4.3.3.1 Monthly Report 318 Building August 2022, 4-11 / 08/2022

Bathroom KWEQ 2 - temperature

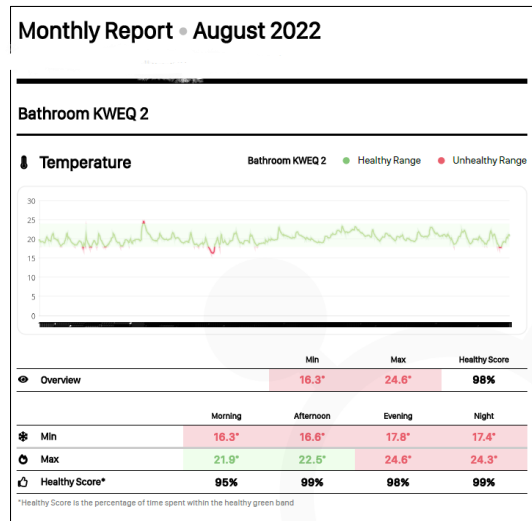


Figure 11. Tether monthly report, Bathroom – temperature

Below given graph demonstrate Humidity and CO2:

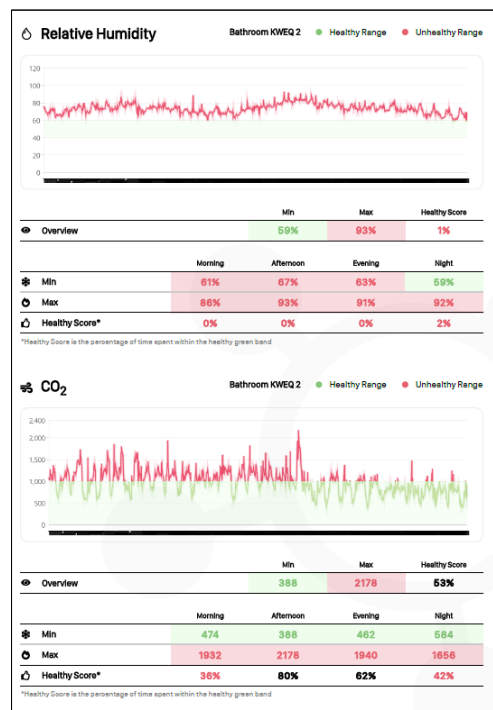


Figure 12. Tether monthly report, Bathroom - relative humidity and CO2

Bedroom1 KWEQ 4

The graphical representation showcased below elucidates the correlation between Temperature and Relative Humidity.



Figure 13. Tether monthly report, Bedroom1 - temperature and relative humidity

The graph below presents a comprehensive analysis of CO2 levels, showcasing the minimum and maximum values and the healthy score ranges.

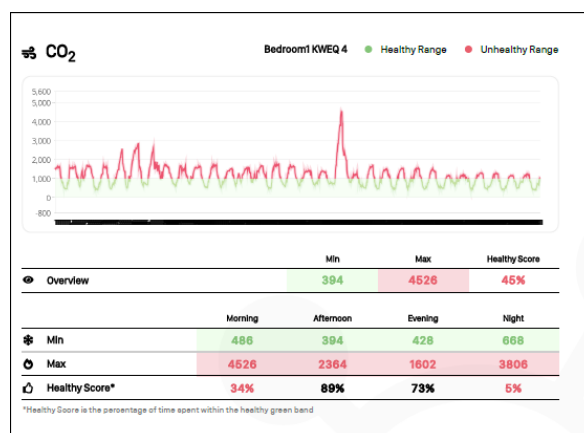


Figure 14. Tether monthly report, Bedroom1 - CO2

Bedroom2 KWEQ 5

The following graph illustrates the correlation between human activities and temperature fluctuations.

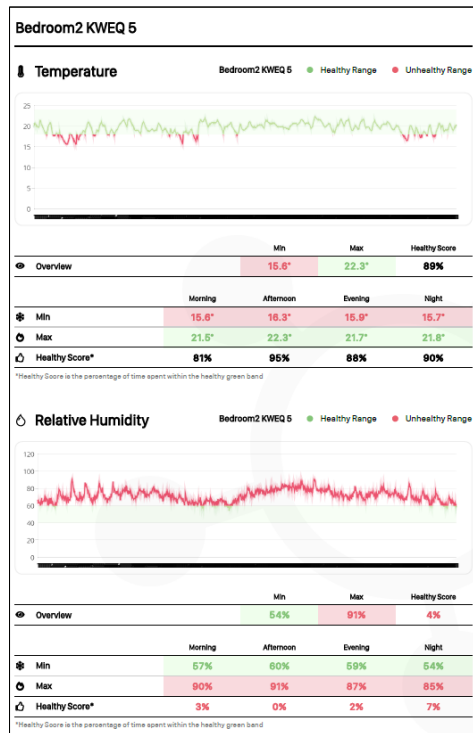


Figure 15. Tether monthly report, Bedroom2 - temperature and relative humidity

The graph below presents an overview of CO2 levels, including minimum, maximum, and healthy scores.

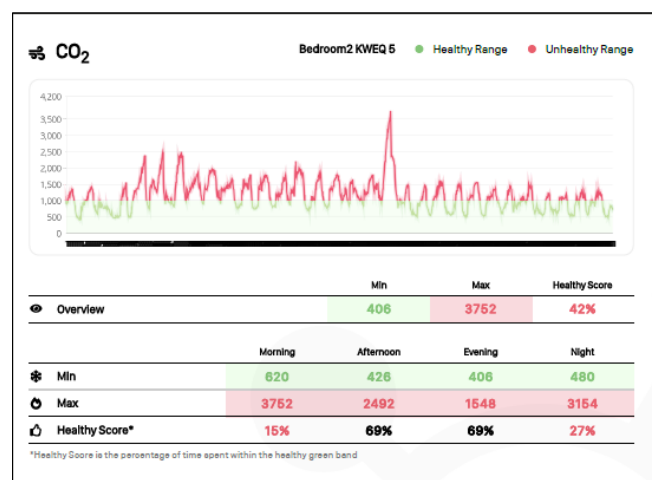


Figure 16. Tether monthly report, Bedroom2 - CO₂

Office KWEQ 1

The chart illustrates the relationship between temperature and human activity levels for KWEQ 1.

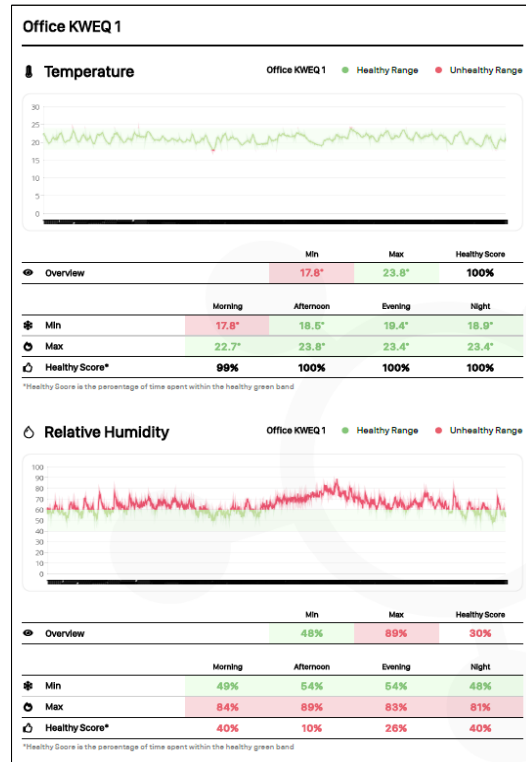


Figure 17. Tether monthly report, Office - temperature and relative humidity

The graph illustrates CO2 levels, including minimum/maximum values and healthy/unhealthy ranges.

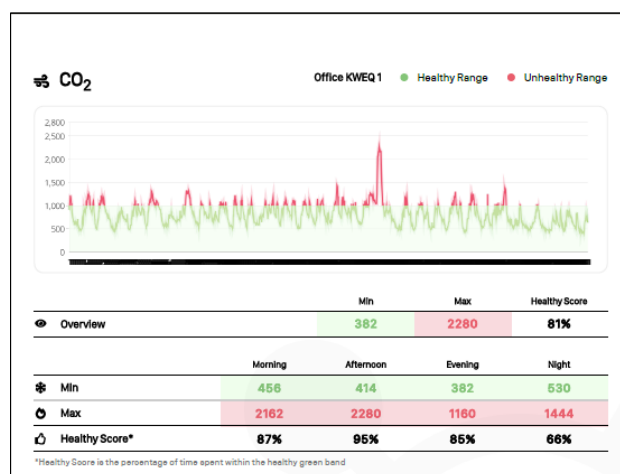


Figure 18. Tether monthly report, Office - CO2

Open Plan Living Room KWEQ 3

The following graph depicts the correlation between the temperature and the relative humidity for KWEQ 3:



Figure 19. Tether monthly report, Open Plan Living Room - temperature and relative humidity

The graph illustrates the minimum, maximum, and healthy CO2 ranges.

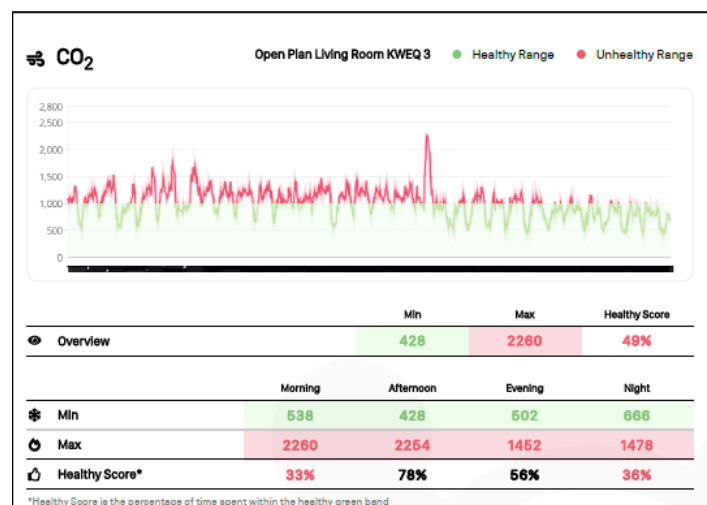


Figure 20. Tether monthly report, Open Plan Living Room – CO₂

Outdoor - Pergola

The graph below illustrates the correlation between temperature and human comfort for an outdoor pergola.



Figure 21. Tether monthly report, Outdoor Pergola - temperature and relative humidity

The graph below shows an overview of CO2 levels, with areas representing healthy and unhealthy ranges based on minimum, maximum, and healthy scores.

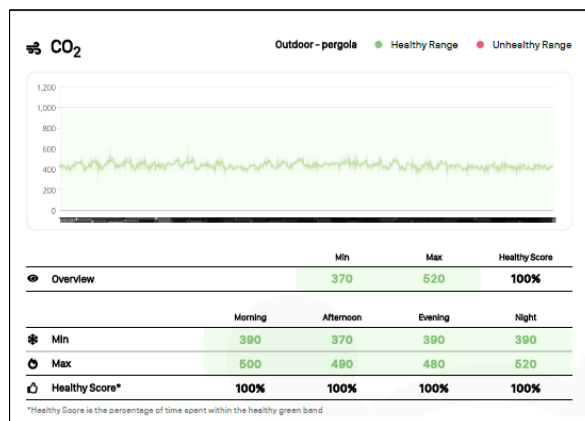


Figure 22. Tether monthly report, Outdoor Pergola – CO₂

4.3.3.2 Monthly Report 320 Building August 2022, 4-11 / 08/2022

KWEQ 10 Bathroom

The graph below illustrates the temperature changes in a bathroom.

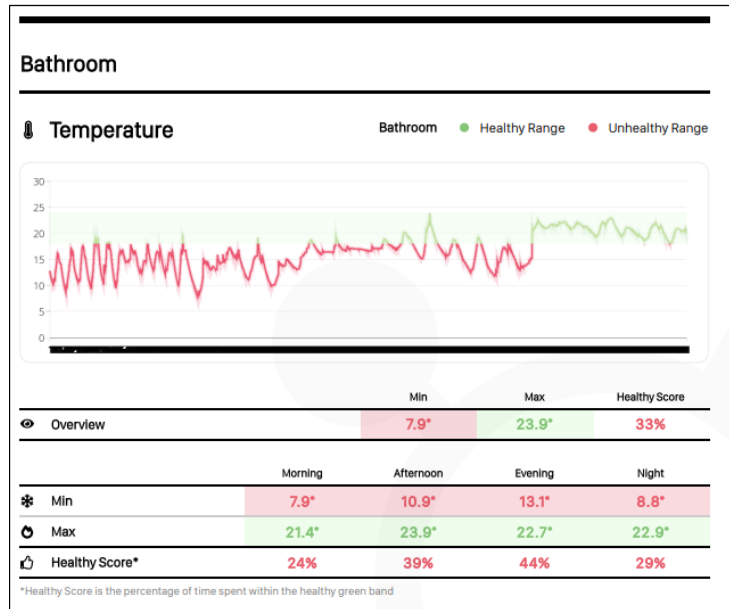


Figure 23. Tether monthly report, Bathroom – temperature

The graph below shows the correlation between the amount of carbon dioxide produced and the level of human activity in a bathroom.



Figure 24. Tether monthly report, Bathroom - relative humidity and CO2

KWEQ 7 Kitchen

The graph below shows the temperature and relative humidity levels in the kitchen.



Figure 25. Tether monthly report, Kitchen - temperature and relative humidity

The graph below illustrates the amount of CO2 emitted in the kitchen.



Figure 26. Tether monthly report, Kitchen – CO2

KWEQ 6 Living Room

The graph below illustrates a living room's temperature and relative humidity levels.



Figure 27. Tether monthly report, Living Room - temperature and relative humidity

The graph below shows the carbon dioxide levels in the living room.



Figure 28. Tether monthly report, Living Room – CO₂

KWEQ 8 Main Bedroom

The graph below shows the main bedroom's temperature and relative humidity levels.



Figure 29. Tether monthly report, Main Bedroom - temperature and relative humidity

The graph below illustrates the levels of CO₂ in the main bedroom.

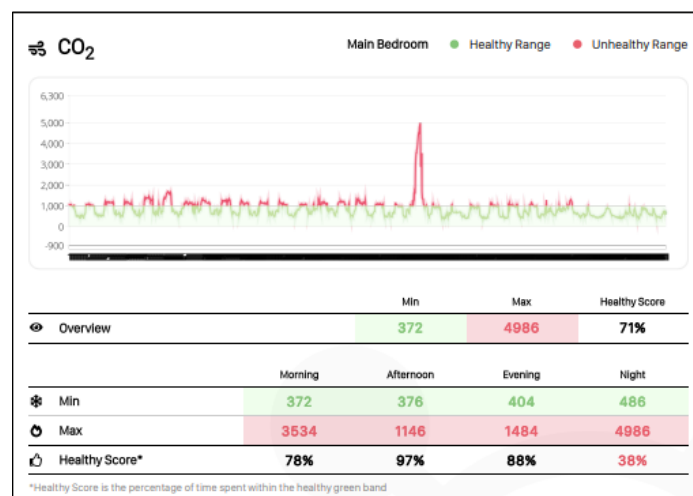


Figure 30. Tether monthly report, Main Bedroom – CO₂

KWEQ 9 Mid Bedroom 2

The graph below illustrates the temperature and relative humidity for the mid-bedroom 2.

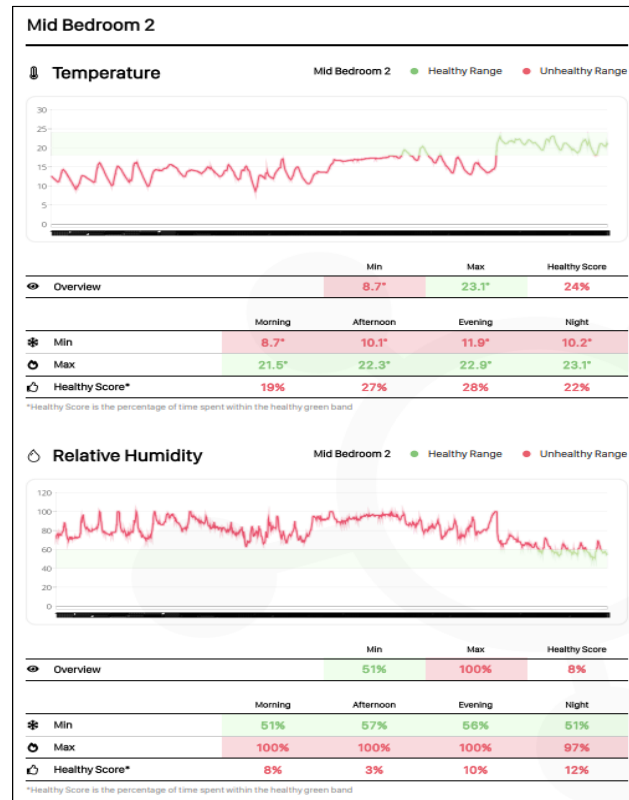


Figure 31. Tether monthly report, Mid Bedroom2 - temperature and relative humidity

The graph below shows the levels of CO₂ in the main bedroom.

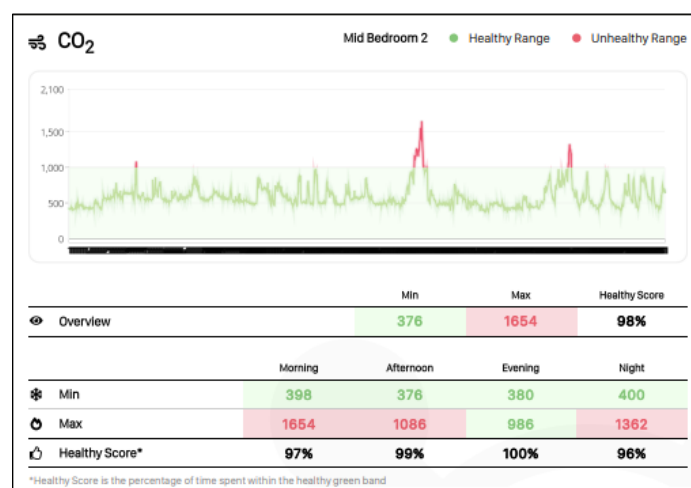


Figure 32. Tether monthly report, Mid Bedroom2 – CO₂

4.3.4 Testo 872 Thermal Imaging Findings

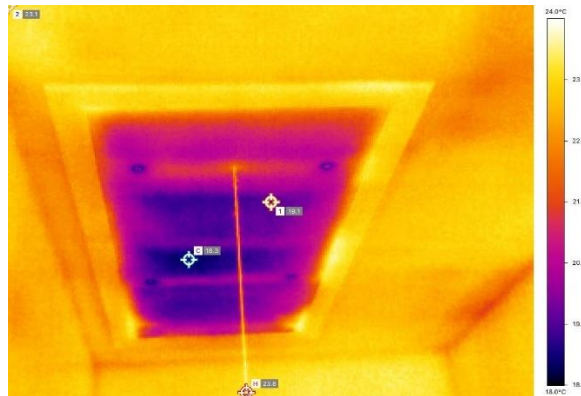


Figure 33. Tether monthly report, Mid Bedroom2 – CO2
Source: Author's contribution

Colour Palette:

To the right of the image, a colour scale is displayed to indicate temperature values. This scale ranges from 18.0°C at the bottom, denoted by the darkest hue, to 24.0°C at the top, represented by the brightest shade. The image's colours reflect the temperatures they signify—the warmer regions are depicted with brighter hues, while darker tones represent the more excellent areas.

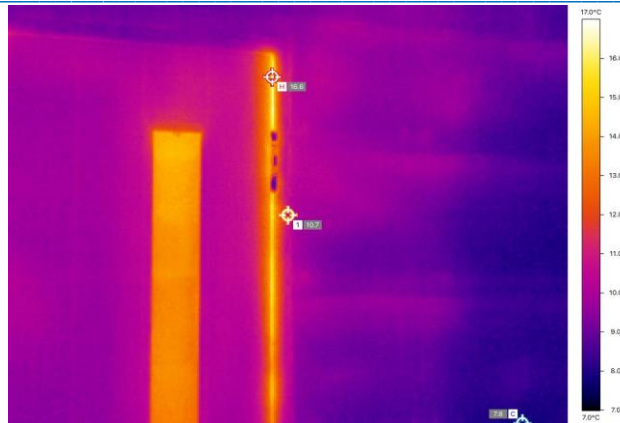
Thermal Distribution:

The rectangular space at the scene's centre emits a cooler temperature than its surroundings. Its colour palette mainly consists of shades of purple and blue, indicating a temperature range of approximately 18.0°C to 21.0°C. In contrast, the frame or wall area surrounding the central space appears significantly warmer, with a yellow-orange hue that suggests a temperature closer to 24.0°C.

Specific Temperature Points:

There are three crosshair markers, each indicating a different temperature value.

- The highest marker denotes a temperature of 19.1°C.
- The middle marker indicates that the coolest point within the central rectangle is at 18.3°C.
- On the other hand, the lowest marker is situated outside the central rectangle, in the surrounding warmer space, and marks a temperature of 23.8°C, close to the warmest point in the image.



*Figure 34. A non-insulated entrance door, heat escape from the side of the door and glass panel
Source: Author's contribution*

Figure 34. has been analysed, and based on the results, some interpretations have been made.

Colour Palette:

The image's right side displays a colour-coded temperature scale ranging from 7.0°C (darkest colour) to 17.0°C (brightest colour). The colours shown in the image are directly proportional to the temperature values they represent.

Thermal Distribution

On the left side of the image, a vertical structure appears to be radiating a bright yellow-orange hue, indicating that it is likely at the higher end of the temperature scale, around 16.0°C to 17.0°C. Adjacent to this structure on the right side is a narrower vertical strip that appears slightly cooler, displaying an array of colours that suggest temperature variations. At the top of this strip, the temperature point indicates a warmer temperature of around 16.6°C, which gradually decreases as we move downwards. The surrounding area in most of the image appears purple, indicating cooler temperatures likely ranging from 7.0°C to 10.0°C.

Specific Temperature Points:

This display has three crosshair markers, and a temperature value accompanies each.

- The top marker on the slender vertical strip indicates a temperature of 16.6°C.
- The middle marker on the slender vertical strip, indicates a temperature of 10.7°C.
- The bottom marker, outside the main structures in the cooler region, indicates a temperature of 7.8°C.



Figure 35. A view of the same door from outside
Source: Author's contribution

The interpretation of the *Figure 35*. has been derived from the analysis of the graph provided:

Colour Palette:

On the right side of the image, there is a colour scale that indicates temperature values, ranging from 5.0°C (darkest colour) to 15.0°C (brightest colour). The colours within the image correspond to this temperature scale.

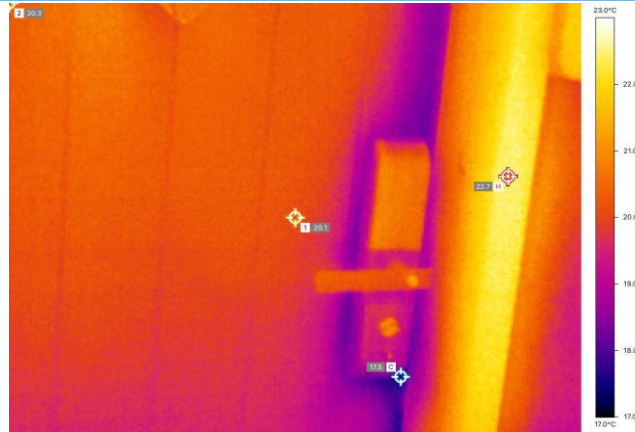
Thermal Distribution:

The image's focal point displays a striking vertical formation with a vivid yellow-orange tint, hinting at its elevated warmth. The temperature appears to reach the upper limits of the spectrum, hovering between 13.0°C and 15.0°C. An interesting aspect is the upright, rectangular hollow or groove on this heated structure, portrayed in a marginally cooler hue than the encompassing region. Furthermore, the backdrop and nearby vicinity of the image are depicted in a cool purple shade, indicating temperatures from 5.0°C to 9.0°C.

Specific Temperature Points:

Three crosshair markers are placed in the image, each associated with a temperature value:

- The top marker, positioned on the upper section of the vertical structure, indicates a temperature of 14.7°C.
- The middle marker, located within the rectangular recess on the vertical structure, indicates a temperature of 9.6°C.
- The bottom marker, which is set in the cooler purple background area, indicates a temperature of 5.7°C.



*Figure 36. A view of the door handle and locker
Source: Author's contribution*

Based on the graph analysis provided above, specific interpretations are being made.

Colour Palette:

The image includes a colour scale on the right side, indicating temperatures ranging from 17.0°C (darkest colour) to 23.0°C (brightest colour). The colours in the image correspond to this temperature scale.

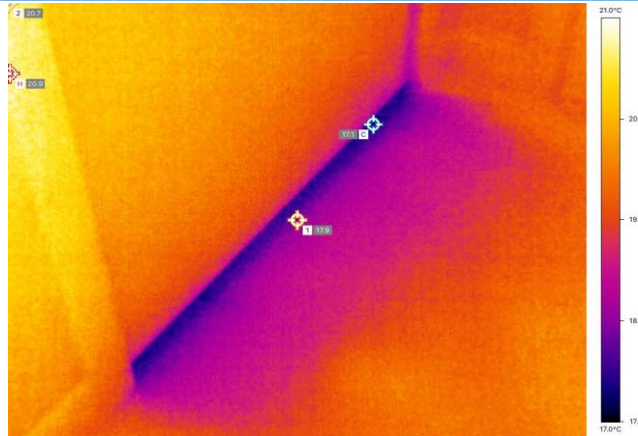
Thermal Distribution:

A significant portion of the image is cast in a vibrant yellow-orange hue on the left side, suggesting a higher temperature range, perhaps closer to 22.0°C - 23.0°C. The right side displays a vertical structure or barrier painted in a rich purple-blue hue, indicating comparatively lower temperature. It appears that the temperature here might be around 17.0°C - 19.0°C. Inside the cooler vertical structure, a particular shape catches the eye, which seems even colder than its surroundings, visible through a darker shade of blue.

Specific Temperature Points:

Three crosshair markers are present in the image, each paired with a temperature value:

- The top marker on the warmer left side, indicates a temperature of 20.8°C.
- The middle marker, positioned on the peculiar shape within the cooler vertical structure, shows a temperature of 18.5°C.
- The bottom marker, placed on the bottom-most part of the vertical structure, indicates a temperature of 17.8°C.



*Figure 37. The doorsill from inside, ingress of the cold air
Source: Author's contribution*

From the analysis of graph above given interpretation are being made:

Colour Palette:

The right side of the image provides a colour scale indicating temperature values, ranging from 17.0°C (darkest colour) to 21.0°C (brightest colour). The hues within the image represent these temperature values.

Thermal Distribution:

A notable image segment, particularly towards the left and upper edges, displays a lively yellow-orange shade. This indicates a higher temperature range, potentially nearing 20.0°C - 21.0°C. Conversely, the lower right corner exhibits a deep purple region, implying a significantly cooler temperature. This zone seems to align more with the 17.0°C - 18.0°C range. The shift from warm to cool areas creates a pleasing gradient of colours.

Specific Temperature Points:

There are three crosshair markers present in the image, each displaying a specific temperature value:

- The top-left marker in the warm zone indicates a temperature of 20.7°C.
- The bottom-right marker, positioned in the cool purple area, shows a temperature of 17.6°C.
- The middle marker, situated at the boundary where the warm and cool regions meet, indicates a temperature of 18.8°C.

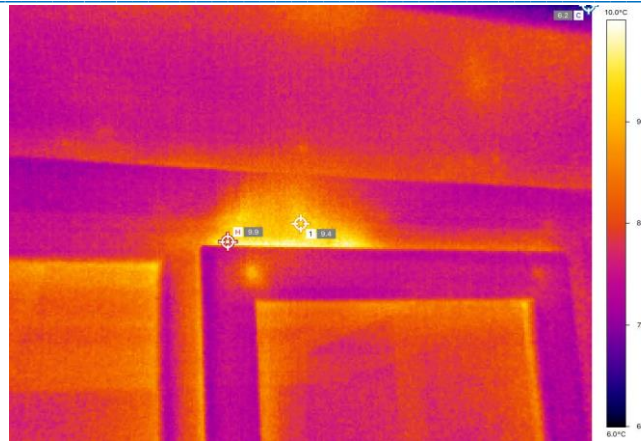


Figure 38. A heat escape from the uPVC double-glazed window frame (uneven surface of the frame or faulty seals)
Source: Author's contribution

After analysing the provided graph, we can draw definite conclusions.

Colour Palette:

The temperature range of the image is represented by a colour scale on the right side. The scale ranges from 6.0°C (darkest shade) to 10.0°C (brightest shade). The colour hues in the image are directly associated with these temperature values. The brighter areas in the image represent warmer temperatures, while the darker areas represent cooler temperatures.

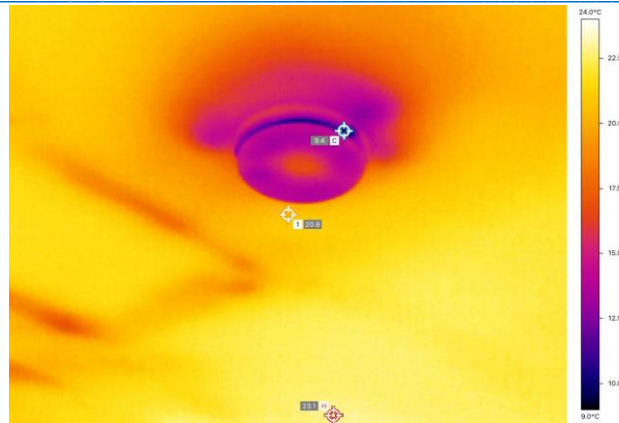
Thermal Distribution:

The highlighted area exhibits a distinct rectangular shape that stands out due to its brighter hue, indicating a higher temperature than its surroundings. The interior of this rectangle, marked by a darker shade, contains a smaller rectangle, which may indicate a frame or border encircling an object or feature. With consistent shading, the background appears to be at a uniform cooler temperature.

Specific Temperature Points:

There are two crosshair markers pinpointing specific temperatures:

- The left marker, located on the exterior bright rectangle, reads 9.9°C.
- The right marker, slightly inward but still on the bright area, reads 9.4°C.



*Figure 39. HRV ducting system shows evidence of blowing cold and dumping air into a living room
Source: Author's contribution*

Based on the graph analysis, specific interpretations can be made.

Colour Palette:

The image's right-hand side exhibits a colour scale representing temperature values ranging from 9.0°C (darkest shade) to 24.0°C (brightest shade). The assorted colours within the image correspond to the range of these temperature values.

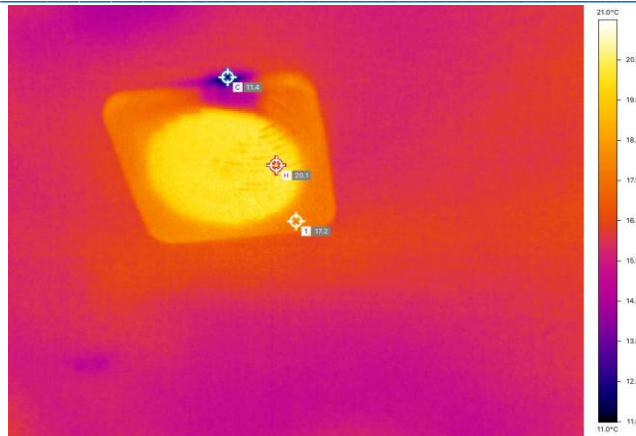
Thermal Distribution:

Most of the image features a noticeable deep purple hue in the central region and edges, hinting at lower temperatures that may fall from 9.0°C to 7.0°C. On the other hand, rectangular structures stand out with yellow-orange hues, which may indicate warmer areas with temperatures around 9.0°C to 10.0°C.

Specific Temperature Points:

Three crosshair markers can be seen in the image, pinpointing specific temperature values:

- The left marker, located on the edge of one of the warmer rectangular regions, indicates 23.1°C.
- The centre marker, also within the warmer region, displays 20.8°C.
- The top-right marker, positioned in the cooler purple zone, shows 9.4°C.



*Figure 40. The bathroom's extractor also extracts (evidently) heat from the ambient
Source: Author's contribution*

Based on the graph analysis shown in *Figure 40.*, interpretations have been made.

Colour Palette:

The temperature scale on the right side of the image ranges from 11.0°C to 21.0°C, with the darkest shade representing the lowest temperature and the brightest shade representing the highest temperature. The colours within the image correspond to these temperature values.

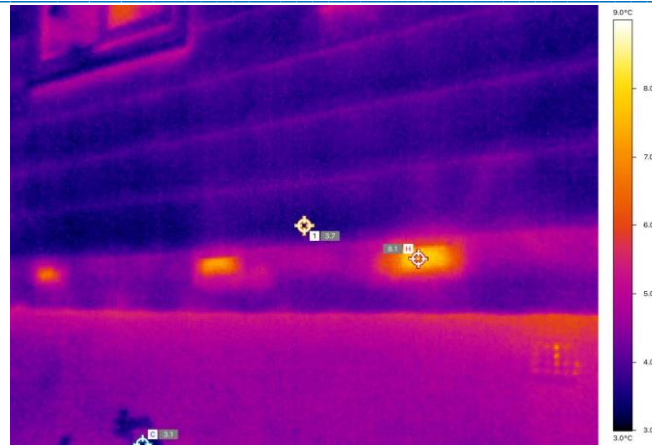
Thermal Distribution:

The predominant shade in the image is a rich, deep purple, which implies a lower temperature, probably within the range of 11.0°C to 12.0°C. Notably, an asymmetrically shaped, yellow-hued portion is in the middle of the image, denoting a warmer region. The yellow tone indicates higher temperatures ranging from 17.0°C to 21.0°C.

Specific Temperature Points:

The temperature display has three crosshair markers indicating specific temperatures.

- The marker in the top-left corner of the warmer region denotes a temperature of 11.4°C, indicating the coldest point due to the escape of cold air from the extractor edge.
- The centre marker, positioned closer to the middle of the warmer region, displays a reading of 20.1°C, suggesting it to be one of the hottest points in the displayed area.
- Lastly, the marker in the bottom-left corner, placed towards the edge of the warmer region, indicates a temperature of 17.2°C.



*Figure 41. A heat escape from the ventilation grills (view from outdoor) that is installed under the floor structure close to the insulation between the joists.
Source: Author's contribution*

Interpretations are being made by analysing the graph given in *Figure 41*.

Colour Palette:

The image has a colour scale on the right-hand side indicating temperature values spanning from 3.0°C (darkest shade) to 9.0°C (brightest shade). The colours present in the image are representative of these temperatures.

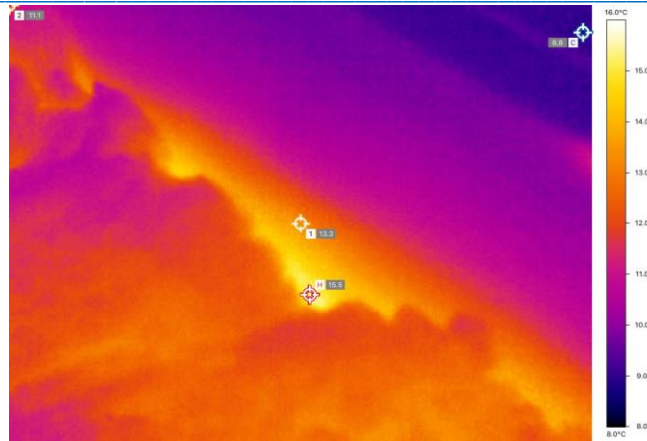
Thermal Distribution:

Most of the image is imbued with a cool purple tone, which typically signifies lower temperatures. Based on the accompanying scale, a significant portion of the area appears to fall within the 3.0°C - 5.0°C range. Notably, horizontal bands of warmer hues, ranging from violet to indigo, could indicate shelves, steps, or layered surfaces. Concentrated in the centre of the image are two distinct patches of warmer yellow-orange tones, pointing to higher temperatures between 6.0°C and 9.0°C.

Specific Temperature Points:

There are three crosshair markers pinpointing specific temperatures:

- The left marker, within one of the warmer patches, indicates a temperature of 8.1°C.
- The marker to its right, located within the warmer region, displays a temperature of 8.7°C, suggesting this is one of the warmest points in the image.
- The bottom-left marker, placed in a cooler region, indicates a temperature of 3.1°C, aligning with the coldest sections of the image.



*Figure 42. Deficiency of insulation on the ceiling roof space
Source: Author's contribution*

Based on the analysis of the graph shown in *Figure 42.*, several interpretations can be made.

Colour Palette:

The image's colour bar on the right side displays a temperature range of 8.0°C (darkest shade) to 16.0°C (brightest shade). The colours used in the image represent these temperatures accurately.

Thermal Distribution:

On the left side of the image, we see a bold display of vibrant orange-yellow hues, suggesting warmer temperatures that possibly fall between the 13.0°C to 16.0°C range. As we move towards the right, the warmth gradually fades into a cooler, purple shade, indicating temperatures closer to 8.0°C to 10.0°C. Observing the gradient where the warm and cool areas converge is fascinating, creating a region with fluctuating temperatures.

Specific Temperature Points:

Three crosshair markers indicate specific temperatures:

- The leftmost marker indicates a temperature of 15.5°C, indicating that this is a notably warm area.
- The central marker registers 13.3°C, denoting a transitional gradient between the warm and cool regions.
- Finally, the rightmost marker is situated in the cooler region and records 8.4°C, falling within the coldest sections of the image.

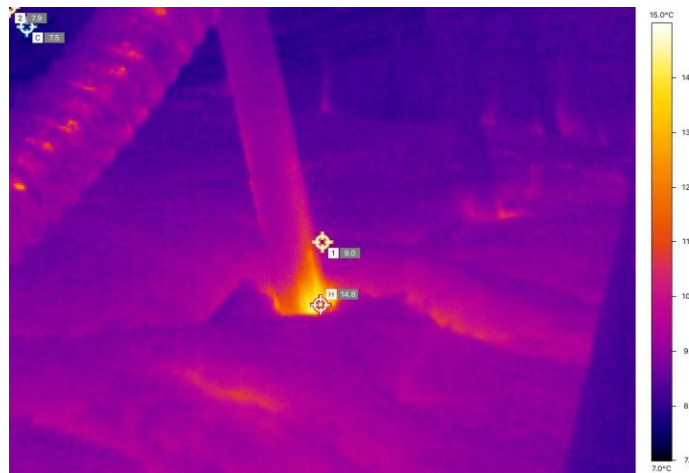


Figure 43. Deficiency of insulation on the ceiling roof space-support rafter penetration
Source: Author's contribution

Based on the graph analysis presented in *Figure 43.*, interpretations have been made.

Colour Palette:

The colour scale on the right represents the temperature range from 7.0°C (darkest) to 15.0°C (brightest). Corresponding colours within the image indicate temperatures.

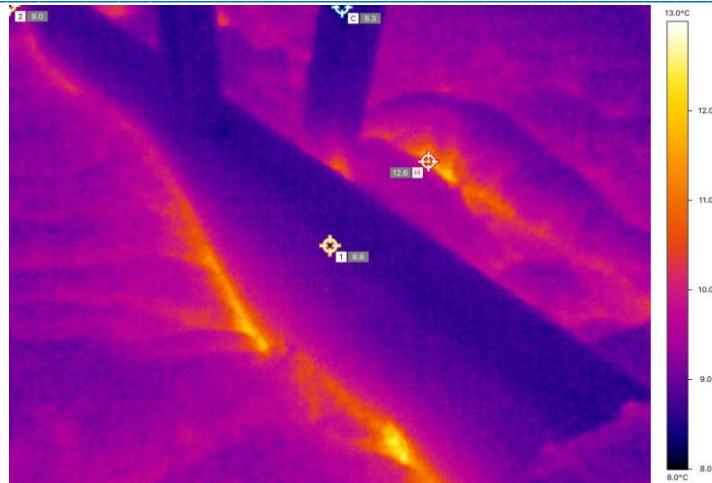
Thermal Distribution:

The central portion of the image features a distinct bright orange-yellow region, indicating a localised hotspot. This zone suggests a significantly warmer area compared to its surroundings. Around the warm centre are shades of purple, representing cooler temperatures, likely within the range of 7.0°C to 10.0°C.

Specific Temperature Points:

Two crosshair markers are utilised:

- The top marker indicates a temperature of 9.0°C, placed just at the edge of the hotspot.
- The bottom marker within the hotspot records 14.8°C, aligning with the image's warmest section.



*Figure 44. The ceiling roof space has gaps alongside the beam due to a lack of insulation
Source: Author's contribution*

Based on the graph analysis shown in *Figure 44.*, specific interpretations are being made.

Colour Palette:

The colour gradient displayed on the right side of the image represents a temperature range of 8.0°C (indicated by the darkest shade) to 13.0°C (indicated by the brightest shade). The colours assigned to various parts of the image signify their respective temperatures.

Thermal Distribution:

The visual representation highlights a couple of prominent streaks or lines that emanate a vibrant yellow-orange hue, denoting a temperature rise. These streaks exhibit some degree of bifurcation and possess a slightly non-uniform contour. Encircling these warm streaks are regions reflecting colder temperatures, portrayed by darker shades of purple and violet.

Specific Temperature Points:

Three crosshair markers provide exact temperature readings at their locations:

- The top marker reads 8.8°C and is placed in a relatively cooler region.
- The middle marker reads 12.8°C and is placed on one of the warm streaks, emphasising its higher temperature.
- The bottom marker indicates 8.6°C, also situated in a cooler zone.



Figure 45. Thermal bridging was created by the corner of the building that has not been insulated (common defect even with 'modern' builds). Source: Author's contribution

Each individual stud, especially those at corners, reduces R-value resistance and creates thermal bridging. Based on the analysis of the graph in *Figure 45.*, we can draw the following conclusions:

Colour Palette:

The colour scale on the right indicates a temperature range from 16.0°C (darkest shade) to 22.0°C (brightest shade). The colours in the image correspond to these temperatures.

Thermal Distribution:

One prominent characteristic of this image is a distinct warm region on the left side, resembling a window with blinds or shutters. The orange-yellow hue of this area implies that it is hotter than its surrounding environment. A noticeable vertical strip with a blue-purple hue, which runs between two warmer regions, indicates a potential separation or source of draft between two separate spaces or rooms. The remainder of the image depicts a relatively uniform warm temperature with a consistent orange hue.

Specific Temperature Points:

Three crosshair markers provide specific temperature readings:

- The marker on the left, situated on the window or blinds, reads 21.9°C, highlighting it as a significant heat source.
- The marker in the middle on the cooler vertical strip reads 18.7°C, reinforcing the idea of a cooler separation or draft area.
- The bottom marker indicates 16.1°C, marking the coolest point in the image, located at the bottom corner.

4.4 Quantitative Analysis

Two surveys were conducted as part of this research project. The first survey focused on the participants' homes' ventilation systems, heating sources, and configurations. It consisted of 13 closed-ended questions and was distributed for over eight days. The aim of analysing the survey data is to gain insight into the comfort and perception of occupants in spaces with varying air quality, humidity, and temperatures.

Demographics

Four participants, three females and one male, aged 25-50, live in independent buildings 318 and 320.

4.4.1 Graphical Interpretations (Survey 1)

1. Choose the Date/Time

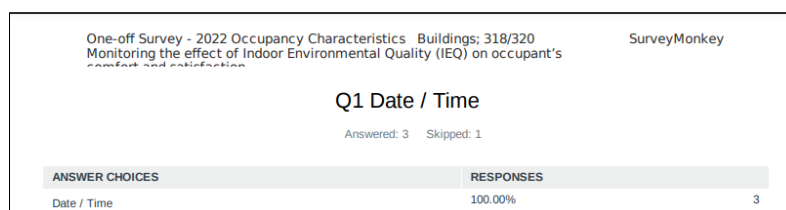


Figure 46. Date / Time - Building 318/320

2. Tick the appropriate building number you are living at.

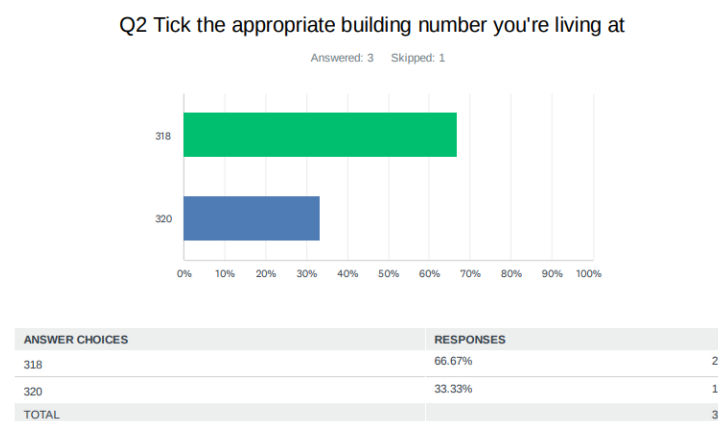
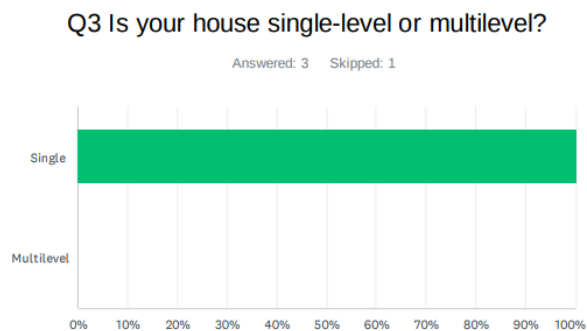


Figure 47. Demographics Building 318/320

After reviewing the answers, it was found that three people had answered the question. Two of them lived in Building 318, while the third person lived in Building 320.

3. Is your house single-level or multilevel?

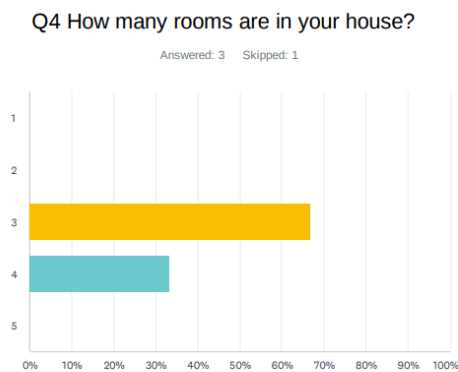


ANSWER CHOICES	RESPONSES	
Single	100.00%	3
Multilevel	0.00%	0
TOTAL		3

Figure 48. Demographics - single level building

Based on the survey responses, all 3 participants have a single-level house.

4. How many rooms are in your house?



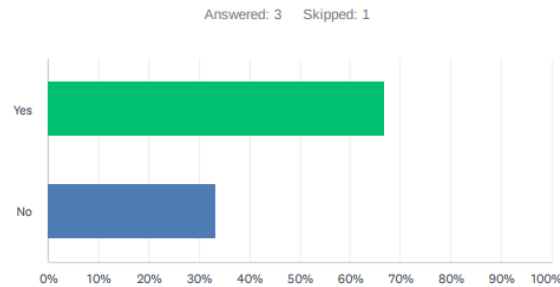
ANSWER CHOICES	RESPONSES	
1	0.00%	0
2	0.00%	0
3	66.67%	2
4	33.33%	1
5	0.00%	0
TOTAL		3

Figure 49. Demographics – rooms

The study revealed that out of the respondents, two reported having three rooms in their house, while one reported having a single room.

5. Is there an office space/room in your house?

Q5 Is there an office space/room in your house?



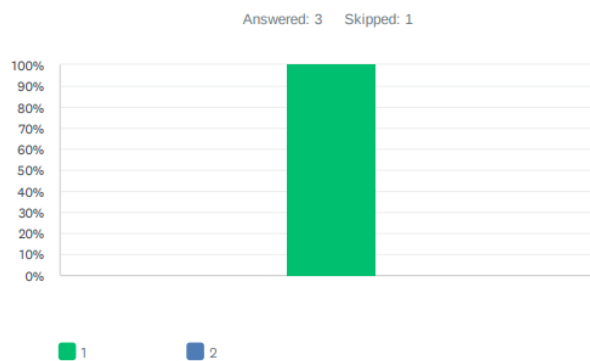
ANSWER CHOICES	RESPONSES
Yes	66.67% 2
No	33.33% 1
TOTAL	3

Figure 50. Demographics - configuration

Based on the results, the study revealed that two participants affirmed having a designated office space within their residential property, whereas one participant did not have one.

6. How many bathrooms are in your house?

Q6 How many bathrooms are in your house?



ANSWER CHOICES	RESPONSES
1	100.00% 3
2	0.00% 0
TOTAL	3

Figure 51. Demographics - configuration2

According to the results, the study revealed that the three participants had only one bathroom in their respective homes.

7. Is there any kitchen facility in an open-concept space in your house?

Q7 Is there any kitchen facility in an open concept space in your house?

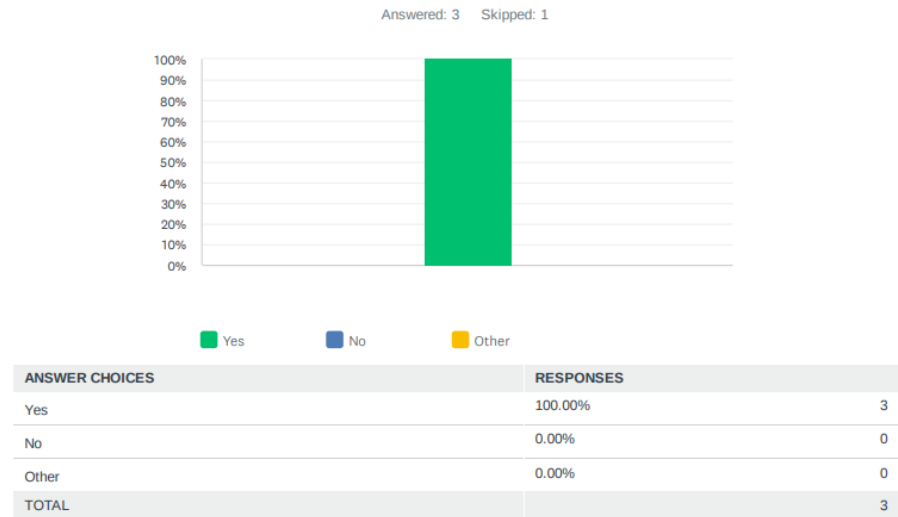


Figure 52. Demographics - configuration3

From the responses, the study found that all three participants answered yes, which means they have a kitchen facility in an open-concept space in their house.

8. How many people living in this household?

Q8 How many people living in this household?

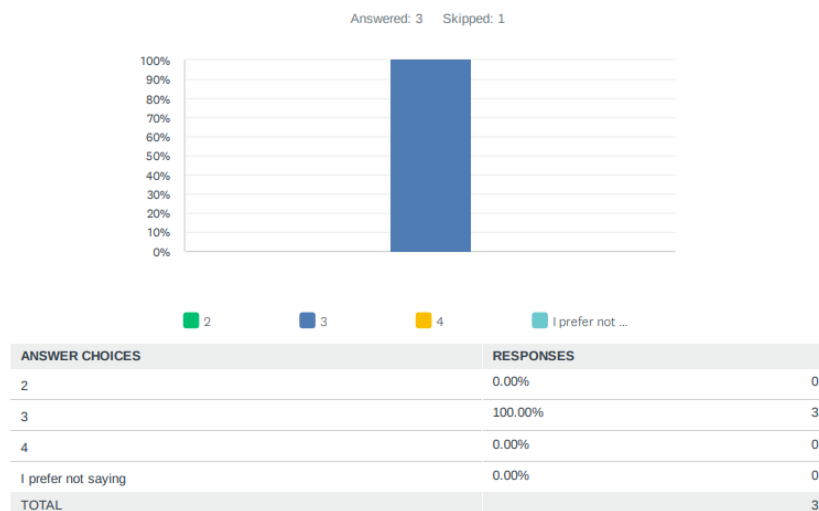


Figure 53. Demographics

The findings found that all three participants have three people living in their household.

9. Are there any pets living indoors with you?

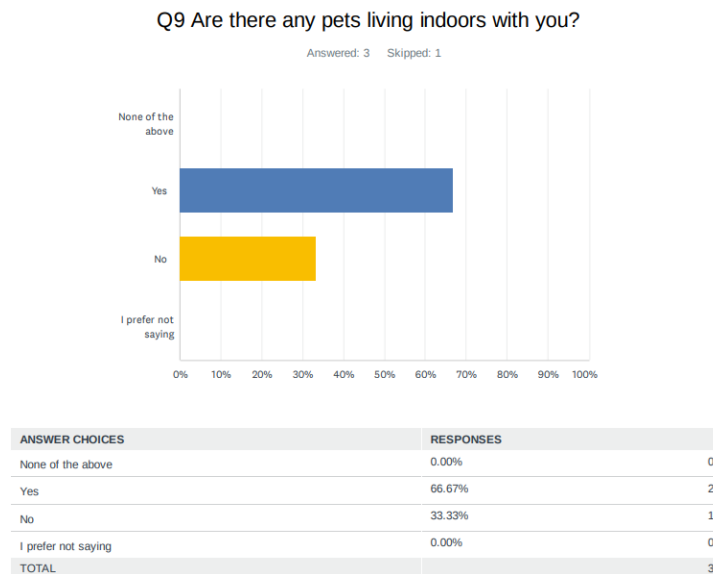


Figure 54. Demographics2

Based on the collected responses, the study has concluded that two participants have reported having indoor pets cohabitating with them, while one participant has reported having no pets indoors.

10. How many heating appliances are in your house?

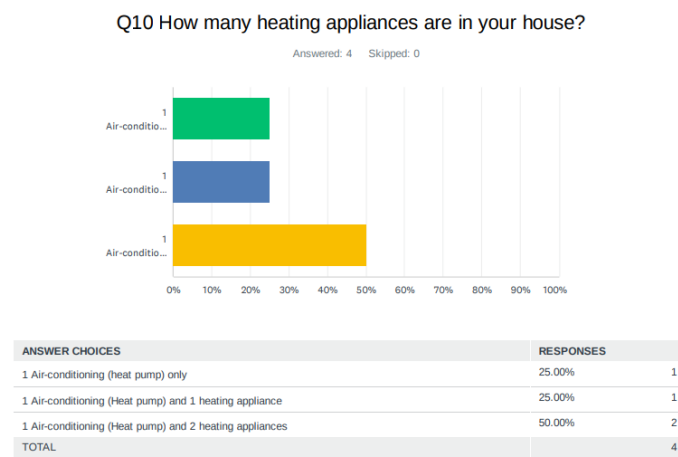


Figure 55. Heating sources

According to the findings, four participants stated they only had air conditioning (heat pump), while one reported having one air conditioning (heat pump) and one heating appliance. Responding to the question, most participants revealed they possessed one air conditioning (heat pump) and two heating appliances.

11. Is there any mechanical ventilation in your house?

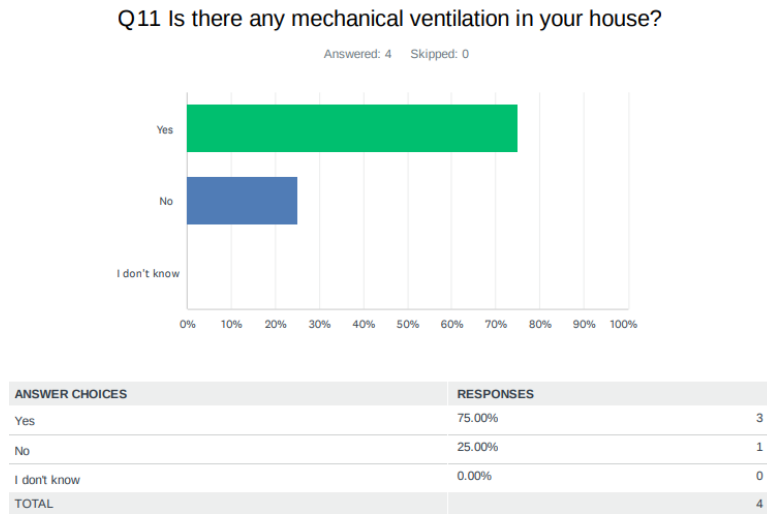


Figure 56. Ventilation

Based on the collected data, the study determined that three participants who responded to the question had installed mechanical ventilation systems in their households. However, one participant answered negatively to the same question.

12. Do you open windows and doors to ventilate indoors?

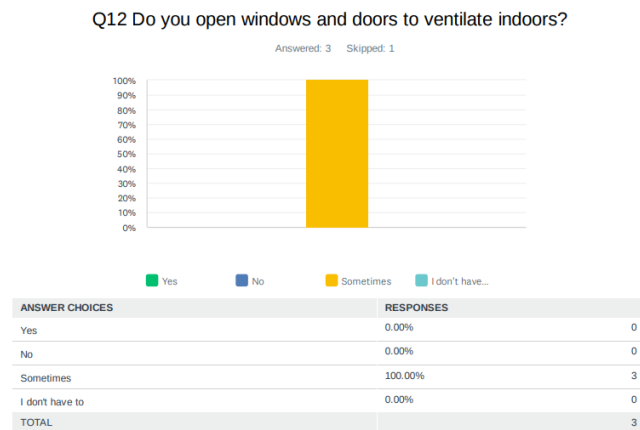


Figure 57. Passive ventilation

Based on the collected data, the study concluded that three respondents reported occasionally using natural ventilation by opening windows and doors to improve indoor air quality.

13. What would you do to improve heating/cooling and ventilation in your house?

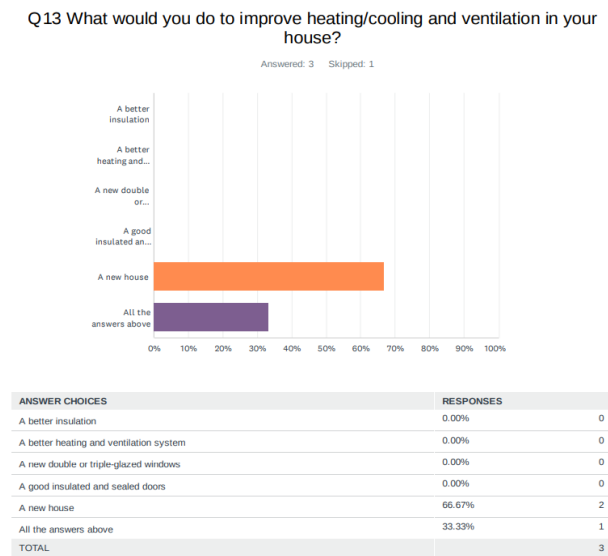


Figure 58. Personal preferences

Based on the collected responses, the study revealed that three participants provided an answer to the question. Out of those, two participants expressed their desire to seek a new residence to enhance their cooling, heating, and ventilation systems. However, one participant provided a comprehensive response that included various options such as improved insulation, better heating and ventilation systems, new double or triple-glazed windows, well-insulated and sealed doors, and, ultimately, a new home.

4.4.2 Graphical Representation (Survey 2)

The second survey was conducted to gather data from two detached houses that were occupied during the survey period from the 4th of August to 11, 2022. The survey gathered a total of 31 responses from the 4 participants and consisted of a comprehensive 10-question questionnaire. The results from the survey were analysed to derive valuable insights.

The timeframe of completing the survey includes:

Morning between 8-11 am	16%	5 Answers
Afternoon between 1-4 pm	16%	5 Answers
Evening between 5-8 pm	52%	16 answers
Late evening/night between 9-11 pm	16%	5 answers

Table 2. Timeframe completed survey answers.

1. Date



Figure 59. Date

2. Please select the building you are currently in.

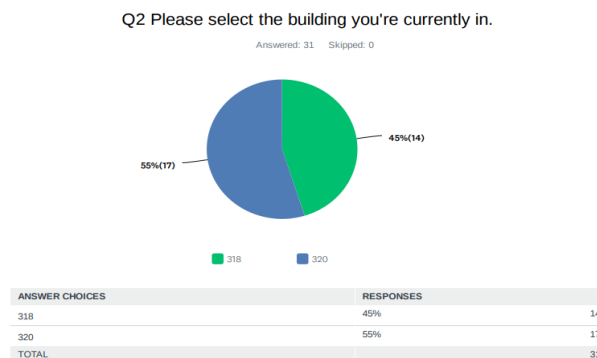


Figure 60. Buildings

A study gathered the responses and found that 14 answers (45%) were from Building 318 and 17 answers (55%) were from Building 320 at that time.

3. What is the time frame you are completing the survey?

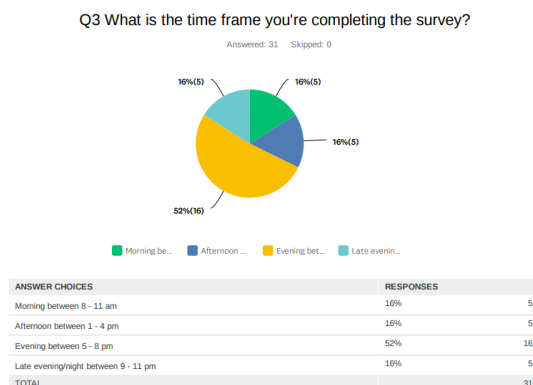


Figure 61. Time frame

Based on the collected responses, the study revealed that five answers provided their input during the morning hours of 8-11 am (16%), while another five answers provided their input during the afternoon hours of 1-4 pm (16%). Furthermore, most answers, totalling 16, were provided their input during the evening hours of 5-8 pm (53%), while five answers were provided during the late evening/night hours of 9-11 pm (16%).

4. When responding to this survey, where are you at that moment?

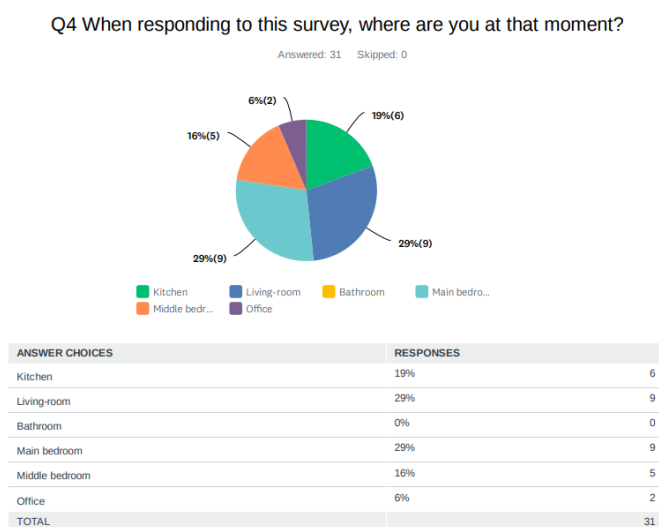


Figure 62. Location during the survey

The study analysed the locations from which participants responded to the survey. The results indicate that 19% of the participants completed the survey in the kitchen, 29% in the living room, 29% in the main bedroom, 16% in the middle bedroom, and 6% in the office.

5. Regarding the internal environmental aspects, how do you feel?

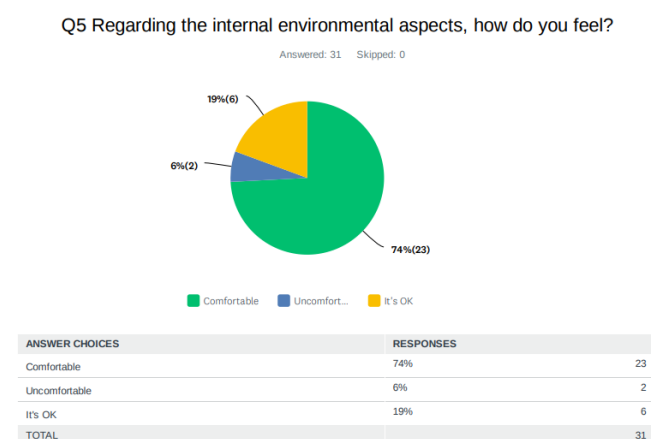


Figure 63. Well-being in relation to the IEQ

From the gathered responses, the study found that 23 answers (74%) were comfortable with the internal environmental aspects, whereas two answers (7%) were uncomfortable. The rest of the 6 answers are 'OK' with the internal environmental aspects.

6. Describe your house during this survey.

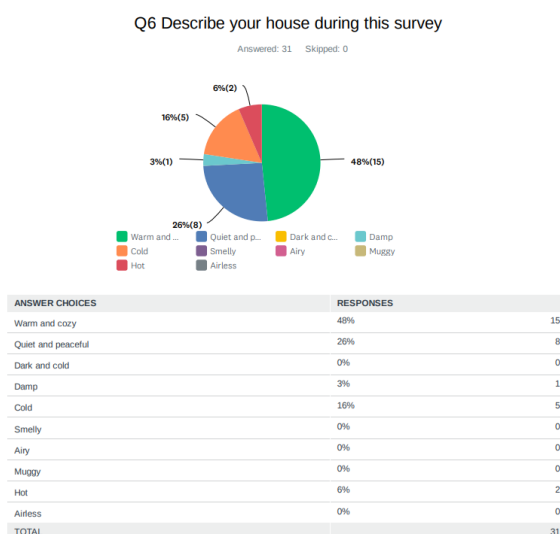


Figure 64. IEQ

Based on the collected responses, the study revealed that 48% of the participants (15 answers) perceived their house as warm and cosy. In comparison, 26% (8 answers) reported it as quiet and peaceful, and only 3% (1 answer) complained of dampness. On the other hand, 16% (5 answers) felt their house was cold, while two answers characterised it as hot.

7. What would you prefer the internal temperature to be?

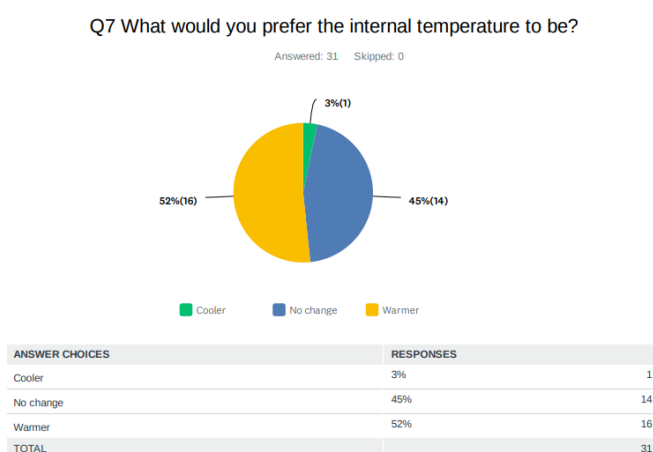


Figure 65. Personal preferences

The study analysed the responses of participants regarding their preferred internal temperature. Among the participants, 3% preferred a cooler internal temperature, 45% preferred no change in the temperature, and the remaining 52% preferred a warmer internal temperature.

8. What would be your light preference?

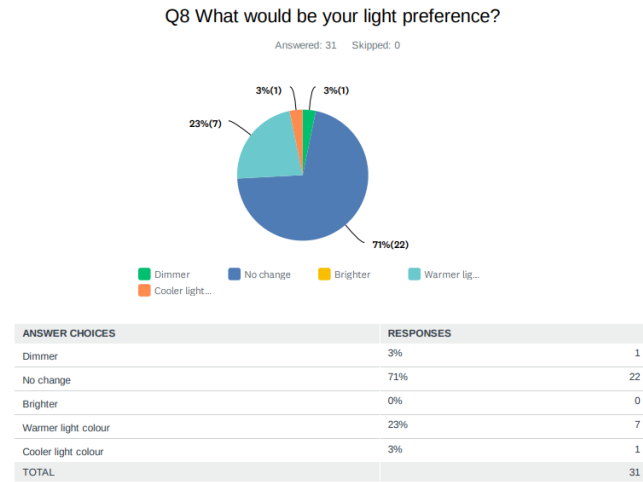


Figure 66. Light preferences

Based on the collected responses, it was found that 71% of the participants did not prefer any change in the light intensity. In contrast, seven answers (23%) preferred warmer light colour, and one answer (3%) preferred dimmer light. Additionally, the remaining 3% of the participants preferred cooler light colours.

9. What would be your air preferences?

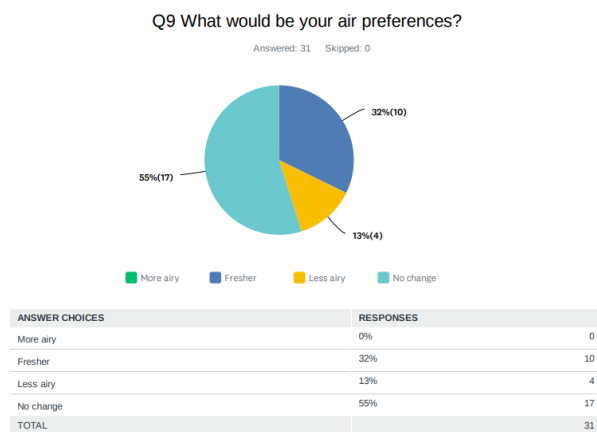


Figure 67. Air preferences

From the gathered responses, the study found that ten answers from participants (32%) preferred fresher air, and (13%) answered less airy. In comparison, the remaining seventeen answers (55%) shared no change.

10. What clothes are you wearing?

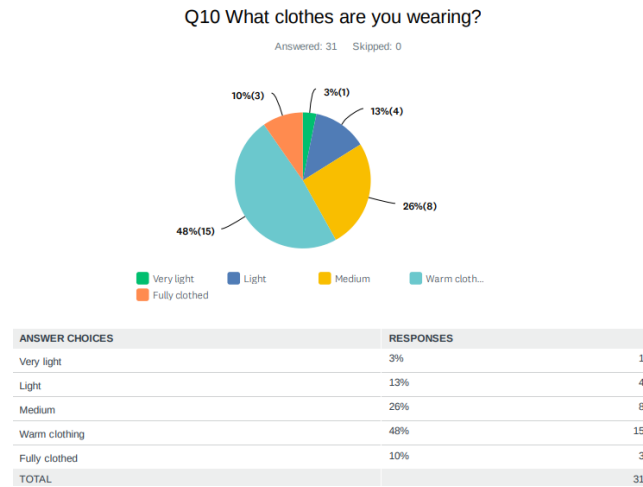


Figure 68. Clothing preferences

The study collected responses from participants regarding their preferred clothing wearing during the survey for a particular situation. Out of the participants, 3% chose very light clothes, 13% preferred light, 26% opted for medium, and 10% went for the fully clothed option. Most of the participants (48%) chose warm clothing.

4.4.3 Insights and Data Trends

- Total responses 31
- Completion rate 100%
- Typical time spent 1m:49s.
- Most-skipped question Q1- Date (skipped:1)

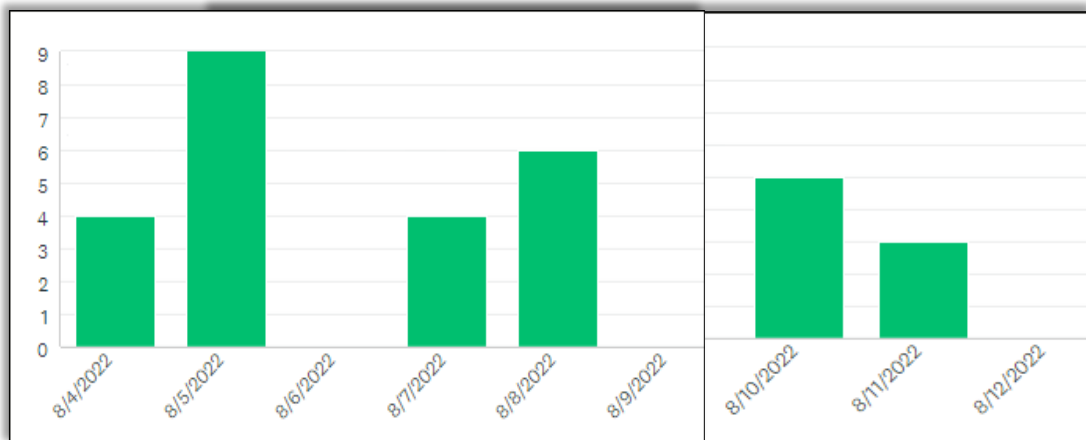


Figure 69. Connected two pictures to give a full participation date from 4 to 11 of October 2022

4.4.4 Data Preparation and Testing for Analysis

The data was collected using SurveyMonkey and then processed in Excel for further analysis and testing.

Regression Analysis and Discussion

➤ Correlation Output

	Heat index	Humidity	Temp	Occupant comfort
Heat index	1			
Humidity	-0.034482759	1		
Temp	0.437487289	-0.039771572	1	
Occupant	-0.10380685	0.2076137	-0.047891314	1

Table 3. Correlation output

➤ Regression Output

Regression Statistics	
Multiple R	0.229049
R Square	0.052464
Adjusted R Square	-0.05687
Standard Error	0.623485
Observations	30

Table 4. Regression output

➤ ANOVA

	DF	SS	MS	F	F Significance
Regression	3	0.559611	0.186537	0.479858771	0.699093063
Residual	26	10.10706	0.388733		
Total	29	10.66667			

Table 5. ANOVA I

	Coefficients	Standard Error	T Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-25.764	50.1818	-0.51341	0.611997908	-128.9141525	77.38617	-128.914	77.38617
Heat Index	-0.32603	0.705339	-0.46224	0.647755767	-1.775878222	1.12381	-1.77588	1.12381
Humidity	0.678832	0.63476	1.069431	0.294703865	-0.625935745	1.9836	-0.62594	1.9836
Temp	0.024331	1.62736	0.014951	0.988185297	-3.32075648	3.369418	-3.32076	3.369418

Table 6. ANOVA 2

Description:

1. **DF** (Degree of freedom): These are the numbers of independent variables used in our model
2. **SS** (Sum of the square): Total variation in the dependent variable that the regression model explains
3. **MS** (Mean Squared errors): mean of the sum of squares or the sum of squares divided by the degrees of freedom
4. **F** (testing of hypothesis): Used for testing the hypothesis
5. **F Significance** (P-value): The P-value shows whether a significant relationship exists between independent, and dependent variables. If the P-value is less than 0.05, then a significant value exists and if the P-value exceeds 0.05, then is statistically an insignificant relationship.
6. **Coefficient** (Linear relationship): shows the linear relationship between variables
7. **Standard error** (estimated standard deviation of the distribution of coefficients).
8. **T- statistic - t- statistic** or t-value of the test and its value is equal to the coefficient divided by the standard error
9. **P-value** (significance value) - The t-statistic is compared with the t distribution to determine the p-value. We only consider the p-value of the independent variable.
10. **Lower and Upper 95%** (confidence intervals)- Values less than 0.05 or 95% confidence interval are considered significant.

The regression and correlation data analysis show that the heat index, humidity, and temperature do not significantly impact occupant satisfaction. The P values in the regression analysis exceeded the 95% confidence interval, indicating that the results were insignificant. Additionally, the correlation analysis showed a significance value above 0.05, meaning no observed relationship or association between these factors and occupant satisfaction exists. A recent study by Albuainain et al. (2021) also found no significant relation between window, satisfaction, lighting, and temperature. Therefore, the key takeaway from our study is that enhancing occupant comfort or satisfaction may be more challenging for some indoor environmental quality factors than others.

4.4.5 Facts about mould

As reported by the Asthma and Respiratory Foundation NZ (Asthma et al., 2020), homes in New Zealand are often characterised by cold, damp conditions and are prone to mould growth. These conditions can result in significant pulmonary and respiratory issues, particularly for vulnerable populations such as children and the elderly and may even contribute to the development of cardiovascular disease.



Figure 70. Typical black mould grows with restricted ventilation and elevated humidity due to the condensation and temperature (Twistfix, 2013).

When the conditions are suitable, spores absorb water, which triggers the spore's enzymes and prompts a small germ tube to emerge from the spore. This germ tube extends and matures into hyphae, which can spread and form a visible mould colony. The hyphae produce enzymes that break down organic matter in their surroundings, providing the necessary nutrients for

the mould to survive and reproduce. It is a captivating example of how microorganisms adapt to their environment to thrive and survive. In fact, under optimal conditions, mould can germinate in as little as one day! As an example, *Aspergillus Niger* and *Aspergillus Restrictus* can grow after 64 days in an environment with a relative humidity of about 73%, while at 30°C and with a relative humidity of about 93%, germination can begin in as little as one day.



Figure 71. *Aspergillus* fungus, coloured scanning electron micrograph (SEM). Magnification: x240 at 5x7cm size.

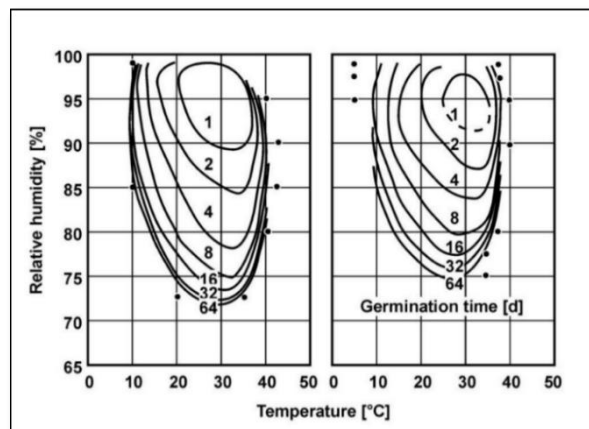


Figure 72. The function of the relative humidity (RH) and temperature as mould germination growth.

The examined case study noted that the initial signs of mould were promptly addressed with homemade solutions and proper ventilation while maintaining a minimum temperature of 18°C. It is worth noting that the onset of mould symptoms is more likely to occur during the winter months. Additionally, it is essential to acknowledge that the two residential properties are located in a semi-rural western suburb of Auckland, which experiences a higher frequency of wet days during the year, particularly in winter.

Chapter 5 Discussion

This study provided an opportunity to analyse data and determine occupant satisfaction levels. The researcher carefully examined various factors, including indoor and outdoor environmental conditions, heating source usage, and occupant behaviour patterns related to ventilation and space use during different times of day and under various weather conditions. By considering these factors, the study aimed to gain a comprehensive understanding of how building design impacts occupant comfort and satisfaction. The present research focused on analysing different refurbished buildings, all renovated. The data collected from two adjacent buildings on the same property was used to analyse real-time building performance and its effect on occupants. In addition to indoor environmental monitoring, the study found evidence of adverse health effects and indoor mould for occupants. However, the research also revealed that living in social housing is often associated with adverse health effects, such as a higher prevalence of respiratory problems, and links to certain living conditions, such as rising pollution due to smoking and other impurities.

Research conducted to analyse Indoor Air Quality (IAQ) indicates that building renovations are common in New Zealand, which can have a negative impact on indoor air quality and occupant satisfaction. Additionally, buildings are responsible for a significant portion of global energy consumption, and countries like New Zealand have implemented measures to reduce greenhouse gas emissions and energy consumption. Conducted study have shown that improving indoor air quality is crucial for occupant comfort and health. Increasing ventilation rates and limiting pollutant entry into buildings are effective strategies for achieving this goal (Dimitroulopoulou et al., 2023).

A recent study reveals that New Zealand has significantly emphasised implementing energy-saving measures. However, the same level of attention has yet to be given to indoor air quality to ensure occupant comfort and satisfaction. As a result, this research focused on individuals' perceptions of comfort in occupied spaces, considering various factors such as temperature, noise, humidity, and the concentration of CO₂. The study also underscores the significance of refurbishing older buildings for the well-being of occupants. The insights gained from this

research can assist construction companies and designers in creating buildings that meet occupants' needs while also considering environmental factors and the country's climate. Ultimately, this can lead to the construction of more well-ventilated buildings with higher thermal insulation for New Zealand building construction or renovation.

Lastly, the presented research is dedicated to an easy understanding of influencing occupant's well-being and comfort and how the internal/external environment with human behaviour affects the indoor environment quality. The findings of this research can be a potential and effective source of information for understanding the best parameters for living in occupied spaces. The research has worked on some significant factors that are primarily highlighted and are better summarised in the next section.

A qualitative analysis was conducted to examine HotDrop findings for two selected buildings. Various factors were evaluated, such as health score, thermal comfort, airborne index, carbon emissions, energy use, estimated energy cost, and energy use intensity. The results of the HotDrop analysis revealed a correlation between temperature and power consumption over time for both buildings. This suggests that the properties are taking steps towards becoming eco-conscious, as evidenced by the decrease in energy use in terms of cost and intensity.

Additionally, the research has yielded insights regarding Personal Weather Station (PWS) data. The data showcases a range of temperatures experienced by different locations, ranging from cold to mild, with occasional rainfall. The study analysed several significant factors, such as wind gusts, speed, direction, pressure, precipitation, humidity, and temperature, among others, to understand minor weather-related fluctuations throughout the month.

The research findings suggest that good insulation, double-glazed windows, and draft-free doors are crucial for internal refurbishments. Clause H1 specifically mandates a minimum R-squared value of 2.9 for the ceilings. Additionally, internal ventilation should exchange heat without increasing moisture levels. Power energy is used to heat the hot water cylinder, and a recovery system with solar air conditioning and hybrid systems is an effective solution.

According to my research findings, outdoor shading structures such as pergolas are crucial for buildings that face the north. This helps prevent excessive shading, sheltering, and overheating. Additionally, a shower dome can be a helpful solution when managing internal moisture from showering. It supports keeping the bathroom and the rest of the home dry and heated. Finally, it has been noted that excessive external substructure vents can create issues with dampness and cold air entering the floor, insulation, and cavity system.

5.1 Factors

Many internal and external factors must be considered when it comes to heating buildings. These factors can include weather conditions, time of day, and individual ventilation and space usage approaches. By carefully analysing these variables, it is possible to develop a heating strategy that meets the occupants' needs while minimising energy usage and costs. A recent study examined data to determine the likelihood of occupant satisfaction. According to Second Albuainain et al. (2021), researchers considered indoor and outdoor environmental conditions, heating source usage, and occupant behaviour towards ventilation and space utilisation under various weather conditions and times of day. By exploring these factors, the study aimed to understand how building design impacts occupant comfort and satisfaction. Recognising that these factors may differ depending on personal preferences and cultural contexts is essential. However, addressing these key aspects can help improve occupants' satisfaction and well-being within buildings.

5.1.1 Indoor environmental quality

Indoor environmental factors, such as air quality, temperature, humidity, lighting, and noise levels, considerably impact the comfort and satisfaction of occupants. Proper ventilation, precise temperature control, appropriate lightning conditions, and acoustic insulation significantly contribute to creating a favourable indoor environment, as per the research conducted by Abbaszadeh et al. in 2006.

5.1.2 Building layout and functionality

Efficient building layout and design are critical factors in ensuring occupant satisfaction. A well-planned layout prioritising accessibility, ease of navigation, and operational efficiency can significantly enhance user experience and overall satisfaction (Kwon et al., 2019).

5.1.3 Amenities and facilities

The availability and quality of amenities and facilities within the building, such as common areas, recreational spaces, fitness centres, parking, and food services, contribute to occupant satisfaction. Access to these amenities can enhance the overall experience of building users.

5.1.4 Building maintenance

Building maintenance is a crucial aspect of ensuring the optimal performance and appearance of a building. Proper and consistent maintenance practices, including regular cleaning, inspection, and repair measures, can significantly impact occupant satisfaction, safety, and overall building efficiency. Neglecting maintenance needs can lead to costly repairs, safety hazards, and reduced occupant comfort and productivity. Therefore, building owners and managers should prioritise implementing effective maintenance plans and allocating adequate resources to ensure timely and quality maintenance services are provided.

5.1.5 Safety and security measures

Ensuring occupant satisfaction is strongly dependent on the safety and security measures within a building. Robust security systems, advanced emergency preparedness, and adequate safety measures, including fire alarms, smoke detectors, sprinklers, and adequately illuminated pathways, contribute to occupant satisfaction.

5.1.6 Integration with natural environment

Architectural designs that consider a region's unique climate and weather patterns can significantly improve the quality of life for occupants. Incorporating efficient windows, shading elements, and green spaces can effectively regulate temperatures and foster a stronger connection with the natural surroundings, ultimately reducing stress and anxiety (Lolli et al., 2022).

5.1.7 Energy efficiency and sustainability

Energy-efficient and sustainable buildings mitigate environmental impact and enhance occupant satisfaction. Features such as efficient HVAC systems, renewable energy sources, and green building certifications demonstrate a solid commitment to sustainability that can positively influence user satisfaction. These technical solutions offer a range of benefits, including reduced energy consumption, improved indoor air quality, and increased occupant comfort, all of which can contribute to a healthier and more productive building environment.

5.1.8 Factors related to the landlord and owners

There are numerous measures that building owners and landlords can undertake to enhance the quality of living and overall satisfaction of their tenants. One crucial aspect for property owners is actively listening to tenant feedback and taking appropriate steps to address concerns. By doing so, landlords can improve the living experience of their tenants, ensuring their health and well-being are prioritised (Freeze, 2023).

5.1.9 Factors related to the architects and designers

The construction industry heavily relies on various architectural information encompassing various design stages and requires cooperation from multiple disciplines. This information is produced and managed throughout the building's lifecycle, starting from conceptual design to construction and maintenance. To maximise productivity and efficiency in the construction industry, the technology of business information modelling (BIM) takes advantage of generated information throughout the facility's lifecycle to construct a consistent system. Choi, Lee, and Kim (2020) note that BIM technology is increasingly used quantitatively in engineering, construction, and architecture disciplines. However, to ensure quality improvement in BIM-designed projects, it is essential to develop a checking and evaluation procedure for the architectural design based on BIM.

5.1.10 Factors related to the contractors

According to Construction Procurement (2019), government agencies need to adhere to the guidelines related to construction procurement to improve the consistency and quality of procurement practices. Additionally, this research highlights the critical importance of occupant health, and property owners should, therefore, consider air quality factors when implementing suitable rules and guidelines.

5.1.11 Factors related to Regulatory Authorities

According to Taptiklis and Phipps (2017), the state of housing in New Zealand needs to be better. These authors researched the condition of houses in the country, using QV data to determine that the average condition is 0.5% on a scale of -1 to 1. Additionally, their findings align with BRANZ's regular survey on house condition, with the most recent study in 2010 showing that the overall mean condition of 550 sampled houses was only moderate. Unfortunately, this subpar housing quality has been linked to higher rates of infectious illnesses in New Zealand, underscoring the need for improvements in this area.

5.1.12 Factors related to consultants – (Tether, Tech. support Massey)

New Zealand has seen a significant rise in housing prices, a shortage of available housing, and sluggish construction programs in recent years. These factors have contributed to overcrowding, increased homelessness, and the construction of subpar housing (Weerasinghe et al., 2020). As a result, architects and contractors are turning to innovative solutions like Tether, a technology-based company that helps identify and address performance issues in buildings. Through its analysis of factors such as temperature, humidity, and CO2 levels, Tether has proven to be a valuable resource in improving building quality.

Chapter 6

Conclusion and Recommendations

6.1 Conclusion

New Zealand is renowned for its tradition of building and renovating homes, with a vast number of refurbished old buildings. The country's building code has continuously evolved due to the changing climate and the residents' satisfaction. However, the health impacts of building performance and quality on occupants have often been overlooked. Therefore, this research analysed and demonstrated the differences between the two refurbished buildings. The study gathered data from two adjacent buildings located on the same property to understand how occupants' interaction and influence affect the buildings' real-time fluctuations. Internal environmental monitoring was carried out to gather tangible evidence about how the external and internal environment and resident comfort and satisfaction affect interior air quality, temperature, humidity, acoustics, and CO₂ concentration that influence occupants' perception, comfort, and well-being. To analyse occupants' satisfaction and comfort, the research was designed to demonstrate the differences between two monitored buildings, 318/320, located on the same property, in terms of performance, quality, and attributes. The research utilised Tether and other tools to collect real-time readings on the building's performance based on occupants.

This study aims to gain a more profound understanding of the factors that impact occupant comfort and quality of life. By examining the interactions between human behaviour and internal and external environments, aim to identify the optimal conditions for habitation in inhabited spaces. Our findings provide valuable insights into the complex variables related to humidity and CO₂ concentration that impact physical and mental well-being, including respiratory health. Furthermore, our systematic approach emphasises the importance of designing residential structures prioritising tenant happiness and well-being.

To understand the optimal performance of buildings, sensors were installed to collect data at various times of the week and year. The data collected from these sensors and subsequent analysis revealed valuable insights into the factors contributing to poor building quality, such as high air dampness, sources of moisture, gaps, or imperfections. This study provided advanced knowledge beyond basic information published by BRANZ and has the potential to help architects and builders improve building quality by addressing issues related to external moisture and insufficient insulation.

Additionally, the research findings indicate that poor indoor air quality can negatively impact occupants' health. Qualitative analysis was conducted using Tether, HotDrop, and Personal Weather Station (PWS) data to gain further insights. The research also included survey analysis from four occupants to gather their perspectives and provide additional evidence regarding their satisfaction and comfort. The survey analysis aimed to understand better how occupants perceive and experience different air quality, humidity, and temperature conditions in occupied spaces. The data was collected using SurveyMonkey and sorted in Excel for testing purposes. The survey was conducted at various times to accommodate occupants' schedules and ensure accurate measurements and perspectives were obtained.

The study conducted regression and correlation analyses using Microsoft Excel. The results showed that occupants' satisfaction was unaffected by humidity, temperature, or heat index. The P value exceeded 95% confidence internally, indicating that the test outcomes were insignificant. Similarly, the significance value for correlation was above 0.05, indicating an insignificant association between humidity, heat index, temperature, and occupant satisfaction. Survey responses also indicated that the heat index or humidity did not significantly affect health. Moreover, the study found an insignificant relationship between window air, satisfaction with lighting, and temperature. Therefore, the study concludes that obtaining higher occupant comfort or satisfaction is more challenging for some IEQ factors than others.

6.2 Recommendations

Utilising comprehensive tests and surveys, the research findings have led to evidence-based recommendations for enhancing overall quality, satisfaction, energy efficiency, and well-being. The analysis and findings provide potential evidence to support embedding this research as a part of the Residential Tenancies Act (RTA). Additionally, the government of New Zealand should provide financial assistance to meet all mandatory requirements, which can significantly contribute to improving building quality. Based on our present study analysis, the Building Clauses and Code should not be considered a minimum requirement. Instead, other factors, such as reducing the effect of CO₂ and ensuring occupant well-being, should also be given due consideration.

6.2.2 Recommendations for Regulatory Authorities

The building regulatory system is a crucial aspect of the building industry. Its primary objective is to regulate building work and ensure it complies with the necessary building regulations. The implementation of the building regulatory process involves several phases.

- Any health issues must not endanger people who consider the building for a living due to safety issues.
- People considering building for a living can escape the building when it gets emergency and fire.

The act outlines the obligations of designers, owners, (BCA) Building Consent Authorities, and builders to ensure that the building's functionality adheres to the Building Code, which is the primary regulatory framework.

6.2.3 Recommendations for contractors, architects, and designers

Several factors can influence occupant behaviours, including indoor environmental conditions, building characteristics, climate change, building systems and appliances, user-centred design, and building elements. However, previous research often needed to have considered other essential factors like physiological, psychological, social, and time-related elements that can significantly influence energy-driven occupant behaviours. To fully understand occupant energy concerns, examining all relevant and influential factors and parameters significantly connected to occupant comfort and satisfaction is crucial. Therefore, incorporating these factors into building design and energy efficiency techniques is essential. Real-time performance monitoring techniques, like Business Information Modelling (BIM), can also be valuable. Performing a scientific study with building occupants can identify key IAQ characteristics and variables that affect energy behaviours.

6.2.4 Recommendations for consultants

Tether and its team of consultants are committed to promoting healthy living, creating optimal working environments, and facilitating flexible learning. The government has proposed a solution through IoT in response to the pressing need for research on poor indoor air quality and stable environmental conditions in New Zealand. Tether has taken the lead in designing cutting-edge environmental monitoring solutions that accurately gauge indoor air quality and make recommendations for improvement based on their measurements (Tether, 2021).

6.3 Critical challenges and limitations

Although there were some technical limitations regarding sensor placement and obtaining consent from co-tenants, and limited time permission from participants, data collection for the study was conducted from August 4th to August 11th, 2022. In 2023, I experienced a significant health issue and had to relocate to a smaller space, which required rebuilding the office and recollecting all sensor instruments and data. I am grateful for the invaluable support and encouragement from my supervisor, Dr Eziaku Rasheed, who made this possible.

6.4 Future research work

Further investigation is necessary, as this study segment reveals a substantial void within the construction sector and the modernisation or restoration of ageing residences in New Zealand. The primary objective is to focus on residential developments, prioritising occupants' welfare, comfort, and well-being.

Here are some potential avenues for future research to enhance indoor air quality (IAQ) in residential buildings. These focus areas may serve as a springboard for future research initiatives to improve IAQ in newly built or renovated residential buildings.

1. Ventilation Systems Optimisation:

Designing and optimising ventilation systems to enhance air circulation and reduce indoor pollutants.

2. Smart Sensors Integration:

Investigate the integration of intelligent sensors for real-time monitoring of indoor air quality parameters and prompt feedback systems.

3. Natural Ventilation Strategies:

Study the effectiveness of natural ventilation methods like window placement, skylights, and building orientation for improved air quality.

4. Air Filtration Innovation:

Explore advanced air purification technologies and filters to effectively remove pollutants and allergens from indoor air.

5. Material Selection Research:

Research on selection of low-emission building materials to reduce the release of volatile organic compounds (VOCs) post-renovation.

6. User-Centered Design:

Research on designing indoor environments that promote occupant well-being by considering their preferences, comfort levels, and individual needs.

7. Biophilic Design Integration:

Investigate incorporating biophilic elements such as natural light, indoor plants, and green spaces to enhance occupants' connection to nature and mental well-being.

8. Psychological Impact Studies:

Conduct studies to understand the psychological effects of indoor air quality on occupants and how it influences their satisfaction and productivity.

9. Occupant Feedback Systems:

Develop feedback mechanisms for occupants to provide input on air quality and comfort levels, enabling proactive adjustments for enhanced satisfaction.

10. Health Monitoring Technologies:

Implementation of the health monitoring technologies to assess the impact of IAQ on occupants' physical well-being and comfort.

References

- Abbass, M.A.B. and Hamdy, M., 2021. A Generic Pipeline for Machine Learning Users in Energy and Buildings Domain. *Energies*, 14(17), p.5410.
- Abbaszadeh, S., Zagreus, L., Lehrer, D., & Huizenga, C. (2006). *Occupant satisfaction with indoor environmental quality in green buildings*. Escholarship.org. <https://escholarship.org/uc/item/9rf7p4bs>
- Abdulaali, H. S., Usman, I., Hanafiah, M., Abdulhasan, M., Hamzah, M., & Nazal, A. (2020). Impact of poor indoor environmental quality (IEQ) to inhabitants' health, wellbeing and satisfaction. *International Journal of Advanced Science and Technology*, 29(3), 1-14. https://www.researchgate.net/profile/Mushtaq-Talib-2/publication/340278976_Impact_of_poor_Indoor_Environmental_Quality_IEQ_to_Inhabitants'_Health_Wellbeing_and_Satisfaction/links/5f450b6e299bf13404f1d9f6/Impact-of-poor-Indoor-Environmental-Quality-IEQ-to-Inhabitants-Health-Wellbeing-and-Satisfaction.pdf
- Abdullah, A., 2022. Experimental study of natural materials for an evaporative cooling design in hot-arid climate. *Building and Environment*, 207, p.108564.
- Ade, R., & Rehm, M. (2021). Summertime comparative evaluation of indoor temperature and comfort in Auckland New Zealand: a survey of green certified, code and older homes. *Building Research & Information*, 49(3), 336-351.
- Ahmed, T., Kumar, P., & Mottet, L. (2021). Natural ventilation in warm climates: The challenges of thermal comfort, heatwave resilience and indoor air quality. *Renewable and sustainable energy reviews*, 138, 110669. <https://doi.org/10.1016/j.rser.2020.110669>
- Ala-Kotila, P., Vainio, T., & Laamanen, J. (2020). The influence of building renovations on indoor comfort—A field test in an apartment building. *Energies*, 13(18), 4958. <https://doi.org/10.3390/en13184958>

-
- Albuainain, N., Sweis, G., AlBalkhy, W., Sweis, R., & Lafhaj, Z. (2021). Factors affecting occupants' satisfaction in governmental buildings: The case of the kingdom of bahrain. *Buildings*, 11(6), 231. <https://doi.org/10.3390/buildings11060231>
- Alfalah, G., Al-Sakkaf, A., Abdelkader, E. M., & Zayed, T. (2022). An Integrated Fuzzy-Based Sustainability Framework for Post-Secondary Educational Buildings: A User-Perspective Approach. *Sustainability* 2022, 14, 9955. https://www.researchgate.net/profile/Abobakr-Al-Sakkaf/publication/362633935_An_Integrated_Fuzzy-Based_Sustainability_Framework_for_Post-Secondary_Educational_Buildings_A_User-Perspective_Approach/links/62f536f679550d6d1c739569/An-Integrated-Fuzzy-Based-Sustainability-Framework-for-Post-Secondary-Educational-Buildings-A-User-Perspective-Approach.pdf
- Altomonte, S., Allen, J., Bluysen, P. M., Brager, G., Hescong, L., Loder, A., ... & Wargocki, P. (2020). Ten questions concerning well-being in the built environment. *Building and Environment*, 180, 106949. <https://doi.org/10.1016/j.buildenv.2020.106949>
- Amerio, A., Brambilla, A., Morganti, A., Aguglia, A., Bianchi, D., Santi, F., ... & Capolongo, S. (2020). COVID-19 lockdown: housing built environment's effects on mental health. *International journal of environmental research and public health*, 17(16), 5973. <https://doi.org/10.3390/ijerph17165973>
- Anand, P., Cheong, D., & Sekhar, C. (2022). A review of occupancy-based building energy and IEQ controls and its future post-COVID. *Science of the Total Environment*, 804, 150249. <https://www.sciencedirect.com/science/article/pii/S0048969721053262>
- Andargie, M. S., & Azar, E. (2019). An applied framework to evaluate the impact of indoor office environmental factors on occupants' comfort and working conditions. *Sustainable Cities and Society*, 46, 101447. <https://doi.org/10.1016/j.scs.2019.101447>
- Argarwal, N., Gao, R., & Garner, M. (2023). Renters, rent inflation and renter stress. *RBA Bulletin*, 1-9. <https://www.rba.gov.au/publications/bulletin/2023/mar/pdf/bulletin-2023-03.pdf#page=5>

-
- Aspiredil. (2022). *Aspiredil on LinkedIn: Il problema della indoor generation*.
Https://Www.aspiredil.com. https://www.linkedin.com/posts/aspiredil-il-problema-della-indoor-generation-activity-6933111183902134272-Bft2?utm_source=linkedin_share&utm_medium=member_desktop_web
- Asthma and Respiratory Foundation NZ. (2015). *Respiratory disease*.
Https://Www.asthmafoundation.org.nz/. <https://s3-ap-southeast-2.amazonaws.com/assets.asthmafoundation.org.nz/documents/Respiratory-Disease-in-NZ.pdf>
- Asthma foundation NZ. (2020). *Health conditions related to cold and damp houses*.
Www.asthmafoundation.org.nz.
<https://www.asthmafoundation.org.nz/research/health-conditions-related-to-cold-and-damp-houses/>
- Bennett, D., Barrett, A., & Helmich, E. (2019). How to analyse qualitative data in different ways. *The clinical teacher*, 16(1), 7-12.
- Bluyssen, P. M. (2020). Towards an integrated analysis of the indoor environmental factors and its effects on occupants. *Intelligent Buildings International*, 12(3), 199-207.
<https://doi.org/10.1080/17508975.2019.1599318>
- Bortolini, R., & Forcada, N. (2021). Association between building characteristics and indoor environmental quality through post-occupancy evaluation. *Energies*, 14(6), 1659.
- BRANZ. (2015). *2015 House Condition Survey results*. Wwww.branz.co.nz.
<https://www.branz.co.nz/healthy-homes-research/hcs/2015-results/>
- Build Magazine187. (2022, January). Thermal bridging in timber - framed walls. *Build*, 18.
www.branz.co.nz/pubs/previous-webinars.
- Building regulatory system. (n.d.). Building regulatory system | Ministry of Business, Innovation
- Calleja, K. (2018). Risk in a Changing Urban Environment: Anxieties of Heritage, Identity and Culture (Master's thesis, University of Malta).
- Cheung, C. to, Schiavon, S., Graham, L. T., & Tham, K. W. (2020). Occupant satisfaction with the indoor environment in seven commercial buildings in Singapore. *Building and Environment*, 107443. <https://doi.org/10.1016/j.buildenv.2020.107443>

-
- Construction procurement,. (2019, September 19). Retrieved from New Zealand Government Consumer NZ. (2020). *5 tips for saving money on your hot water*. Consumer NZ. <https://www.consumer.org.nz/articles/hot-water-energy-saving-tips>
- Critical Care Practitioner. (2023). *Mechanical ventilation: Physiologic effects of mechanical ventilation*. Critical Care Practitioner. <https://www.criticalcarepractitioner.co.uk/mechanical-ventilation-physiologic-effects-mechanical-ventilation/>
- Čulić, A., Nižetić, S., Šolić, P., Perković, T., Anđelković, A., & Čongradac, V. (2022). Investigation of personal thermal comfort in office building by implementation of smart bracelet: A case study. *Energy*, 260(260), 124973. <https://doi.org/10.1016/j.energy.2022.124973>
- DeJonckheere, M., & Vaughn, L. M. (2019). Semistructured interviewing in primary care research: a balance of relationship and rigour. *Family medicine and community health*, 7(2).
- Dimitroulopoulou, S., Dudzińska, M. R., Gunnarsen, L., Hägerhed, L., Maula, H., Visualisation, R. S., ... & Haverinen-Shaughnessy, U. (2023). Indoor air quality guidelines from across the world: An appraisal considering energy saving, health, productivity, and comfort. *Environment International*, 108127.
- Domínguez-Amarillo, S., Fernández-Agüera, J., Cesteros-García, S., & González-Lezcano, R. A. (2020). Bad air can also kill: residential indoor air quality and pollutant exposure risk during the COVID-19 crisis. *International Journal of Environmental Research and Public Health*, 17(19), 7183. <https://doi.org/10.3390/ijerph17197183>
- Dong, B., Prakash, V., Feng, F., & O'Neill, Z. (2019). A review of a smart building sensing system for better indoor environment control. *Energy and Buildings*, 199, 29-46.
- Dreamstime. (2022). *thumbs-cold-window-written-pane-condensation*. Dreamstime.com. <https://thumbs.dreamstime.com/b/cold-window-written-pane-condensation-56792914.jpg>

-
- El-Salamouny, H. E. S., Abdou, A., & Ghoneem, M. (2019). Effects of Indoor Environmental Quality on Occupant's Satisfaction, Health and Productivity. *Port-Said Engineering Research Journal*, 23(1), 10-18. <http://dx.doi.org/10.21608/pserj.2019.32532>
- Elsayed, M., Pelsmakers, S., Pistore, L., Castaño-Rosa, R., & Romagnoni, P. (2023). Post-occupancy evaluation in residential buildings: A systematic literature review of current practices in the EU. *Building and Environment*, 110307. <https://doi.org/10.1016/j.buildenv.2023.110307>
- Fisk, W. J., Singer, B. C., & Chan, W. R. (2020). Association of residential energy efficiency retrofits with indoor environmental quality, comfort, and health: A review of empirical data. *Building and Environment*, 180, 107067. <https://doi.org/10.1016/j.buildenv.2020.107067>
- Freeze, P. (2023, August 2). The Role of Tenant Feedback in Improving Rental Property Services. Retrieved from Bay Property Management Group website: <https://www.baymgmtgroup.com/blog/tenant-feedback/>
- Fyfe, C., Grimes, A., Minehan, S. and Taptiklis, P., 2022. Warmer Kiwis Study: Interim Report. An impact evaluation of the Warmer Kiwi Homes programme.
- Hou, H.C., Zhang, D. and Lai, J.H., 2023. Qualitative and quantitative investigation into the indoor built environment of modular student housing: A multiple-room case study. *Energy and Buildings*, 280, p.112734. <https://www.mbie.govt.nz/cross-government-functions/regulatory-https://www.procurement.govt.nz/procurement/specialised-procurement/construction-procurement/construction-procurement-guidelines/>
- Jimenez, J. L. (2021). Exhaled CO₂ as a COVID-19 infection risk proxy for different indoor environments and activities. *Environmental Science & Technology Letters*, 2021. Tether Limited.
- Kakoulli, C., Kyriacou, A., & Michaelides, M. P. (2022). A review of field measurement studies on thermal comfort, indoor air quality and virus risk. *Atmosphere*, 13(2), 191. <https://www.mdpi.com/2073-4433/13/2/191>

-
- Kallio, J., Vildjiounaite, E., Koivusaari, J., Räsänen, P., Similä, H., Kyllönen, V., Muuraiskangas, S., Ronkainen, J., Rehu, J. and Vehmas, K., 2020. Assessment of perceived indoor environmental quality, stress and productivity based on environmental sensor data and personality categorization. *Building and Environment*, 175, p.106787.
- Kamali, M., Hewage, K., & Milani, A. S. (2018). Life cycle sustainability performance assessment framework for residential modular buildings: Aggregated sustainability indices. *Building and Environment*, 138, 21-41.
- Kelly, F. J., & Fussell, J. C. (2019). Improving indoor air quality, health and performance within environments where people live, travel, learn and work. *Atmospheric Environment*, 200, 90-109. <https://doi.org/10.1016/j.atmosenv.2018.11.058>
- Kiger, M. E., & Varpio, L. (2020). Thematic analysis of qualitative data: AMEE Guide No. 131. *Medical teacher*, 42(8), 846-854.
- Kim, S. D., & Carswell, A. T. (2022). The mediation effect of indoor air quality on health: A comparison of homeowners and renters. *Indoor air*, 32(9), e13108. <https://doi.org/10.1111/ina.13108>
- Kinnebrew, E., Shoffner, E., Farah-Pérez, A., Mills-Novoa, M. and Siegel, K., 2021. Approaches to interdisciplinary mixed methods research in land-change science and environmental management. *Conservation Biology*, 35(1), pp.130-141.
- Krishnamurthi, R., Kumar, A., Gopinathan, D., Nayyar, A. and Qureshi, B., 2020. An overview of IoT sensor data processing, fusion, and analysis techniques. *Sensors*, 20(21), p.6076.
- Kwon, M., Remøy, H., & van den Bogaard, M. (2019). Influential design factors on occupant satisfaction with indoor environment in workplaces. *Building and Environment*, 157(157:356-365), 356–365. <https://doi.org/10.1016/j.buildenv.2019.05.002>
- La Crosse. (2022). *LTV-TH3 Thermo-Hygro Sensor*. La Crosse Technology. <https://www.lacrosstechnology.com/products/ltv-th3>
- La Crosse. (2022). *V42-PRO Complete Personal Remote Monitoring Weather Station*. La Crosse Technology. <https://www.lacrosstechnology.com/products/v42-pro>
- Lee, E. (2019). Indoor environmental quality (IEQ) of LEED-certified home: Importance-performance analysis (IPA). *Building and Environment*, 149, 571-581.

-
- Lee, J.Y., Wargocki, P., Chan, Y.H., Chen, L. and Tham, K.W., 2019. Indoor environmental quality, occupant satisfaction, and acute building-related health symptoms in Green Mark-certified compared with non-certified office buildings. *Indoor air*, 29(1), pp.112-129.
- Li, E. and Zhu, J., 2022. Parametric analysis of the mechanism of creating indoor thermal environment in traditional houses in Lhasa. *Building and Environment*, 207, p.108510.
- Li, P., Froese, T.M. & Brager, G., 2018. Post-occupancy evaluation: State-of-the-art analysis and state-of-the-practice review. *Building and Environment*, 133, pp.187-202.
- Licina, D., & Yildirim, S. (2021). Occupant satisfaction with indoor environmental quality, sick building syndrome (SBS) symptoms and self-reported productivity before and after relocation into WELL-certified office buildings. *Building and Environment*, 204, 108183. <https://doi.org/10.1016/j.buildenv.2021.108183>
- Lochmiller, C. R. (2021). Conducting thematic analysis with qualitative data. *The Qualitative Report*, 26(6), 2029-2044.
- Lolli, F., Marinello, S., Coruzzolo, A. M., & Butturi, M. A. (2022). Post-Occupancy evaluation's (POE) applications for improving indoor environment quality (IEQ). *Toxics*, 10(10), 626. <https://doi.org/10.3390/toxics10100626>
- Malmqvist, J., Hellberg, K., Möllås, G., Rose, R., & Shevlin, M. (2019). Conducting the pilot study: A neglected part of the research process? Methodological findings supporting the importance of piloting in qualitative research studies. *International journal of qualitative methods*, 18, 1609406919878341.
- Mammoth Insulation Ltd. (2022). *mammoth.co.nz*. [Www.mammoth.co.nz](http://www.mammoth.co.nz). <https://www.mammoth.co.nz/news/building-code-changes-affecting-new-homes>
- MBIE. (2019). *Acceptable Solutions and Verification Methods For New Zealand Building Code Clause H1 Energy Efficiency H1*. <https://www.building.govt.nz/assets/Uploads/building-code-compliance/h1-energy-efficiency/asvm/h1-energy-efficiency-4th-edition-amendment-4.pdf>
- MBIE. (2022). *Tenancy Services - Healthy homes insulation standard*. Tenancy Services. <https://www.tenancy.govt.nz/healthy-homes/insulation-standard/>

-
- MBIE. (2022a). *Building Code update 2022 - Transition period for the energy efficiency of housing* | Ministry of Business, Innovation & Employment. [Www.mbie.govt.nz. https://www.mbie.govt.nz/have-your-say/building-code-update-2022-h1-transition-period/](https://www.mbie.govt.nz/have-your-say/building-code-update-2022-h1-transition-period/)
- MBIE. (2022b). *Tenancy Services - Healthy homes insulation standard*. Tenancy Services. <https://www.tenancy.govt.nz/healthy-homes/insulation-standard/>
- Megahed, N. A., & Ghoneim, E. M. (2021). Indoor Air Quality: Rethinking rules of building design strategies in post-pandemic architecture. *Environmental research*, 193, 110471. <https://doi.org/10.1016/j.envres.2020.110471>
- Ministry of Business, Innovation & Employment. (2022). *Tenancy Services - Healthy homes insulation standard*. Tenancy Services. <https://www.tenancy.govt.nz/healthy-homes/insulation-standard/>
- Naegler, T., Sutardhio, C., Weidlich, A., & Pregger, T. (2021). Exploring long-term strategies for the german energy transition-A review of multi-Sector energy scenarios. *Renewable and Sustainable Energy Transition*, 1, 100010. <https://doi.org/10.1016/j.rset.2021.100010>
- National Ethics Advisory Committee. (2019). *National ethical standards for health and disability research and quality improvement*. Wellington: Ministry of Health.
- NIOSH. (2019). *CDC - Indoor Environmental Quality - NIOSH Workplace Safety and Health Topic*. The National Institute for Occupational Safety and Health (NIOSH). <https://www.cdc.gov/niosh/topics/indoorenv/default.html>
- O'Donovan, A., & O'Sullivan, P. D. (2023). The impact of retrofitted ventilation approaches on long-range airborne infection risk for lecture room environments: design stage methodology and application. *Journal of Building Engineering*, 68, 106044. <https://www.sciencedirect.com/science/article/pii/S2352710223002231>
- Ortiz, M., Itard, L., & Bluysen, P. M. (2020). Indoor environmental quality related risk factors with energy-efficient retrofitting of housing: A literature review. *Energy and Buildings*, 221, 110102. <https://doi.org/10.1016/j.enbuild.2020.110102>

-
- Ratajczak, K., & Basińska, M. (2021). The Well-Being of Children in Nurseries Does Not Have to Be Expensive: The Real Costs of Maintaining Low Carbon Dioxide Concentrations in Nurseries. *Energies*, 14(8), 2035. <https://doi.org/10.3390/en14082035>
- Rosen, E., Garboden, P. M., & Cossyleon, J. E. (2021). Racial discrimination in housing: how landlords use algorithms and home visits to screen tenants. *American Sociological Review*, 86(5), 787-822. <https://journals.sagepub.com/doi/abs/10.1177/00031224211029618?journalCode=asra>
- Sadrizadeh, S., Yao, R., Yuan, F., Awbi, H., Bahnfleth, W., Bi, Y., ... & Li, B. (2022). Indoor air quality and health in schools: A critical review for developing the roadmap for the future school environment. *Journal of Building Engineering*, 104908. <https://doi.org/10.1016/j.jobe.2022.104908>
- Schweiker, M., Ampatzi, E., Andargie, M.S., Andersen, R.K., Azar, E., Barthelmes, V.M., Berger, C., Bourikas, L., Carlucci, S., Chinazzo, G. and Edappilly, L.P., 2020. Review of multi-domain approaches to indoor environmental perception and behaviour. *Building and Environment*, 176, p.106804.
- Science Photo Library (SPL). (2023). *Aspergillus fungus - stock image - B250/0869 - science photo library*. [Www.sciencephoto.com. https://www.sciencephoto.com/media/13737/view/aspergillus-fungus](https://www.sciencephoto.com/media/13737/view/aspergillus-fungus)
- Sovacool, B. K., Axsen, J., & Sorrell, S. (2018). Promoting novelty, rigor, and style in energy social science: Towards codes of practice for appropriate methods and research design. *Energy research & social science*, 45, 12-42.
- Spena, Angelo & Palombi, Leonardo & Corcione, Massimo & Carestia, Mariachiara & Spena, Vincenzo. (2020). On the Optimal Indoor Air Conditions for SARS-CoV-2 Inactivation. An Enthalpy-Based Approach. *International Journal of Environmental Research and Public Health*. 17. 6083. 10.3390/ijerph17176083. (2020). *International journal of environmental research and public health*. Research Gate. <https://www.researchgate.net/publication/343807991> [On the Optimal Indoor Air Conditions for SARS-CoV-2 Inactivation An Enthalpy-](https://www.researchgate.net/publication/343807991)

[Based Approach/citation/download](#)

stewardship/regulatory-systems/building-regulatory-system/

Stocktake of New Zealand's Housing. (2021). *Facts*. Dwell.org.nz. <https://dwell.org.nz/housing-facts>

SurveyMonkey. (2022). *Survey1 - Winter July/August 2022 Buildings; 318/320*. Surveymonkey.com https://www.surveymonkey.com/analyze/data-trends/f7hzjqFoZQ_2BUIGK4rofQpxVZpPISpgSQrNg7ng3NPc_3D#

Taher Tolou Del, M. S., Saleh Sedghpour, B., & Kamali Tabrizi, S. (2020). The semantic conservation of architectural heritage: the missing values. *Heritage Science*, 8, 1-13. <https://link.springer.com/article/10.1186/s40494-020-00416-w>

Tang, H., Ding, Y., & Singer, B. (2020). Interactions and comprehensive effect of indoor environmental quality factors on occupant satisfaction. *Building and Environment*, 167, 106462.

Taptiklis, P., & Phipps, R. (2017). Indoor air quality in New Zealand homes and schools.

Testo. (2022). *Search Testo 872 | Testo, Inc.* Wwww.testo.com. <https://www.testo.com/en-US/search/?text=Testo+872>

Tether Limited. (2020). *Tether | solving building performance problems | New Zealand*. Tether. <https://tether.co.nz>

Tether. (2021, November 10). Tether's Indoor Air Quality Monitoring Solution Enables Healthy Environments. Retrieved October 30, 2023, from thinextra.com website: <https://thinextra.com/blog/tether-thinextra-partner-profile/>

Türkeş, M. C., Oncioiu, I., Aslam, H. D., Marin-Pantelescu, A., Topor, D. I., & Căpuşneanu, S. (2019). Drivers and barriers in using industry 4.0: a perspective of SMEs in Romania. *Processes*, 7(3), 153.

Twistfix. (2013, October 24). *Condensation damp and mould. stick with twistfix*. Twistfix. <https://www.twistfix.co.uk/condensation-damp-and-mould>

Villeneuve, H., & O'Brien, W. (2020). Listen to the guests: Text-mining Airbnb reviews to explore indoor environmental quality. *Building and Environment*, 169, 106555.

Vutility. (2022). *The HotDrop, from Vutility. Submetering solution that provides actionable, real-*

time data. Vutility.com. <https://vutility.com/hotdrop>

Wagner, A., O'Brien, W., & Dong, B. (2018). Exploring occupant behavior in buildings. Wagner, A., O'Brien, W., Dong, B., Eds.

Weerasinghe, A. S., Rasheed, E., & Rotimi, J. O. B. (2020, November). Occupant Energy Behaviours—A Review of Indoor Environmental Quality (IEQ) and Influential Factors. In Proceedings of the International Conference of Architectural Science Association, Auckland, New Zealand (pp. 26-27).

Weerasinghe, Achini Shanika, Eziaku Rasheed, & James Olabode Bamidele Rotimi. "Occupant energy behaviours—a review of indoor environmental quality (IEQ) and influential factors." In 54th International Conference of the Architectural Science Association, ANZAScA, Auckland, New Zealand, pp. 805-814. 2020. https://www.researchgate.net/profile/Achini-Weerainghe/publication/346580473_Occupant_Energy_Behaviours_-_A_Review_of_Indoor_Environmental_Quality_IEQ_and_Influential_factors/links/6001d7b645851553a0491eb9/Occupant-Energy-Behaviours-A-Review-of-Indoor-Environmental-Quality-IEQ-and-Influential-factors.pdf

Weston, R., Cen, S., Newman, P., & Posner, I. (2019). Probably unknown: Deep inverse sensor modelling radar. In 2019 International Conference on Robotics and Automation (ICRA) (pp. 5446-5452). IEEE.

White, B. J., Amrine, D. E., & Larson, R. L. (2018). Big data analytics and precision animal agriculture symposium: Data to decisions. *Journal of Animal Science*, 96(4), 1531-1539.

Yock, Y. S. H. (2021). The relationship between indoor environment, outdoor environment, and behavior on indoor air quality and health. University of California, Los Angeles. <https://escholarship.org/content/qt5k0204r7/qt5k0204r7.pdf>

Zambrano, J. M., Oberegger, U. F., & Salvalai, G. (2021). Towards integrating occupant behaviour modelling in simulation-aided building design: Reasons, challenges and solutions. *Energy and Buildings*, 253, 111498. <https://doi.org/10.1016/j.enbuild.2021.111498>

Zhang, W., Wu, Y. and Calautit, J.K., 2022. A review on occupancy prediction through machine learning for enhancing energy efficiency, air quality and thermal comfort in the built environment. *Renewable and Sustainable Energy Reviews*, 167, p.112704.

Zuhaib, S., Manton, R., Griffin, C., Hajdukiewicz, M., Keane, M.M. and Goggins, J., 2018. An Indoor Environmental Quality (IEQ) assessment of a partially-retrofitted university building. *Building and Environment*, 139, pp.69-85.

Appendices

Appendix A

Information Sheet and Participant Consent Form. Low-risk notification – Ethics Notification
Number: 4000026290



Research Project

INFORMATION SHEET AND CONSENT FORM

Project Description and Invitation

My name is Kris Wang. I am a post-graduate student at the School of Built Environment, Massey University. I am carrying out a research project titled; **Monitoring the effect of Indoor Environment Quality on occupant's comfort and satisfaction** as a part of my 90 credit Thesis for courses; 218.828, 218.829 Part 1 and 2 at the School of Built Environment.

I would highly appreciate it if you could participate in this exciting research project to monitor the building performance as a building occupier or building owner. This project will analyse and show the differences between two refurbished buildings in IEQ (Indoor Environmental Quality) and energy use.

Internal environmental monitoring; will take the tangible evidence of how the external and internal environment with human behaviour acts on; interior air quality, temperature, humidity, acoustics, illuminance and concentration of CO2 influencing occupants' perception, comfort and wellbeing. Harvested data will be crucial to understanding the optimum performance in two rental setups with the occupants in a building at different times of the week (weekends) and the year (seasons). To achieve this, the occupied buildings for the research project will be examined concerning the following objectives:

- Analysing perception of the persons (building occupier) during their activities at different times of the day during the seasons at their home
- What is the people's comfort and perception in the occupied space area in a specific situation exposed to the differences in; temperature, humidity, air quality, noise or illuminance?
- How important is it to keep up with a 'good' refurbishment of the old buildings for the health of the occupants?
- How and what are the best solutions we can provide to meet or exceed second the H1/AS1 Energy Efficiency for the internal occupants' comfort and wellbeing?

Data Management

Information collected in this project will be kept strictly confidential and used solely for academic purposes only. The information provided will be destroyed upon completion of the project. I undertake to provide you with a summary of the study's key findings if you could complete the attached form requesting the summary or by contacting me directly through my contact details provided below.

Participation in this research is voluntary, and you are under no obligation to accept this invitation. If you decide to participate, you have the right to:

- decline to answer any particular question;
- withdraw from the participation of the project at any time.
- ask any questions about the research project at any time during participation;
- be given access to a summary of the research project findings when it is concluded.

Low-Risk Notifications: Ethics Notification Number: 4000026290

This project has been evaluated by peer review and judged low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The student named above is responsible for the ethical conduct of this exercise.

If you have any concerns about the conduct of this research project that you wish to raise with someone other than the researcher(s), don't hesitate to get in touch with Dr Eziaku O. Rasheed, The Research Project Coordinator and Supervisor.

e.o.rasheed@massey.ac.nz

Thank you very much for your time and help in making this project possible. If you have any queries, please contact me through my contact details below.

Kris Wang (researcher)

[Redacted contact details]

Participant's Consent

I have read the Information Sheet and have had the details of the study explained to me. My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I agree to participate in this study under the conditions set out in the Information Sheet.

Signature:



Date:

6-7-22

Full Name - printed

Mikki Wang

Low-Risk Notifications: Ethics Notification Number: 4000026290

This project has been evaluated by peer review and judged low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The student named above is responsible for the ethical conduct of this exercise.

If you have any concerns about the conduct of this research project that you wish to raise with someone other than the researcher(s), don't hesitate to get in touch with Dr Eziaku O. Rasheed, The Research Project Coordinator and Supervisor.

e.o.rasheed@massey.ac.nz

Thank you very much for your time and help in making this project possible. If you have any queries, please contact me through my contact details below.

Kris Wang (researcher)

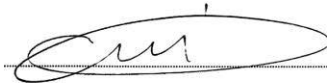
██████████
██████████

Participant's Consent

I have read the Information Sheet and have had the details of the study explained to me. My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I agree to participate in this study under the conditions set out in the Information Sheet.

Signature:



Date:

06/07/22

Full Name - printed

RIKKI STEWART

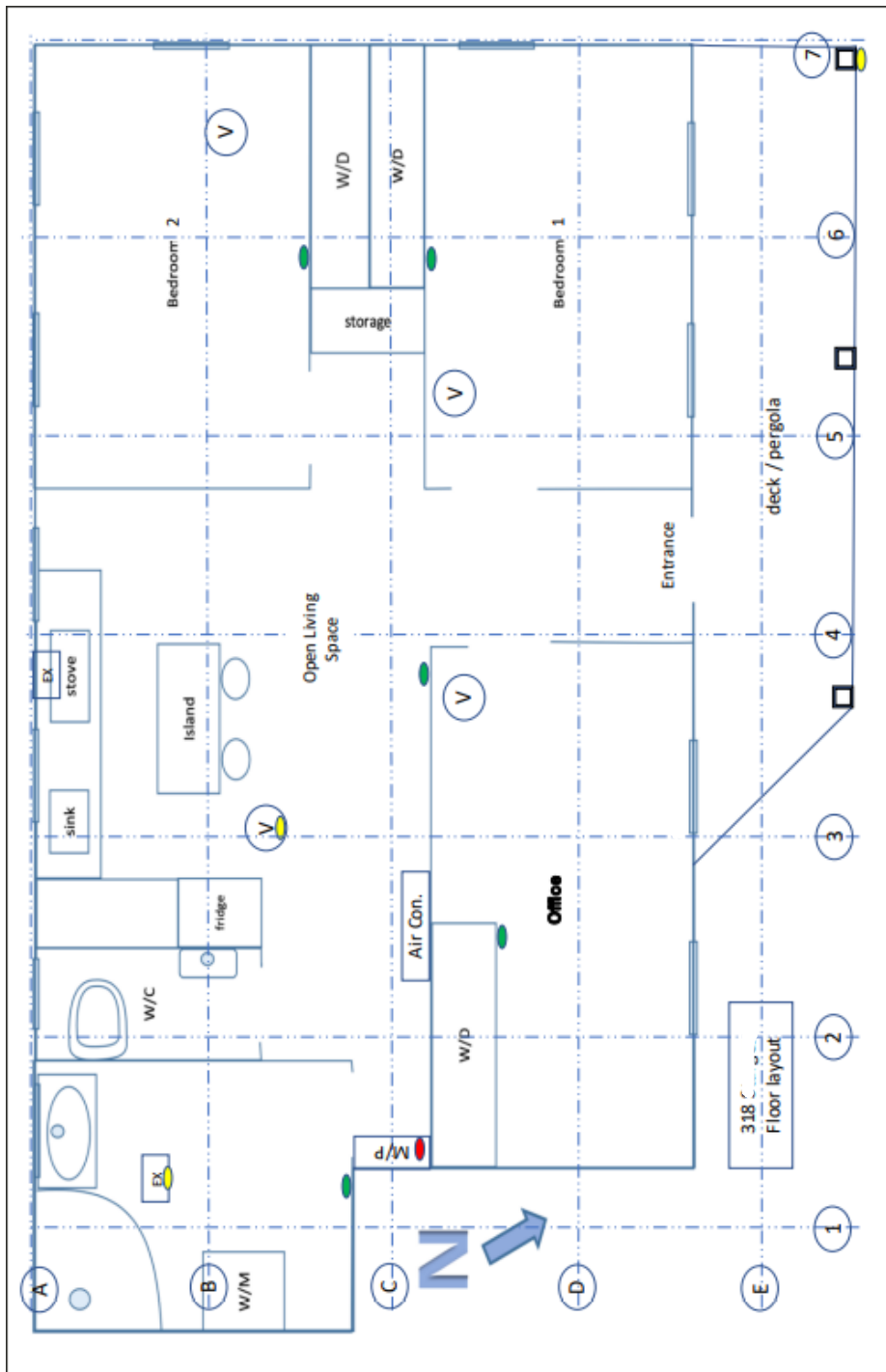
Appendix B

Satellite aerial view of the property and layout floor plans of the occupied and rented spaces at; 318 and 320 situated within the same property.



Satellite aerial view - Buildings 318, and 320.

Appendix C



Unit 318, Floor layout with a total space of 102 sqm approximately.

Kris Wang's Research Project as a part of 90 credits Thesis for courses; 218.828, 218.829 titled;

- Monitoring the effect of Indoor Environment Quality on occupant's comfort and satisfaction.

House 1, 318

Tether EnviroQ (KWEQ - Kris Wang EnviroQ). Marking and placement of the sensors.



- KWEQ 1 Office Grid C-2
- KWEQ 2 Bathroom/Laundry Grid B-1
- KWEQ 3 Open Plan Living Room/Kitchen Grid C-3
- KWEQ 4 Bedroom 1 Grid C-5
- KWEQ 5 Bedroom 2 Grid B-5

Tether HotDrop (KWHD - Kris Wang HotDrop). Marking and placement of the sensors.



- KWHD 1 Grid C-1

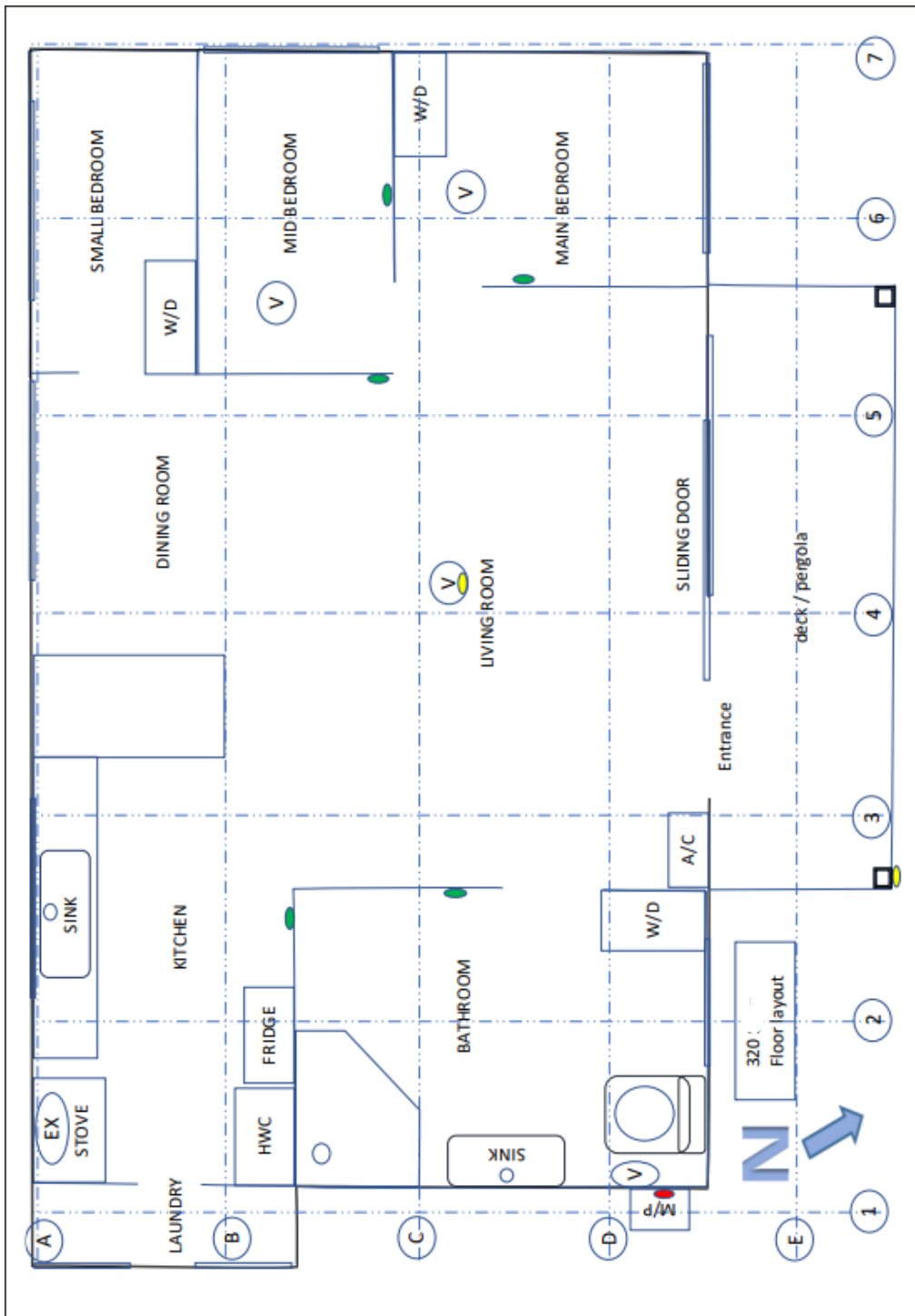
PWS (Personal Weather Station) La Crosse Technology - V40A Pro with LTV - TH3 Thermo-Hygro Sensors
(KWTH - Kris Wang Thermo-Hygro). Marking and placement of the sensors.






- KWTH 1 Outdoor (North) Grid E-7
- KWTH 2 Indoor AirVent Duct Grid B-3
- KWTH 3 Bathroom Extractor/Fan Grid A-1
- KWTH 4 Roof Space/Loft Grid B-5

Placement of the sensors, building 318

Appendix D



Detached house at 320, Floor layout with a total space of 95 sqm approximately.

House 2, 320		
Tether EnviroQ (KWEQ -) EnviroQ). Marking and placement of the sensors.		
		
- KWEQ 6	Living Room	Grid B-5
- KWEQ 7	Kitchen	Grid B-2
- KWEQ 8	Main Bedroom	Grid C-5
- KWEQ 9	Mid Bedroom	Grid B-6
- KWEQ 10	Bathroom	Grid C-2
Tether HotDrop (KWHD -) HotDrop). Marking and placement of the sensors.		
		
- KWHD 2	Main Power Box (M/P)	Grid D-1
PWS (Personal Weather Station) La Crosse Technology - V40A Pro with LTV - TH3 Thermo-Hygro Sensors		
(KWTH -) Thermo-Hygro). Marking and placement of the sensors.		
		
- KWTH 5	Outdoor (North)	Grid E-2
- KWTH 6	Indoor AirVent Duct	Grid C-4

Placement of the sensors, building 320

Appendices' - abbreviation

- » A/C - Air conditioning
- » E/EX - Extractor (rangehood)
- » HWC - Hot water cylinder
- » V - Ventilation (Fan, HRV or DVS)
- » W/C - Toilet
- » W/M - Washing machine
- » W/D - Wardrobe

Appendix E

Questionnaires A

One-off Survey – 2022 Occupancy Characteristics Building; 318/320

Monitoring the effect of Indoor Environmental Quality (IEQ) on occupant's comfort and satisfaction

P1: 1st part of **survey dedicated to** House configuration.

Winter - August 2022

1. Date/Time
2. Tick the appropriate building you're living at
318
320
3. The house you live is single-level or multilevel?
Single
Multilevel
Any comments/questions?
4. How many rooms are in your house?
1, 2, 3, 4, 5 ...
5. Is there an office space/room in your house?
Yes, no
6. How many bathrooms are in the house?
1, 2
7. Is there any kitchen facility in an open concept space in your house?
Yes, no

P1.2.: 2nd part of the survey dedicated to **Occupancy - Background**

8. How many people living in this household?
2, 3, 4, 5...
9. Are there any pets living indoor with you?
Yes, No, I prefer not saying

P1.3.: 3rd part of the survey dedicated to **Heating and Ventilation**

10. How many heating appliances are in your house?
 - 1 Air conditioning (heat pump) only
 - 1 Air conditioning (heat pump) and 1 heating appliances
 - 1 Air conditioning (heat pump) and 2 heating appliances
11. Is there any mechanical ventilation?
Yes, No, I don't know
12. Do you open windows and doors to ventilate indoors?
Yes, No, Sometimes, I don't have to

13. What would you do to improve heating/cooling and ventilation in your house?

- A better insulation
- A better heating and insulation system
- A new double-glazed window
- A good insulated and sealed doors
- A new house
- All the answers above

Any suggestions/questions?

Appendix F

Questionnaires B

Survey2 – Winter August 2022

Buildings; 318/320

Monitoring the effect of Indoor Environmental Quality (IEQ)
on occupant's comfort and satisfaction.

SURVEY – Comfort and satisfaction – Winter – August 2022

1. Date
2. Please select the building you're currently in
 - 318
 - 320
3. What is the time frame you're completing the survey?
 - Morning between 8-11am
 - Afternoon between 1-4pm
 - Evening between 5-8pm
 - Late evening/night between 9-11pm
4. When responding to this survey, where are you at that moment?
 - Kitchen
 - Living room
 - Bathroom
 - Main bedroom
 - Middle bedroom
 - Office

Any comments/questions?

5. Regarding the internal environment aspects, how do you feel?
 - Comfortable
 - Uncomfortable
 - It's OK

Any comments/questions?

6. Describe your house during this survey.

- Airless
- Airy
- Hot
- Quiet and peaceful
- Cold
- Muggy
- Smelly
- Dark and cold
- Warm and cosy
- Damp

Any comments/questions?

7. What would you prefer the internal temperature to be?

- Cooler
- No change
- Warmer

Any comments/questions?

8. What would be your light preference?

- Dimmer
- No change
- Brighter
- Warmer light colour
- Cooler light colour

Any comments/questions?

9. What would be your air preferences?

- More airy
- Fresher
- Less airy
- No change

Any comments/questions?

10. What clothes are you wearing?

- Very light
- Light
- Medium
- Warm clothing
- Fully clothed

Any comments/questions?

Appendix G

Equipment notification and serial number

	A	B	C	D	E	F	G	H	I	J	K	L
1		Ezi Eqpt check off			1/07/2022		Kris Wang	21013739				
2	Qty		ID	ID	S/N							
3	10	• Tiny Tags:	1		N/A	Returned to Massey Uni as the cable and software not available & measure only temperature (not wireless) (20/07/2022)						
4		"	2		N/A							
5		"	3		N/A							
6		"	4		N/A							
7		"	5		N/A							
8		"	6		N/A							
9		"	7		N/A							
10		"	8		N/A							
11		"	9		N/A							
12		"	10		N/A							
13												
14	1	• Thermal Camera:	1	KWTC 1	Testo 872	WAF-2016 TIF AM						
15												
16	20	• Apple watch (Cozie App)	1	KWA 1	Not received yet	Awaiting for the app developer						
17		"	2	KWA 2	Not received yet	Awaiting for the app developer						
18		"	3									
19		"	4									

37		Ezi Eqpt check off			1/07/2022		Zone/Grid			
38	10	• EnviroQ: 10 pieces	1	KWEQ 1	B40C 4039	Office	C-2	318		
39		"	2	KWEQ 2	E7EA 24D6	Bathroom	B-1	318		
40		"	3	KWEQ 3	OD3D B0DD	Open Spa	C-3	318		
41		"	4	KWEQ 4	0713 7CC1	Bedroom	C-5	318		
42		"	5	KWEQ 5	2585 0794	Bedroom	B-5	318		
43		"	6	KWEQ 6	2917 B469	LivingRoom	B-5	320		
44		"	7	KWEQ 7	5AD06931	Kitchen	B-2	320		
45		"	8	KWEQ 8	93CF B4CA	MainBedro	C-5	320		
46		"	9	KWEQ 9	94D6 19BA	MidBedroo	B-6	320		
47		"	10	KWEQ 10	9917 7510	Bathroom	C-2	320		
48										
49	2	• HotDrop: 2 pieces	1	KWHD 1	BK0LA01052	MainPowe	C-1	318		
50		"	2	KWHD 2	BK0LA03609	MainPowe	D-1	320		
51										
52	30	• Batteries: 30 pieces			Not received/ sensors have already batteries with 85% of power					
53										

Appendix H

Minimum requirements of the R values ($\text{m}^2 \text{ }^\circ\text{C/W}$) at the time of the data collection.

H1 Minimum requirements R-values required at the time of the research (August 2022).

Building thermal envelope component	Minimum R-values ($\text{m}^2 \text{ }^\circ\text{C/W}$)		
	Climate zone 1	Climate zone 2	Climate zone 3
Roof	R 2.9	R 2.9	R 3.3
Wall	R 1.9	R 1.9	R 2.0
Floor	R 1.3	R 1.3	R 1.3
Glazing (vertical)	R 0.26	R 0.26	R 0.26
Glazing (skylights)	R 0.26	R 0.26	R 0.31

NOTE:

- (1) The R-values given in this table are those applicable to the reference building as described in this Standard (NZS 4218).
- (2) Climate zone boundaries are shown in Appendix B (of NZS 4218).
- (3) If the sum of the area of glazing on the East, South and West facing walls (see Appendix H of NZS 4218) is more than 30% of the total wall area of all of these walls, then the calculation or modelling method shall be used.
- (4) Carpets or floor coverings are not included in the floor R-value. The floor R-value is met by concrete slab-on-ground and suspended floors with continuous closed perimeter with 100 mm draped foil. Exposed floors will require additional treatment (e.g. pole houses).
- (5) The R-values for glazing refer to whole window R-values (glass and frame). The values in this table are for a standard WERS window (see Appendix G of NZS 4218). Any proposed area of glazing shall be considered to have an R-value as given in Appendix G (of NZS 4218).
- (6) There are no R-value requirements for the opaque parts of a door or a door set.
- (7) Total area of skylights must be no more than 1.2 m^2 . The calculation or modelling methods must be used for designs where the total area of skylights is more than 1.2 m^2 .
- (8) An R-value of $0.26 \text{ m}^2 \text{ }^\circ\text{C/W}$ may be used for traditional leadlight glass when the total area of leadlight glass is no greater than 2.6 m^2 and either the schedule method or calculation method is used.

H1 Minimum requirements of R-values

