Facing the Heat: Utilizing the Internet of Things (IoT) to Enhance Preparedness Against Extreme Heat Events in Canadian Households

by

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Examining Committee Membership

The following served on the Examining Committee for this thesis. The decision of the Examining Committee is by majority vote.

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Author's Declaration

This thesis contains material all of which I authored or co-authored: please see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by the examiners.

I understand that my thesis may be made electronically available to the public.

Statement of Contributions

This thesis contains four manuscripts that have been published or submitted for publication.

Exceptions to sole authorship:

Oetomo, A., Jalali, N., Costa, P. D.P., Morita, P.P. (2022). Indoor Temperatures in the 2018 Heat Wave in Quebec, Canada: Exploratory Study Using Ecobee Smart Thermostats. JMIR Formative Research, 6(5), e34104.

Chapter 4: The primary author, Arlene Oetomo, was responsible for designing the study and developing the research strategy. Data processing and analysis were completed with Dr. Niloofar Jalali. Drs. Plinio Pelegrini Morita and Paula Dornhofer Paro Costa supervised the manuscript writing, editing, and revisions. All authors contributed to the article and approved the submitted version.

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Chapter 5: The primary author, Arlene Oetomo, developed the research strategy and extracted the data. Drs. Peter Berry, Deirdre Pfeiffer, and Lisbeth Berbary provided feedback. Drs. Plinio Pelegrini Morita and Zahid Butt supervised the manuscript's writing, editing, and revisions. All authors approved the submitted version.

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Chapter 6: Arlene Oetomo designed and wrote the manuscript. Health Canada was consulted regarding the relevancy and accuracy of the keywords. Irfhana Zakir Hussain assisted with Twitter data extraction via an API, coherence score analysis, and LDA topic modelling. Drs. Peter Berry, Deirdre Pfeiffer, and Lisbeth Berbary provided feedback. Drs. Plinio Pelegrini Morita and Zahid Butt supervised the manuscript's writing, editing, and revisions. All authors approved the submitted version.

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Chapter 7: Arlene Oetomo designed the study under the supervision of Dr. Plinio Pelegrini Morita. BC Housing and Ottawa Public Health supported data collection. Ottawa Public Health, Vancouver Coastal Health, and Fraser Health aided in survey development. Kang Wang and Dr. Jasleen Kaur developed and executed the ecobee data API. Arlene Oetomo conceptualized real-time email alerts with scripting assistance from Dr. Kaur. The stakeholder dashboard was conceptualized by Oetomo and built by Irfhana Zakir Hussain

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Arlene Oetomo wrote the remaining chapters under Dr. Plinio Morita's supervision.

Abstract

Background Heat waves pose a severe and growing health risk in Canada, with an estimated 17 million people likely to experience extreme heat in the coming decades. These risks are heightened in urban areas, where the urban heat island effect exacerbates dangerous temperatures. Extreme heat events are increasingly frequent, intense, and widespread, with record-breaking heat waves affecting almost every region globally. Despite increasing awareness, many of the dangers associated with extreme heat are only now being fully realized. This work addresses data gaps related to indoor heat vulnerability needed to create safe indoor conditions. Education and early warnings are critical to protecting the population, especially vulnerable groups. Extreme heat is a climate justice issue, disproportionately affecting marginalized groups with fewer resources to cope.

Methods This study used smart thermostats (ecobee) to collect real-time indoor temperature data, developing a hyperlocal alert system for indoor heat risks. First, we analyzed ecobee's "Donate Your Data" dataset to identify homes without air conditioning and to explore indoor and outdoor temperature differences during the 2018 Quebec heat wave. Next, a scoping review assessed the use of IoT or similar devices, focusing on climate-related impacts. Canadians were surveyed through Google Opinion Rewards to evaluate their understanding of heat waves and preferences for receiving heat-related information. Online discourse about heat waves was analyzed using Latent Dirichlet Allocation (LDA) topic modelling on tweets from Twitter (now X), via natural language processing (NLP), and manually using an inductive approach to observe emerging narratives and themes. Finally, in the summer of 2022, a full-scale deployment of smart thermostats was conducted in community housing without air conditioning in collaboration with housing and public health organizations. Indoor temperature data was collected from 70 British Columbia and Ottawa homes, with results shared via daily emails and an elastic dashboard. Three surveys captured details on building types, resident behaviours, and heat-related habits.

Results The scoping review found that using IoT and low-cost sensors for indoor heat monitoring is an emerging field that could strengthen early warning systems and heat response efforts. The survey results showed that most Canadians preferred to receive heat wave information online, with income correlating to the usage of mobile devices. Older demographics still preferred traditional media like TV, radio, and newspapers. Online discussions centred around activities, personal experiences, advice, and warnings related to heat waves. Emerging trends of climate denial were present in both survey and tweet samples. Indoor temperature data revealed that homes frequently exceeded emerging threshold recommendations of 26°C and 31°C, with some homes recording temperatures as high as 38°C on non-heat wave days. Participants in British Columbia were better prepared

and had higher heat safety awareness than other regions. This is the first Canadian study to explore the use of IoT smart thermostats in near-real-time indoor temperature monitoring to protect vulnerable populations from extreme heat. Significant differences were observed between indoor and outdoor temperatures ($P < 0.001$).

Discussion and Conclusion This work shows the potential of IoT devices and social media to improve real-time monitoring and inform evidence-based public health interventions for extreme heat. The widespread adoption of smart thermostats in Canadian homes and the prevalence of social media provide valuable opportunities to address existing data and knowledge gaps. However, the persistence of climate misinformation and denial challenges public health communication efforts. Indoor heat is a public health and equity issue related to poverty, substandard housing, urban planning, and energy access. These interconnected issues must be considered in policy frameworks to protect vulnerable populations. Low-cost sensors and solutions, such as natural ventilation mobile alerts, could support the response to heat health by addressing a data gap. Rapidly analyzing these areas is important as digital spaces evolve to support public health communication. Policymakers must take immediate action to prevent unsafe indoor conditions and protect marginalized communities from the growing threat of extreme heat.

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What a time it has been—the most unprecedented of unprecedented times. We experienced a global pandemic, ongoing social reckonings here in so-called Canada, and collective awakenings globally while striving for collective liberation.

I'm reminded of the incredible privilege of living, working, and thriving on the unceded territories of Turtle Island. Miigwech, Îsnîyes to our Indigenous elders, warriors, and youth who have protected these lands since time immemorial and continue to do so today.

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Dedication

While the impacts of air pollution from wildfires, floods, and extreme heat waves have reached doorsteps across this country, their impacts have not been felt equally. I hope this work will help to improve policies and legislation to reduce societal inequities.

For the victims of extreme heat and their loved ones.

Table of Contents

Examining Committee ii

Author's Declaration iii

Statement of Contributions iv

Abstract vi

Acknowledgements viii

Dedication x

List of Figures xx

List of Tables xxiv

List of Abbreviations xxvi

Statement of Positionality xxviii

1 Introduction 1

1.1 It is getting hotter 1

1.2 The Internet of Things 4

1.3 My motivation 5

1.4 Structure of the thesis 8

2 Background **10**
2.1 Literature review . . . 10
2.1.1 Defining heat and heat waves . . . 10
2.1.2 Historical context . . . 12
2.1.3 Causes and mechanisms of extreme heat . . . 14
2.2 Impacts of extreme heat . . . 15
2.2.1 Individual level impacts . . . 16
2.2.2 Community level impacts . . . 18
2.2.3 Societal level impacts . . . 19
2.3 Housing and extreme heat . . . 20
2.3.1 Indoor heat exposure . . . 21
2.3.2 Outdoor heat exposure . . . 23
2.4 Protecting against extreme heat . . . 24
2.5 Awareness and preparation for extreme heat . . . 25
2.6 Regulatory and policy frameworks . . . 28
2.6.1 In the workplace . . . 30
2.6.2 In living spaces . . . 31
2.7 Solutions . . . 32
2.7.1 Building-related . . . 33
2.7.2 Nature-based . . . 34
2.7.3 Technology-based . . . 35
2.8 Challenges, barriers, and ethical considerations . . . 36
2.9 Methodologies . . . 37

3 Study rationale and objectives **39**
3.1 Rationale . . . 39
3.1.1 Significance of the Topic . . . 39
3.1.2 Contextual Relevance . . . 40

3.1.3 Research Gaps . . . 41
3.2 Objectives . . . 43
3.2.1 Primary Objective . . . 43
3.3 Research questions . . . 43

4 Novel approach using IoT data sources 46
4.1 Relevance of IoT . . . 46
4.2 The path to using IoT . . . 47
4.3 Validation of ecobee as indoor temperature measurement for extreme heat 48
4.3.1 Abstract . . . 48
4.3.2 Study Objectives . . . 49
4.3.3 Methods . . . 52
4.3.4 Results . . . 54
4.3.5 Discussion . . . 56

5 Leveraging IoT technologies for indoor climate change mitigation: A scoping review 61
5.1 Introduction . . . 61
5.1.1 Smart home technology . . . 62
5.1.2 Benefits and challenges . . . 63
5.1.3 Gaps and relevance . . . 64
5.1.4 Objectives and research question . . . 65
5.2 Methods . . . 65
5.2.1 Search strategy . . . 65
5.2.2 Data extraction . . . 66
5.3 Results . . . 67
5.3.1 Study characteristics . . . 69
5.3.2 Findings . . . 75

5.4 Discussion . . . 78
5.4.1 Key Findings . . . 78
5.4.2 Study Characteristics . . . 79
5.4.3 Study methods and objectives . . . 79
5.4.4 Outcomes . . . 80
5.4.5 Measuring other indoor hazards . . . 81
5.4.6 Policy and Program Implications . . . 82
5.4.7 Challenges . . . 83
5.4.8 Ethics of IoT technologies . . . 84
5.4.9 Energy demands and sustainability . . . 87
5.4.10 Strengths and limitations . . . 88
5.4.11 Recommendations . . . 90
5.5 Conclusion . . . 91

6 Perceptions of extreme heat in Canada: A study of social media discourse and survey insights 92
6.1 Introduction . . . 92
6.2 Background . . . 94
6.2.1 Motivation . . . 97
6.2.2 Objectives . . . 98
6.2.3 Research questions . . . 98
6.3 Methods . . . 99
6.3.1 Google Survey . . . 99
6.3.2 Twitter data . . . 99
6.4 Results . . . 103
6.4.1 Google survey . . . 103
6.4.2 Twitter data . . . 106
6.5 Discussion . . . 112

6.5.1 Survey insights . . . 112
6.5.2 Heat wave-related salient topics . . . 115
6.5.3 Monitoring emerging trends . . . 119
6.5.4 Implications . . . 122
6.5.5 Outliers and research gaps . . . 122
6.5.6 Strengths and limitations . . . 123
6.6 Conclusion . . . 124

7 Enhancing heat resilience in community housing: Smart thermostats and early warning systems in British Columbia and Ontario 125

7.1 Introduction . . . 125
7.1.1 Indoor heat . . . 127
7.1.2 Objectives . . . 128
7.2 Methods . . . 128
7.2.1 Ethics and Recruitment . . . 129
7.2.2 Sensors . . . 129
7.2.3 Data pipeline and real-time alerts . . . 131
7.2.4 Study sites . . . 132
7.2.5 Participants . . . 137
7.2.6 Data collection . . . 137
7.2.7 Analysis . . . 139
7.3 Results . . . 140
7.3.1 The summer of 2022 . . . 140
7.3.2 Descriptive statistics . . . 141
7.3.3 Visualizations of indoor temperature . . . 142
7.3.4 Survey results . . . 150
7.3.5 ecobee DYD from 2022 . . . 158
7.4 Findings . . . 159

7.4.1 Key Findings . . . 159
7.4.2 Challenges in data collection . . . 159
7.4.3 Window film treatment at Hall Tower . . . 160
7.4.4 Real-time automated alerts and thresholds . . . 162
7.4.5 Indoor temperature patterns . . . 165
7.4.6 Comparison of indoor and outdoor temperatures in Ontario and BC 167
7.5 BC thermostat data . . . 168
7.5.1 Daily averages, maximums, and minimums . . . 169
7.5.2 Highest average and daily max . . . 170
7.5.3 Comparison with ecobee DYD . . . 171
7.6 Survey findings . . . 172
7.6.1 Housing characteristics . . . 172
7.6.2 Demographic characteristics . . . 173
7.6.3 Summer 2022 experience . . . 174
7.6.4 Access to cool spaces . . . 176
7.6.5 Staying cool in during heat waves . . . 177
7.6.6 Heat health information channels . . . 180
7.6.7 Heat health actions taken in 2022 . . . 181
7.6.8 Canada's heat preparedness . . . 184
7.6.9 Additional findings . . . 185
7.7 Discussion . . . 186
7.7.1 Implications . . . 186
7.7.2 Technology in the home . . . 187
7.7.3 Real-time alerts and dashboard . . . 188
7.7.4 Indoor heat interventions . . . 189
7.7.5 Commercial determinants of health . . . 190
7.7.6 Framework for IoT-based indoor systems . . . 191

7.7.7 Strengths and limitations . . . 195
7.8 Lessons learnt and recommendations . . . 196
7.8.1 Study implementation and insights . . . 196
7.8.2 Recruitment challenges and solutions . . . 196
7.8.3 Operational considerations . . . 197
7.8.4 Recommendations for future studies . . . 197
7.8.5 Future work . . . 198
7.9 Conclusion . . . 199

8 Discussion and future work **201**
8.1 Future of early heat warning systems . . . 201
8.2 Improvements and extensions . . . 202
8.2.1 Scaling solutions . . . 202
8.2.2 Within the UbiLab . . . 204
8.2.3 Identifying and predicting vulnerable homes . . . 205
8.3 Ethical and privacy considerations . . . 206
8.3.1 Protection of participants . . . 206
8.3.2 Environmental cost of technology . . . 207
8.3.3 Low-cost and non-technical solutions . . . 208
8.3.4 Heat as a gendered issue . . . 209
8.4 Implications for public health policy and research . . . 210
8.4.1 Short-term recommendations for policy and practice . . . 210
8.4.2 Long-term recommendations for policy and practice . . . 211
8.5 Interdisciplinary solutions . . . 212
8.5.1 Interventions . . . 212
8.5.2 Initiatives . . . 213
8.5.3 Policy level actions . . . 214
8.6 Additional experiences of extreme heat . . . 215
8.7 Reflections . . . 215

9 Conclusion **217**

9.1 Contributions of this dissertation 218

References **221**

APPENDICES **294**

A Appendix A **295**

A.1 Global major heat wave events 295

A.2 Heat-related illnesses and symptoms 296

A.3 How to prevent and treat heat-related illness 298

A.4 Greenhouse gas emissions 300

A.5 Insulation R Value progress 301

B Appendix B **302**

B.1 How to modify ecobee thermostats for data collection 302

B.2 Assembly and installation of thermostat stand 305

C Appendix C **307**

C.1 Weather station and number of associated ecobee households in Quebec 2018 308

C.2 Quebec Health Regions that declared heat waves in the summer of 2018 . . 309

D Appendix D **310**

D.1 Search strategy 310

E Appendix E **313**

E.1 Survey questions 313

E.2 Keywords used to collect relevant tweets from X (Twitter) 316

F Appendix F **317**

F.1 Project plan . . . 318
F.2 Recruitment poster . . . 319
F.3 Stand graphics . . . 320
F.4 Email alert template . . . 321
F.5 Threshold trigger examples . . . 322
F.6 Email alert from June 28th, 2022 . . . 323
F.7 Elastic dashboard . . . 325
F.8 Images from study . . . 326
F.9 Estimation of energy cost to participants . . . 327
F.10 Survey 1 - Housing characteristics questionnaire . . . 328
F.11 Survey 2 - Demographic characteristics questionnaire . . . 332
F.12 Survey 3 - Summer activities questionnaire . . . 338
F.13 Project budget BC . . . 344

G Appendix G **345**

G.1 OCH site maps . . . 345
G.2 Beat the Heat - English . . . 349
G.3 Beat the Heat - Français . . . 351
G.4 Project budget ON . . . 353

H Appendix H **354**

H.1 Authored and co-authored related papers . . . 354
H.2 Features . . . 355

Glossary **359**

List of Figures

1.1 Projected shift in climate trends where the mean and variance increase from a normal temperature distribution. Source: [IPCC, 2001]. 2

1.2 Indoor temperatures from office during the heat wave in Southwestern Ontario the week of June 17 - 24, 2024. 7

2.1 Map of air temperature anomalies across the United States and Canada on June 27, 2021. Source: NASA Earth Observatory. 12

2.2 Global surface temperature changes in °C relative to 1850–1900. Adapted from [Intergovernmental Panel on Climate Change, 2023]. 14

2.3 Causal pathways illustrating how climate change impacts health and well-being through exposure pathways and vulnerability factors. 16

2.4 How to avoid damages by addressing loss and damage through action. [Panwar et al., 2023]. 17

2.5 Cost of climate change to households. Source: Climate Institute for Climate Choices 20

2.6 NWS Heat Risk interactive colour-numeric-based index that forecasts the risk of heat-related impacts occurring over 24 hours. Source: [NWS, 2024]. 27

2.7 5 Pillars of Integrated Heat Health Action. Source: GHHIN. 28

3.1 Overview of research questions, partners, data sources, and outputs. 44

4.1 Screenshot from the RShiny app, which shows a comparison of indoor (gray lines) and outdoor (blue line) temperatures for non–air conditioned houses in the Montreal/St. Hubert weather station region on June 30, 2018. . . . 54

4.2 The number of households that experienced indoor temperatures equal to or greater than 26°C for each date. Official heat wave days indicated by a red dot. 55

4.3 The average duration (in hours) with indoor temperature equal to or greater than 26 ºC for houses without air conditioning. Official heat wave days indicated by a red dot. 56

4.4 Average indoor temperatures for 47 households on heat wave days over time. 56

5.1 PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart 68

6.1 Heat wave search term popularity from 2004 to 2024. Numbers represent search interest relative to the highest point on the chart for the given region and time. A value of 100 is the peak popularity for the term. A value of 50 means that the term is half as popular. A score of 0 means there was not enough data for this term. Source: Google Trends 97

6.2 Word clouds from the Google Survey Question 8 - "Why do you think heat waves pose a risk to your health?" on the left and word cloud from 500 tweets on the right. 106

6.3 Number of relevant tweets by year 107

6.4 Tweets by province or territory 107

6.5 The coherence scores for distinct topics with the extracted tweets. 108

6.6 The Intertopic distance map generated using multidimensional scaling (MDS). The map visualizes the relationships between topics based on their similarity, with closer proximity indicating greater overlap in content. The three blue areas represent specific topic categories, grouping closely related topics. Principal components (PC) are used to position topics in a two-dimensional space for interpretability. 109

6.7 Pair plot matrix visualizing the relationships between sentiment analysis scores derived from two models: VADER and RoBERTa. Each plot shows how the sentiment scores correlate across the dataset, with data points colour-coded by year (2013 to 2022) for temporal analysis. The diagonal plots represent the distribution of individual sentiment scores, while the off-diagonal plots illustrate pairwise relationships between different sentiment metrics across time. 111

7.1 Left: An ecobee thermostat on a wooden stand during the set-up visit in May. Right: Multiple ecobee thermostats in the UbiLab, University of Waterloo preparation phase. 130
7.2 Examples of floor plans showing the placement of the ecobee thermostat in participants' homes. Locations were chosen based on outlet proximity, minimal obtrusiveness, and available space. 131
7.3 Data pipeline illustrating the real-time capture, transmission, processing, and utilization of data for email alerts and dashboard updates during the study. 132
7.4 Map of three study sites in Ottawa, Canada, indicated by the black stars and images of the three study sites. Map created and images taken by Arlene Oetomo 133
7.5 Map of five study sites in the lower mainland of British Columbia, Canada, indicated by the black stars and images of the five study sites. Map and images of MacLean Park, Ross Tower, and Hall Towers were created and taken by Arlene Oetomo. Images of Rosewood and American are from Google Maps 136
7.6 Daily Maximum Indoor Temperature 143
7.7 Heatmap of indoor temperatures for a thermostat on the 14th floor of an apartment building in Burnaby, BC 144
7.8 Heatmap of indoor temperatures for a thermostat in a two-storey townhouse in Ottawa, Ontario. 145
7.9 Daily average indoor temperatures from all thermostats in British Columbia 146
7.10 Daily average indoor temperatures from all thermostats in Ontario 147
7.11 Daily maximum indoor temperatures from all thermostats in British Columbia 148
7.12 Daily maximum indoor temperatures from all thermostats in Ontario . . . 149
7.13 No-film versus film on the 19th (shown in red) and 18th floor (shown in brown and yellow) of Hall Tower. The outside temperature is shown in blue. 161
7.14 Integrated Framework for Heat Adaptation and Mitigation Strategies Over Time: The framework visualizes various heat adaptation and mitigation interventions, categorized by their time frames (hourly, daily, yearly, etc.) and their scope from individual action to broader systemic change. It integrates real-time insights, early-warning systems, social capital, and nature-based solutions to create climate-resilient communities. 193

9.1 Search results for Canada's most common natural disasters in the past five years. Source: Google Trends 219

C.1 Source: www.climatedata.ca/case-study/extreme-heat-waves-in-quebec/ . . 309

F.1 Images captured during the project, including boxes of Ecobee thermostats, thermostats mounted on stands during site visits, and three key study locations: MacLean, Hall, and Ross. Also pictured are Arlene Oetomo (University of Waterloo) and Stephanie Thompson (BC Housing) during the setup phases in May and October 2022. 326

List of Tables

2.1 Types of policies and regulations related to indoor heat exposure, heat waves, and building standards. 29

4.1 Indoor temperature comparisons. 55

5.1 Inclusion and exclusion criteria 66

5.2 Study characteristics 70

5.3 Study methods and objectives 71

6.1 Google Survey sample characteristics (n=201) 104

6.2 Responses to questions related to heat waves in Canada. 105

6.3 Stratification of heat wave-related salient topics by most frequent words, themes, and examples. 110

7.1 Number of days thermostats that reached Level 1 (26°C up to 30.9°C) and Level 2 (31°C and above) spent in those temperature ranges. *Homes without air conditioning. 150

7.2 Baseline characteristics of the study sample (n=36). 151

7.3 Demographic characteristics of the study sample. 152

7.4 Questions on experience over the 2022 summer, activities and perceptions on preparedness. 153

7.5 Questions of perception and knowledge of heat waves 156

7.6 The average indoor temperatures recorded during 2022. 158

7.7 Thermostats that reached Level 2 during the study and days spent at Level 2 and 1 in British Columbia. 163

7.8 Thermostats that reached Level 2 during the study and days spent at Level 2 and 1 in Ottawa. *Homes without air conditioning. 164

C.1 Weather station and number of ecobee households in each location 308

D.1 Search strings (last search on Jan 4, 2024) 311

List of Abbreviations

AC air conditioning 3, 5, 6, 11, 13, 40, 48, 82, 125, 205

AI Artificial Intelligence 3, 35, 64, 78, 92, 203

ASHRAE American Society of Heating, Refrigerating and Air-Conditioning Engineers 30, 31, 204

BC British Columbia 6, 11, 22, 39, 96

BCH BC Housing 126

CCOHS Canadian Centre for Occupational Health and Safety 32

CHO Chief Heat Officer 2

CSA Group Canadian Standards Association 30

DYD Donate Your Data 8, 47, 139, 158, 198, 204

ECCC Environment and Climate Change Canada 25, 126

FH Fraser Health 126

GHGs greenhouse gases 1, 3, 14, 24, 211

GHHIN Global Heat Health Information Network 27, 219

HARS Heat Alert Response Systems 13, 45, 76, 125, 128, 191

HEWS Heat Early Warning Systems 13

HHWS Heat Health Warning Systems 13

HVAC Heating, Ventilation, and Air Conditioning 34, 61

HWIS Harmonized Heat Warning and Information System 13

IoT Internet of Things 4, 35, 36, 39, 43, 45, 46, 125, 218

LDA Latent Dirichlet Allocation 99

MRT Mean Radiant Temperature 22

NLP Natural Language Processing 102

OCH Ottawa Community Housing 126

ODI Overseas Development Institute 15

ON Ontario 11, 126

OPH Ottawa Public Health 126

SDGs Sustainable Development Goals 219

SHT Smart Home Technology 43

SRO Single-room Occupancy 134

TSW Tenant Support Worker 137, 182

UHI Urban Heat Island 2, 10, 22, 34, 136

UNDRR United Nations Office for Disaster Risk Reduction 15

VCH Vancouver Coastal Health 126

WHO World Health Organization 28, 93–95

WMO World Meteorological Organization 28, 195, 219

Statement of Positionality

I am an able-bodied, cis-het woman (she/her) of Southeast Asian heritage, a guest and settler on these unceded lands on Turtle Island. My upbringing as a child of low-income immigrant parents and education in the white settler colonial state has shaped my worldview. I am actively unlearning and deprogramming learned biases, histories, and legacies. Born in so-called Canada, I acknowledge and am grateful to live and work in the traditional territories of the Mississaugas of the Credit, the Anishnabeg, the Chippewa, Haudenosaunee, and Wendat and home to a diverse collective of Indigenous, First Nations, and Metis people today. I was also fortunate to be able to conduct research in the territories of the Anishinabe Algonquin Nation, colloquially today called Ottawa, Ontario, and on the unceded traditional territories of the Musqueam, Squamish, and Tsleil-Waututh Nations, today called the greater Vancouver-area, British Columbia.

My motivations for conducting this research are rooted in the belief that all humans have a right to health and safe housing, and we must ensure systems of oppression do not erase the experiences of the most underserved members of society. With technology increasingly factoring into our lives, solutions to the climate crisis require collaboration among all actors, integrating nature-based, low- and high-technology solutions to prepare for a warmer climate.

By sharing the findings from this work within my spheres of influence, I hope to create meaningful changes in policies and practices to ensure everyone has access to safe environments, especially during extreme heat events.

Chapter 1

Introduction

To love a place is not enough. We must find ways to heal it. We need acts of restoration, not only for polluted waters and degraded lands, but also for our relationship to the world.

Dr. Robin Wall Kimmerer

1.1 It is getting hotter

Climate change is the greatest threat to human health and life in the 21st Century [Romanello et al., 2021, Watts et al., 2015, Whitman et al., 1997]. The cost of industrial progress has pushed our planet's systems to the brink of collapse [Warren and Lulham, 2021, Intergovernmental Panel on Climate Change, 2023], Canada is warming two times faster than the global average, and areas in the north are warming four times quicker [Lulham et al., 2023, Canadian Nurses Association et al., 2023]. 2023 was the hottest year on record, posting a global average temperature 1.5°C above pre-industrial levels of warming [Copernicus, 2024]. The warming is here, and the answer to the question of how much hotter it will become on Earth will depend on our collective actions to curb greenhouse gases (GHGs) emissions today [Powis et al., 2023, Masson-Delmotte et al., 2018, Intergovernmental Panel on Climate Change, 2023].

Experts estimate that 17 million Canadians will face extreme heat in the coming decades. Heat waves are forecasted to contribute to 1.6 million fatalities by 2050 and place a $7.1 trillion burden on systems globally due to lost productivity [Eyquem and Feltmate, 2022, World Economic Forum, 2024]. These exposed populations are concentrated along the southern border in densely populated urban centres, where the

built environments exacerbated the Urban Heat Island (UHI) effect [Voelkel et al., 2016, Health Canada, 2009, Health Canada, 2020]. However, the impacts of a warming climate are already here, especially in the country's far north, where travel and land-based subsistence depend on colder temperatures [Lulham et al., 2023, Bush et al., 2019]. The shifting temperatures around the globe, Figure 1.1, are creating an increased demand for energy and cooling, along with thermal stress challenging power grid systems [Jay et al., 2021, Joshi et al., 2022, Masson-Delmotte et al., 2018].

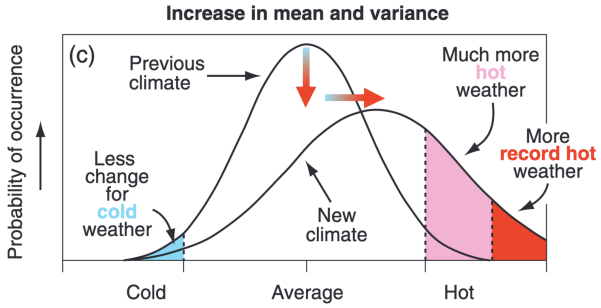


Figure 1.1: Projected shift in climate trends where the mean and variance increase from a normal temperature distribution. Source: [IPCC, 2001].

Record-breaking heat waves, which have been increasing in frequency, intensity, and severity, have affected nearly every area of the globe [The Lancet, 2021]. Research demonstrates that the high number of excess deaths due to heat waves is a result of systemic issues including age and related to poverty, class, isolation, mental health, disability, access to resources, a lack of preparedness, and general knowledge of safety during an extreme heat event [Ebi et al., 2021b, Kovats and Koppe, 2005, Turek-Hankins et al., 2021, Hass et al., 2021]. Protecting those most at risk during a heat wave requires a coordinated intersectional approach, ensuring various government bodies and local organizations work together. This need has created a new role within communities, called a Chief Heat Officer (CHO). CHO positions are being established worldwide, including in Athens, Dhaka, Freetown, Melbourne, Miami, Phoenix, and Santiago [Arsht-Rock, 2024]. Their role is to unify the municipal/city's governmental response to extreme heat, liaising with all necessary stakeholders due to the intersectional nature of extreme heat.

A study by Zhao et al. estimated that 489,000 heat-related deaths occurred globally between 2000-2019 [Zhao et al., 2021a], and many more will be claimed as global temperatures continue to rise [Lancet Countdown, 2023]. Zhao et al. found that more than half of excess deaths occurred in Asia, identifying key areas of concern among low-lying

and crowded coastal cities in Eastern and Southern Asia, while eastern Europe had the highest heat-related excess death rate [Zhao et al., 2021a]. Eastern and southern Asia have been shaped by historical colonial exploitation that entrenched economic disparities and environmental vulnerabilities, and Eastern Europe is grappling with post-Soviet economic transitions and geopolitical tensions, faces mounting challenges from extreme heat and climate impacts, necessitating targeted investments in climate resilience and public health infrastructure to address these compounded vulnerabilities [IMF, 2024, World Bank, 2024].

The interplay of capitalism, inequality, and governance profoundly influences climate-related mortality. Decades of profit-driven extraction have destabilized the planet, and unequal resource distribution heightens vulnerabilities to climate hazards [Guerrero, 2018]. The countries of the Global North, including Canada, experience extreme heat, where access to air conditioning (air conditioning (AC))can protect one from mortality; high numbers of fatalities indicate that vulnerable groups require additional support and programs to prevent heat-related illness [Gross, 2022, Beugin et al., 2023]. Action by the wealthiest countries is urgently needed to provide equitable financial support to the most affected nations, facilitate transitions to clean and renewable energy, and promote equity-focused policies alongside robust public systems [Ogunbode et al., 2024, World Health Organization, 2023]. Challenging the capitalist patriarchal systems to fight gross inequities requires data and shifting policies across all levels of government and organizations. Protecting those most vulnerable to extreme heat is dependent on strong policies, such as safe working conditions, curbing of GHGs, programs and services for those without access to safe indoor spaces, and indoor air temperature regulations [Eyquem and Feltmate, 2022].

The dangers of being indoors in unair-conditioned environments during extreme heat events are being explored in several ways: by epidemiologists, who have attributed heat-related illnesses and deaths to very high or extreme indoor temperatures [Quinn and Shaman, 2017, Hajat et al., 2006, BC CDC, 2022, BCCS Death Panel, 2022], by physiologists who are testing the capacity and limits of the human body's thermoregulation [Kenny et al., 2016, Meade et al., 2020], and by engineers, urban planners, and architects who have explored impacts of natural elements, outdoor spaces, design elements, building materials, and maintaining thermal comfort in hot and cool environments [Humphreys et al., 2011, Vanos et al., 2016, Siu et al., 2023, Andargie et al., 2019, Stopps and Touchie, 2020]. Simultaneously, meteorologists and data scientists have been forecasting and predicting extreme temperatures using data from environmental or outdoor meteorological weather stations and using machine learning and Artificial Intelligence (AI) [Luber and McGeehin, 2008, Hassani et al., 2019, Tseng et al., 2023]. However, there is a significant gap in our understanding of the indoor temperatures experienced during extreme heat events and a general lack of studies and data on indoor temperatures.

Despite the amount of research conducted abroad and within Canada [Horton et al., 2016, Campbell et al., 2018, Conti et al., 2022], 17 million Canadians are at risk from extreme heat, driven by gaps in data, policies, and actions that perpetuate unsafe indoor conditions, especially in urban metropolitan areas with higher proportions of renter households and infrequent extreme heat events [Eyquem and Feltmate, 2022, Quick, 2024]. Additionally, given that six in ten Canadians took action to protect themselves and their families from the impacts of climate change, there is still a proportion who may not know how to protect themselves best or who are unable to do so due to health or financial barriers [Health Canada, 2022, Intact Centre on Climate Adaptation, 2023]. Serving Canada's diverse population requires thoughtful planning and organization to ensure no one is left behind [ENBL, 2023, Government of Canada, 2022]. The issue of extreme heat is undeniably a climate justice issue, where the impacts are most heavily felt by those on the margins of society with the least resources, and despite the barriers, demonstrate significant adaptive capacity and climate resilience [Berry and Schnitter, 2022, Mazumdar, 2020].

This thesis will explore and address the need for data on indoor temperatures in Canada and the social media discourse of Canadians regarding and during heat waves. It will leverage smart home technologies to create a hyperlocal mesh network of indoor temperature sensors that can be utilized in real-time to provide timely responses during extreme heat events. The findings will help to inform the development of policies and education and support the Canadian government's efforts to eliminate heat-related deaths by 2040.

1.2 The Internet of Things

The Internet of Things (Internet of Things (IoT)) refers to a network of interconnected physical devices, embedded with sensors and software, that collect, transmit, and act on data via the Internet [Madakam et al., 2015]. These devices range from smart thermostats and wearable health monitors to industrial sensors and autonomous vehicles [Maraveas et al., 2022, Abdul-Qawy et al., 2015] The benefits of IoT are extensive, offering efficiency improvements, cost savings, and enhanced decision-making across industries [Brous et al., 2020]. For instance, IoT enables smart homes that reduce energy consumption, predictive equipment maintenance in manufacturing, and supply chain optimization in logistics [Hossein Motlagh et al., 2020]. It contributes to societal advancements, such as personalized healthcare, improved urban planning through smart cities, and resource efficiency for environmental sustainability [Verdejo Espinosa et al., 2021]. However, IoT faces several challenges. Data privacy and security risks are significant, as interconnected devices can be vulnerable to hacking and data breaches. Other issues include device interoperability,

system scalability, and the environmental impact of manufacturing and electronic waste [Mukhopadhyay and Suryadevara, 2014]. Current trends in IoT include the integration of AI for smarter devices, the use of edge computing for faster data processing, and Blockchain for securing IoT ecosystems [Bibri et al., 2023]. Looking to the future, IoT promises to transform industries and daily life with applications like autonomous transportation, precision agriculture, and advanced healthcare systems [Nižetić et al., 2020]. However, its success will depend on the ability to overcome infrastructure gaps, regulatory concerns, and ethical dilemmas surrounding surveillance and data use [Mittelstadt, 2017, Bibri et al., 2024]. IoT can unlock its full potential to drive innovation and sustainability by addressing these challenges.

1.3 My motivation

My first memory of a heat wave was in 2003 in Toronto, Canada, when the city suffered a major brownout due to a power grid software bug. As a child, I was delighted by the sudden abundance of ice cream we had to consume before it melted. Growing up, AC it was a rare treat, reserved for a couple of unbearably hot days each summer. During the hottest summer days, we would escape to the cool comfort of our half-finished basement, sleeping and playing there to escape the heat. I am familiar with feeling uncomfortable for extended periods, losing sleep, and experiencing overheating laptops, all challenges many Canadians and people worldwide face.

Since then, the effects of the climate crisis have only become more noticeable in Canada. As an individual who loves the outdoors, I have felt these changes acutely, especially during the winters, with a decline in the ability to partake in winter activities such as skating and skiing. My dormitory at the University of Waterloo was also unbearably hot in September and May, with windows that could barely open and no AC.

On December 20, 2013, a severe ice storm swept through Toronto, leaving thousands without power, including my household [BBC News, 2013]. Over five days, our home was plunged into freezing conditions, with indoor temperatures dropping to the low single digits while outdoor temperatures remained below freezing. Despite the power being restored at a nearby shopping mall the following day, our neighbourhood remained dark and cold. I worked in retail at the mall during the holiday break, so each day, I went to my minimum-wage job at the fully functioning shopping centre bustling with holiday shoppers. For four days, every eight-hour shift, I would return home and sleep buried under multiple blankets.

Fortunately, we managed to get through the freezing conditions and had power by noon on December 25. As the storm's aftermath unfolded, the stark contrast between

the relentless drive of holiday consumerism and the vulnerability of those affected by the storm became painfully clear. Tragically, 27 individuals lost their lives to carbon monoxide poisoning as they attempted to stay warm. Other homes were without power until December 29 [Casaletto, 2023].

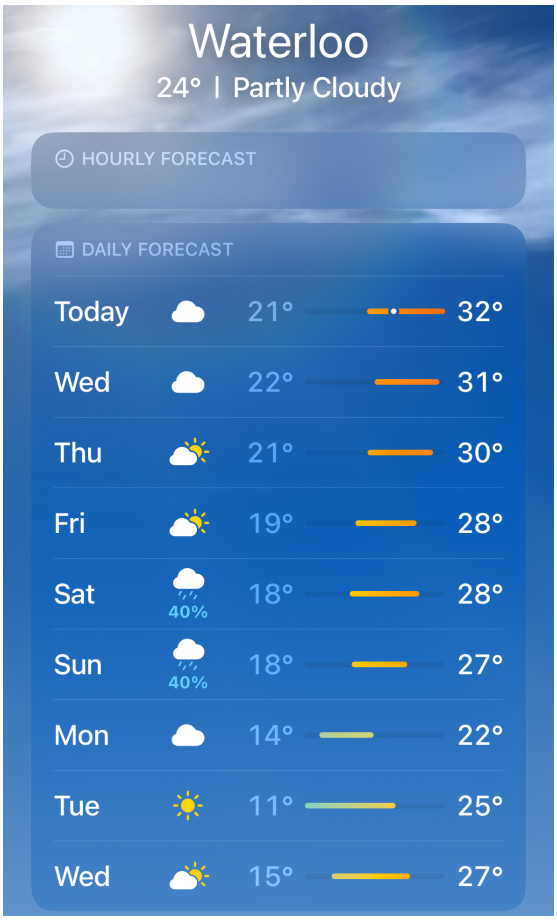
Following the 2018 deadly heat wave in Montreal, Quebec [Litwin, 2018], the idea of using smart home thermostats to monitor heat waves was born. Since then, much of the country has experienced extreme heat and record-breaking temperatures. While it may seem obvious to many that indoor temperatures are typically warmer than outdoors, it has largely been under-recorded. For example, within the British Columbia (BC) Heat Dome Death report [BCCS Death Panel, 2022], there is no official record of the indoor temperatures; the conditions were subjectively described as "hot" or "very hot." This is part of the challenge of tackling extreme heat and will be discussed further.

This dissertation was written in a home without central AC. A daily routine was developed and optimized to cope with the heat over the past four summers. It went like this:

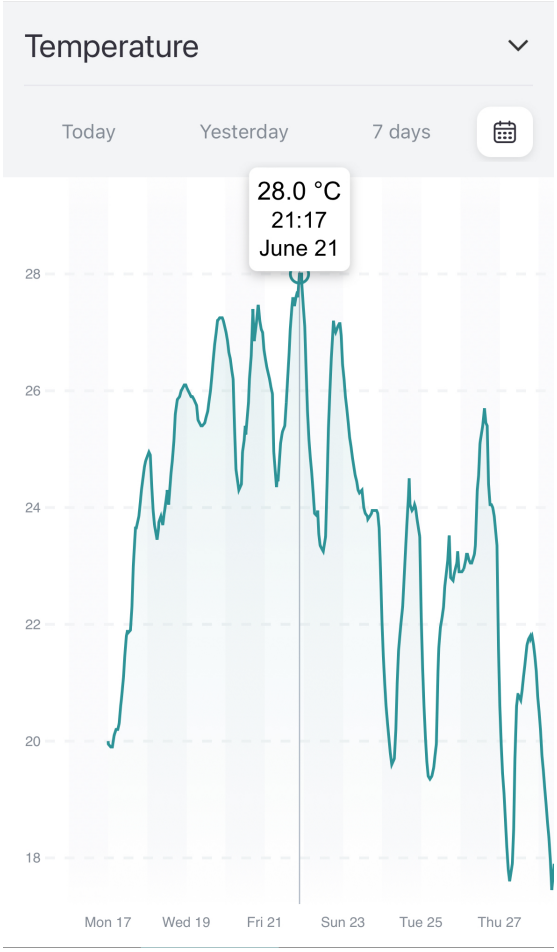
1. Wake up and check the weather: temperature and humidity, and forecast for the day and night,
2. Close the windows and close the blackout curtains once the sun hits them (usually 8 AM),
3. Generate as little heat indoors as possible (limit appliance use, no baking),
4. Check the weather in the evening: temperature and humidity, and forecast for the night and next day,
5. Open the windows and circulate the indoor air with fans (usually 10 PM),
6. If nighttime temperatures are 20°C or higher, then cool bedroom with window AC before bed.

This strategy requires foresight, consideration of electricity prices (Time of Use or TOU rates), and adjusting activities in the home, such as no cooking on the gas stove, running appliances that generate heat, or long hot showers. During the week of June 17 - 24, 2024, these strategies were barely enough to keep my second-floor office from reaching 28°C, see Figure 1.2a and 1.2b. A 5,000 BTU/h window air conditioning unit was needed to sleep and helped to reduce the temperatures during the day. I also had the privilege of working

from home. Such a routine would be challenging with a different work schedule or not being home at certain times to optimize the cooling down of the home in the evening.



(a) Screenshot of the June 18, 2024 weather forecast for Waterloo, Ontario.



(b) Office temperature captured by an Aranet4 HOME sensor.

Figure 1.2: Indoor temperatures from office during the heat wave in Southwestern Ontario the week of June 17 - 24, 2024.

I acknowledge my privilege of having a home, an office, energy security, and knowledge to protect myself from extreme heat. For readers from the global south or who have lived experiences with higher temperatures in the 40°C and beyond, such as those experienced in Bangladesh [Ng, 2024], I urge understanding and consideration of the complex and nuanced

local experiences highlighted in this work. Although the temperatures discussed here may appear modest compared to extreme heat levels in other regions, the risks and impacts are no less serious. I hope this research contributes meaningfully to efforts to protect those enduring extreme heat across the globe.

1.4 Structure of the thesis

This thesis is structured as follows.

- Chapter 1 - In this chapter, I briefly discuss the warming planet and explain my motivations behind this work and the structure of this thesis.
- Chapter 2 - This chapter delves deeper into extreme heat and its impacts across all levels of society. I summarize how protective factors, awareness, and preparation are essential and how they can be attained through regulations in places of work and daily living. Then, I discuss various solutions influencing indoor heat and the challenges, theories, and methodologies.
- Chapter 3 - Herein, I explain the rationale for this work, the objectives of the thesis papers and the research questions.
- Chapter 4 - In Chapter 4, the validation of the ecobee thermostat as a tool to measure indoor temperatures is presented using the ecobee (Donate Your Data (DYD)) dataset from the Montreal 2018 heat wave season.
- Chapter 5 - This chapter discusses the scoping review of the technologies used to study indoor heat.
- Chapter 6 - I discuss the survey results on Canadians' perceptions of extreme heat and the social media discourse on Twitter about heat waves.
- Chapter 7 - Here, I present the findings from our indoor temperature studies in Ottawa and British Columbia in partnership with Ottawa Community Housing and BC Housing, supported by Vancouver Coastal Health, Fraser Health, and Ottawa Public Health. This pilot study was the first in Canada to employ automated real-time indoor temperature alerts delivered to stakeholders.

- Chapter 8 - I discuss the future of this work and areas that may be expanded upon, including work currently ongoing at the Ubiquitous Technology Lab (UbiLab), at the University of Waterloo to predict indoor temperatures. I also discuss the limitations and recommendations and provide suggestions for future indoor temperature monitoring.
- Chapter 9 - In the final chapter, I discuss the contributions of this work to the field, and conclude with final reflections.

Chapter 2

Background

Our lovely blue planet, the Earth, is the only home we know. Venus is too hot. Mars is too cold. But the Earth is just right, a heaven for humans.

Dr. Carl Sagan

2.1 Literature review

2.1.1 Defining heat and heat waves

Heat, the thermal energy transferred between objects of differing temperatures, is invisible. Due to its transient nature, it leaves the crime scene without a trace. Nicknamed the "silent killer," heat waves are disastrous events that cannot be captured on video or in photographs like a tsunami, a tornado, or a wildfire can [Goodell, 2023]. Instead, it is portrayed more positively in the media through images of the sun, people lounging at a local pool or beach, or children joyfully playing in splash pads [O'Neill et al., 2023]. Its more sinister side is elusive and often fails to capture the public's attention, as the symptoms of heat that can be captured are less dramatic than those of other extreme climatic events.

When a heat wave occurs, the average temperature in a specific geographic area increases beyond normal predicted thresholds [Gachon et al., 2016]. The definition of a heat wave depends on where it occurs; because many factors contribute to its frequency, intensity, and duration, there is no universal definition [Kent et al., 2014, Fenner et al., 2019, Di Napoli et al., 2019, Puvvula et al., 2022]. The topographical land features, weather patterns, and built environment create the setting for a UHI [Health Canada, 2009,

Health Canada, 2020]. In Canada, a heat wave is defined as three or more days with temperatures greater than 29°- 31°C, though this definition varies depending on where one is in the country [Health Canada, 2012, Gachon et al., 2016].

Health authorities in Canada define extreme heat and heat waves based on their observed health effects, and Heat Alert and Response Systems (HARS) thresholds are triggered when heat events reach levels associated with measurable health impacts [Public Health Ontario, 2023a, Manitoba Health, Seniors and Long-Term Care, 2024, BC CDC, 2023, Public Health Ontario, 2023b, Berry et al., 2014]. However, it is important to note that many heat-related deaths occur during events that fall below the threshold of a "heat wave," meaning no alerts are issued. This gap highlights the need for more proactive and inclusive monitoring and response systems that address heat risks beyond official thresholds, potentially saving lives by extending protections to vulnerable populations during less severe but still dangerous heat conditions. This includes indoor environments without air conditioning (AC). At the time of writing, extreme heat is not officially classified as a natural disaster in Canada, however advocates including the Intact Centre on Climate Adaptation recommend that classifying it could enhance response and implementation of appropriate response to the risk [Rabson, 2022]. That said, the National Adaptation Strategy emphasizes the importance of building climate resilience to address the increasing frequency and severity of extreme heat events [Environment and Climate Change Canada, 2023]

Heat is quantified in units known as temperature, yet a combination of elements influences how we perceive temperature. However, heat can be gauged by various methods and scales. Air temperature, wind speed, and sunlight directly impact sweating and cooling. One method is the Dry Bulb Temperature, comprising of air temperature, and the Wet Bulb Temperature considers 1) temperature, 2) humidity, 3) wind speed, and 4) sunlight. This is important for understanding the experience of heat stress on the body, especially when outside or in humid environments. This "feels like" quality is also calculated under shady conditions to produce the Heat Index [Gachon et al., 2016]. Indices, like the humidex, are used to measure the combined effect of temperature and humidity [Environment and Climate Change Canada, 2011].

Humidity is the amount of water vapour in the air. While always present, humidity is generally discussed in terms of relative humidity. However, absolute humidity is responsible for sweat evaporation and overall heat stress risk [Simpson et al., 2023, Kenny and Jay, 2013, Cramer et al., 2022]. In Canada, humidity varies greatly from east to west; for example, British Columbia (BC experiences drier summers, while Ontario (Ontario (ON)) and Quebec experience more humid conditions during the summer months. Therefore, humidity should be considered when describing environmental conditions when possible.

2.1.2 Historical context

Heat waves have become increasingly frequent, longer, and more intense; in other words, they are becoming more common [Migdal, 2021]. Some of the major heat waves of the last three decades include Chicago in 1995, Europe in 2003, Russia in 2010, Canada in 2010, India in 2019, and the Pacific Northwest in 2021 (see Appendix A for a list of recent heat waves) [Semenza et al., 1996, Whitman et al., 1997, Stott et al., 2004, Bustinza et al., 2013]. As the global atmospheric carbon dioxide, methane, and nitrous oxide levels have risen, the number of weather-related disasters has increased five-fold [IPCC, 2022, Mazdiyasni and AghaKouchak, 2015]. These heat waves have been marked by significant death tolls, highlighting societal inequities and exposing system-wide gaps [Masson-Delmotte et al., 2018].

The most recent and largest tragedy to occur in Canada affected the provinces of British Columbia and Alberta and the Pacific Northwest of the United States at the end of June and early July 2021 [Gardener, 2021, Isai et al., 2021, CBC News, 2021].

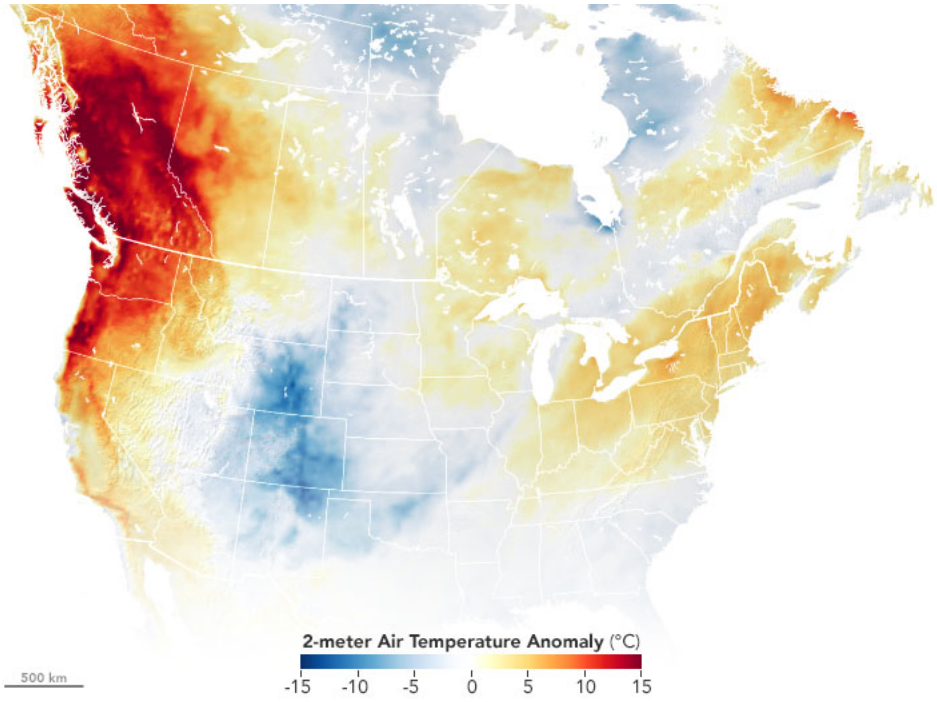


Figure 2.1: Map of air temperature anomalies across the United States and Canada on June 27, 2021. Source: NASA Earth Observatory.

Subsequent analyses indicated that more than 619 individuals died due to the extreme heat, and this 100% increase in mortality largely took place indoors in unair-conditioned homes [BCCS Death Panel, 2022, BC Housing, 2022, Henderson et al., 2022]. The heat wave set many local temperature records; see Figure 2.1. In Lytton, British Columbia, the temperatures reached 49.6°C on June 29, 2021, and on June 30, a devastating wildfire destroyed 90% of the town and killed two individuals [Uguen-Csenge and Lindsay, 2021, Schmunk, 2021]. The cause of the fire has not been determined. However, some locals allege it was caused by sparks from nearby train tracks igniting the dry ground [Follett Hosgood, 2023]. Extreme heat can coincide with other climate extremes (such as drought and wildfires), leading to deadly outcomes, and as a society, we must be prepared to handle multiple crises.

In 2018, a heat wave killed 66 individuals in Montreal, Quebec [Litwin, 2018]. Since the extreme heat events in 2010 in Canada and other parts of the world [Bustinza et al., 2013], there has been an increase in research activities and spurred policy changes in their wake, largely at the national levels [Horton et al., 2016, Campbell et al., 2018, Marx et al., 2021, Klingelhöfer et al., 2023]. Globally, an estimated 5 million people die from extreme heat every year [Zhao et al., 2021a]. Governments have implemented variations of Heat Alert Response Systems (HARS) or Heat Early Warning Systems (HEWS) or Heat Health Warning Systems (HHWS) or Harmonized Heat Warning and Information System (HWIS), all to ensure the safety of citizens from extreme heat [Casanueva et al., 2019, Matzarakis, 2017, Bate-Sprotson, 2023]. Meteorologists have concluded that the 2021 Heat Dome was a once-over-a-thousand or several thousand-year event and made 150 times more likely due to climate change [Zhang et al., 2023]. Recent heat events have brought greater awareness including greater adoption of air conditioning, along with declarations of climate emergencies by municipalities across the country, implementation climate assessments and HARS programs, and legislation mandating mechanical cooling (AC) in new builds [Quick and Tjepkema, 2023, MacDonald et al., 2024, Manitoba Health, Seniors and Long-Term Care, 2024, Durham Region Health Department, 2024, City of Vancouver, 2022]. Despite repeated warnings from experts, many Canadian cities have been slow to act on extreme heat, with Dr. Joanna Eyquem of the Intact Centre on Climate Change noting that, two years after urging policymakers to take immediate action with the release of the report "*Irreversible Heat*," significant progress is still needed to protect Canadians adequately [Eyquem and Feltmate, 2022, Taylor, 2024].

2.1.3 Causes and mechanisms of extreme heat

The total amount of atmospheric carbon dioxide has increased by 50% since the beginning of the Industrial Revolution in the 1800s. As a member of the G7, Canada has contributed significantly to the atmosphere's total GHGs. And it continues to do so today, which is contributing to the climate crisis we are experiencing today [Nielsen et al., 2021, The Economoist, 2019, Environment and Climate Change Canada, 2019]. Anthropogenic climate change, caused by the emission of greenhouse gases through the burning of coal and oil and gas extraction, has resulted in changes to the composition of the earth's atmosphere [Christidis and Stott, 2014]. Carbon dioxide is the main greenhouse gas that, along with other GHGs, absorbs heat from the earth's surface and radiates it in all directions, including back at the Earth [Intergovernmental Panel on Climate Change, 2018]. The greenhouse effect maintains the earth's surface temperatures above freezing, but human activity has supercharged it today [Masson-Delmotte et al., 2018].

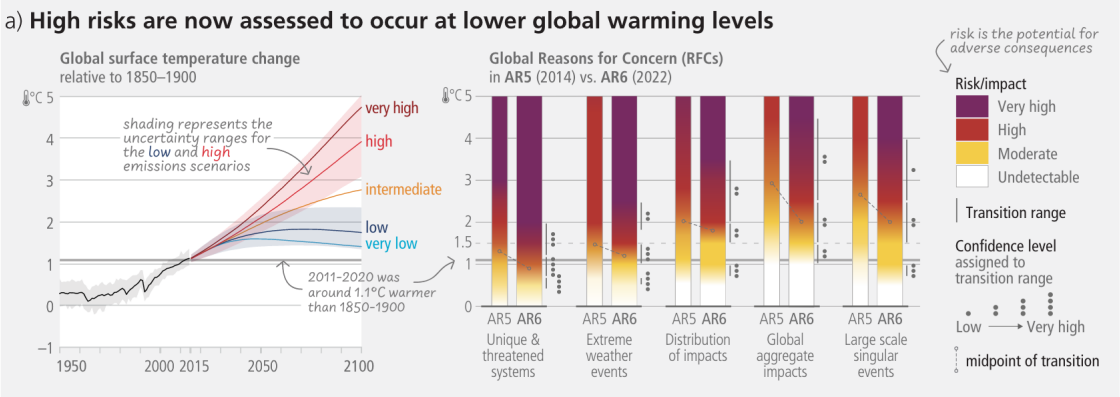


Figure 2.2: Global surface temperature changes in °C relative to 1850–1900. Adapted from [Intergovernmental Panel on Climate Change, 2023].

The warming effect of greenhouse gas emissions has been well-documented since the 1980s. Still, the oil and gas industry and other sectors oppose strong mitigation measures to safeguard their economic profits, maintain market dominance, and prioritize short-term financial interests over long-term sustainability [Taft, 2024, Drilled, 2023]. This resistance reflects a broader systemic issue where capitalist interests—such as protecting profitability and minimizing regulatory burdens—often align across industries, including largely through market-dominating multinational corporations, highlighting the complexities of balancing economic priorities with climate action [Supran and Oreskes, 2021]. Today, the effects are being felt around the globe as sea levels rise and extreme weather events threaten our

societies. They may displace an estimated 140 million climate refugees in the next 30 years [Intergovernmental Panel on Climate Change, 2023]. Many low-lying island nations in the Pacific Ocean are among the first communities forced to reckon with the effects of rising sea levels by establishing deals with other nations, such as the Australia-Tuvalu Falepili Union treaty, to grant homes to displaced Tuvaluans [Hurst and Butler, 2023].

The growing impacts of existential warming are varied due to geography. Northern parts of Canada are warming at a rate four times the global average, affecting Indigenous communities and their ability to live off the land due to warmer winters where the ice does not freeze on their traditional hunting areas [Bush et al., 2019, Rantanen et al., 2022]. Meanwhile, the southern parts of Canada, which are warming at two times the global average rate, have faced more frequent extreme storms, flooding, wildfires and smoke, and heat waves [Warren and Lulham, 2021, Bush et al., 2019, Bansal et al., 2023]. These changes to the stability of our planet will have cascading impacts on communities and require urgent action to build a climate-resilient future.

2.2 Impacts of extreme heat

Climate change pathways indirectly and directly impact health and well-being from the individual to the societal level [WHO, 2021, McGregor and Vanos, 2018]. As climate-related hazards occur, vulnerability factors and exposures create negative health outcomes and challenge our health systems, as shown in Figure 2.3 [WHO, 2021].

Systemic actions to mitigate loss and damage from climate change are essential to reducing impacts and avoiding welfare loss in a timely and appropriate manner [Panwar et al., 2023]. Figure 2.4 from the Overseas Development Institute (ODI) and United Nations Office for Disaster Risk Reduction (UNDRR) demonstrates how effective risk management ensures rapid recovery and resilience against climate-related shocks through strategic financial mechanisms. This framework is particularly relevant to extreme heat and health, highlighting the need for targeted funding and adaptation measures to protect vulnerable populations and reduce health risks. Additionally, it emphasizes the necessity of considering the downstream effects of our actions, ensuring that strategies align with global climate goals and do not inadvertently harm communities or ecosystems in other parts of the world.

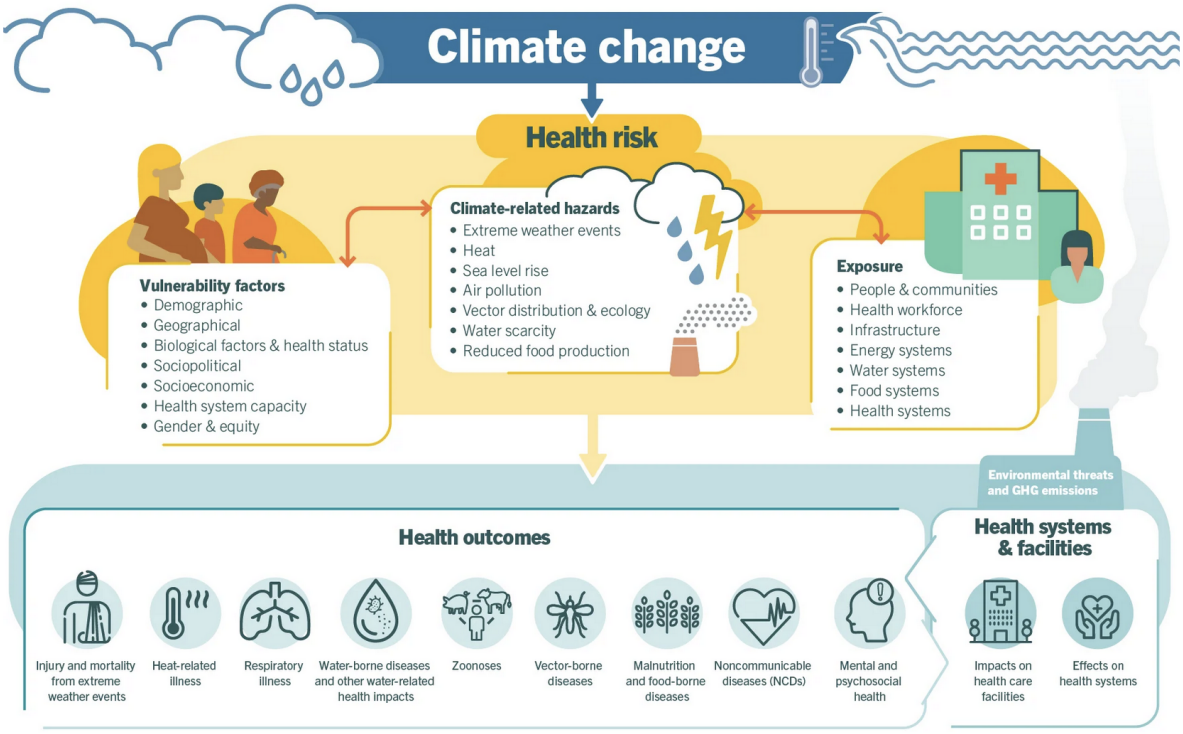


Figure 2.3: Causal pathways illustrating how climate change impacts health and well-being through exposure pathways and vulnerability factors.

2.2.1 Individual level impacts

The impacts of extreme heat are deeply personal, affecting individuals across all stages of life, with consequences ranging from heat-related illnesses to mortality. See Appendix A for a list of heat-related illnesses and symptoms and how to prevent and treat them. Extreme heat effects at the individual level begin pre-birth and continue into old age [Kovats and Koppe, 2005, Ebi et al., 2021b].

An individual's age and health status affect their risk of indoor heat exposure. Being young or old increases the risk of developing heat-related illnesses due to the body's developing systems or having weakened systems [Vanos et al., 2023]. Having pre-existing chronic health conditions and taking certain prescription medications may also affect how the body responds to heat through temperature regulation and sweating.

Another emerging group at risk is pregnant women and the impacts of heat on the

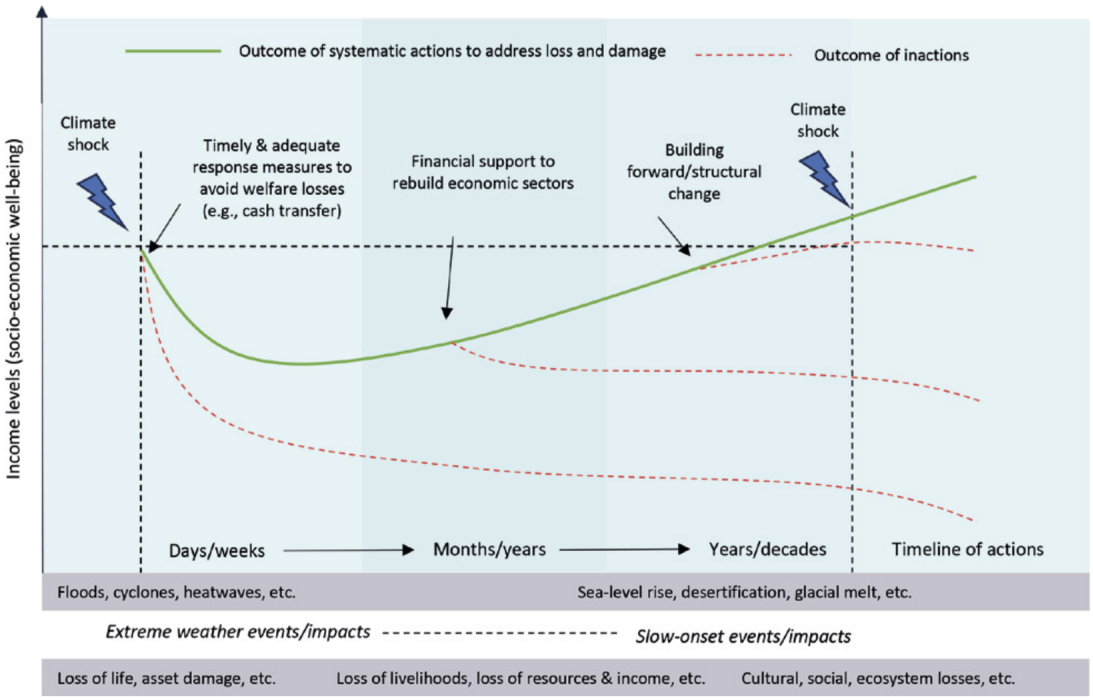


Figure 2.4: How to avoid damages by addressing loss and damage through action. [Panwar et al., 2023].

developing fetus and neonatal health. Heat is a teratogen affecting cardiovascular and nervous system development and results in shorter breastfeeding periods for babies born during a heat season than a cool season, causing lasting health impacts [UNICEF, 2023]. The frequency of conditions such as gestational diabetes, pre-eclampsia, stillbirths, and pre-term birth risks also rises with increasing temperatures [UNICEF, 2022].

When the environment or body temperature is elevated, the body cools itself by moving blood to the skin and sweating [Nogrady, 2024]. This salt-based liquid is released from the apocrine and endocrine sweat glands on the skin's surface and evaporates, cooling the body through radiation of heat and convection as cool air moves over it [Cramer et al., 2022, Baker, 2019]. These functions are essential to maintaining homeostasis and protecting the function of organs and cells [Wong, 2023, Kenny and Jay, 2013]. Babies and young children have developing systems that cannot cool themselves efficiently during extreme heat events and have a higher heat-to-body ratio, resulting in less heat dissipation [Xu et al., 2014].

Exposure to sunlight for extended periods can lead to excessive sweating and increase

the risk of dehydration, which can also cause a cascade of events affecting the kidneys, heart, and other body organs [Wang et al., 2023, Saucy et al., 2021]. If addressed early on, heat-related illnesses and heat stroke can be prevented, but without proper medical treatment, they could lead to death [Sorensen and Hess, 2022]. This can affect anyone, especially older adults, those living with chronic diseases, and those living with mental health conditions such as schizophrenia [Berry and Schnitter, 2022, Crank, 2024].

2.2.2 Community level impacts

At the community level, heat-vulnerable groups include children in schools, incarcerated folks, and older adults living in long-term care facilities. These groups often utilize older facilities built without air conditioning, and the cost of upgrading can be significant. For example, the Toronto District School Board in Toronto, Canada, faces a repair backlog estimated at CAD $3.7 billion before it can begin installing full building air conditioning across all 583 schools, which would cost millions to maintain and operate [Toronto District School Board, 2023]. In other parts of the world, like Bangladesh, schools are closed when it gets extremely hot, and 33 million children cannot go to school during extreme heat periods [Ng, 2024]. Closing schools may also require parents of young children to stay home or find alternatives for childcare, affecting household finances.

Work settings may experience decreased levels of productivity during extreme heat [Yi and Chan, 2017, Richardson et al., 2018, Parsons K, 2009] Calls to emergency services rise, and hospital admissions increase when the temperatures increase, adding additional burden to underfunded and overworked healthcare workers [Duong and Vogel, 2023, Singh et al., 2024, Yoo et al., 2021, Mason et al., 2023]. 74% of Canadians believe that health care in their province is currently in a state of crisis, [Environics Research, 2024]. The heat also increases aggressive behaviour and violence, and research shows that climate control or natural ventilation could reduce hostility in institutions such as workplaces, schools, and prisons [Thompson et al., 2018, Simister and Cooper, 2005, Lynott et al., 2023, Anderson, 2001, Fay and Maner, 2014]. Construction and agricultural workers, many Canadian migrants, are subjected to long work hours under the sun, and some governments have placed restrictions around working under extreme heat conditions [Acharya et al., 2018, Jackson and Rosenberg, 2010, Petropoulos et al., 2023, Canadian Centre for Occupational Health and Safety Government of Canada, 2023a]. Communities across Canada have different levels of vulnerability to extreme heat, and some are better adapted and equipped to cope, while many still need support.

2.2.3 Societal level impacts

The societal impact of heat is often overlooked in research and insufficiently addressed in heat health adaptation plans, leaving gaps in understanding and mitigating its broader consequences [Atlantic Council of the United States, 2021, Yardley et al., 2011]. Still, extreme heat can affect nearly every facet of society, from agriculture to transportation to the ecosystem and public services. During periods of extreme heat, energy demands increase as air conditioner use increases, resulting in blackouts or brownouts [Stone et al., 2023]. Localized outages occurred during the 2021 Heat Dome according to BC Hydro [BC Hydro, 2021b, Aziz, 2024]. Experts have urged energy providers and municipalities to prepare for risks posed during a simultaneous heat wave and power outage. Still, challenges remain due to a lack of standards or coordination, as the responsibility lies between electricity providers, governments, and building managers [Eyquem and Feltmate, 2022]. Research shows that productivity declines during extreme heat and has lasting economic impacts [Dell et al., 2012, Burke et al., 2015]. Climate change is expensive, and as the impacts from extreme weather events increase, so will the costs of insurance, resources, and rebuilding [Hodgson, 2018, Boyd et al., 2020]. Under extreme heat, infrastructure such as roads and railways can become compromised, causing delays in the shipping and transportation sectors [Nguyen et al., 2010]. From melting roadways and rail tracks to impairing working ability and productivity to increasing hostile behaviours, heat affects more than one might initially consider [Dobney et al., 2010, Parsons K, 2009, Vargas et al., 2023]. From an environmental perspective, there are also consequences, such as injury and death, to plant and animal life that have evolved to thrive within a very narrow temperature range. Marine heat waves affect marine life, including sea creatures, like mussels, causing higher mortality rates [Venter et al., 2023, Rosen, 2021]. The prolonged periods of little to no precipitation exacerbate drought conditions, affecting crops, migration of pests and diseases, and creating wildfire conditions.

Additional financial costs to society will be passed onto individuals and families [Canadian Institute for Climate Choices, 2021]. The available funds to adapt and mitigate climate change for families will become increasingly challenged, as shown in Figure 2.5.

The financial cost to individuals to replace lost or damaged property will also increase, as well as monthly premiums or inability to access insurance altogether due to companies not insuring areas deemed uninsurable like flood zones [Hodgson, 2018, Nay, 2024]. These experiences may result in stress and anxiety, in addition to mental health symptoms, related to extreme weather events such as trauma from being displaced due to rising sea levels, being injured during a flood or evacuat-

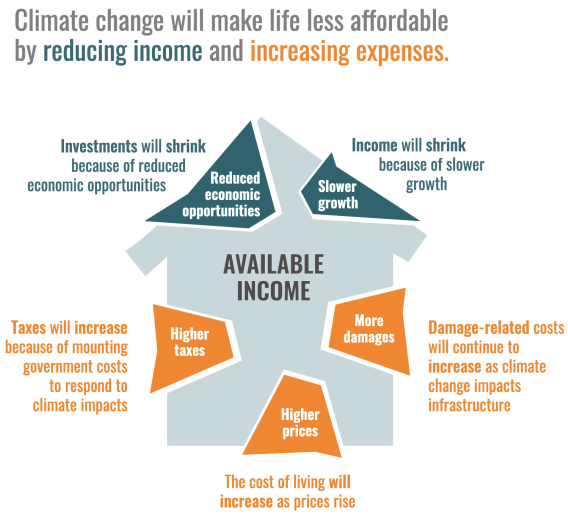


Figure 2.5: Cost of climate change to households. Source: Climate Institute for Climate Choices

ing from a wildfire [Berry et al., 2010, Palinkas and Wong, 2020, Charlson et al., 2021, Mullins and White, 2019, Trombley et al., 2017, Savu, 2023]. The economic factor, along with the other impacts discussed above, serves as a reminder that everything is interconnected and that the impacts of extreme heat are far-reaching.

2.3 Housing and extreme heat

In Western society, houses have traditionally been designed as static structures intended to provide thermal comfort within a fixed geography or climate [FRAME, 2023, Aghamolaei et al., 2023]. The home is also supposed to be a safe place of comfort. These designs presuppose relatively stable environmental conditions, but this static approach is increasingly inadequate with the rapid pace of climate change. To meet the challenges of a warming planet, housing must evolve to respond dynamically to climate shifts, emphasizing designs that harmonize with the environment. This includes incorporating features such as rain gardens for water management, shading from trees and plants to reduce indoor heat, strategic building orientation to optimize sunlight exposure, and materials that can both capture heat when needed and reflect it when unnecessary [Marsalek and Schreier, 2009, Nikoofard et al., 2011, Kumar et al., 2021]. When a house has already been constructed, addressing potential issues can be done via retrofits such as

passive or low-energy technologies, like automated external shades [Aijazi et al., 2024].

Lessons from other cultures, particularly Plains Indigenous communities, demonstrate how housing can adapt to shifting environments. Many Indigenous groups historically migrated between winter and summer camps, aligning their housing with seasonal needs and environmental conditions [Yorkton Tribal Council, 2020]. This dynamic approach to shelter provides a blueprint for climate-resilient housing, emphasizing flexibility and harmony with the natural environment [McGregor, 2018]. Integrating these principles into the vision of modern housing design can enhance resilience and reduce climate vulnerabilities.

Housing is a critical social determinant of health, directly impacting individuals' ability to cope with environmental stressors like extreme heat [Rolfe et al., 2020]. Poorly insulated and leaky homes, inadequate cooling systems, and crowded living conditions can exacerbate health risks during heat events, particularly for low-income and vulnerable populations [Natural Resources Canada, 2014a, Bezgrebelna et al., 2024, Riva, 2024]. In many places in the global south, tin roofs and traditional methods of open-flame indoor cooking contribute to indoor heat and indoor air pollution [Sparks et al., 2024, Sax and Goodman, 2014, Sun et al., 2020]. On the other hand, adaptive, environmentally attuned housing can mitigate these risks and enhance overall well-being.

2.3.1 Indoor heat exposure

Indoor heat exposure is a complex phenomenon influenced by individual health, behaviours, and environmental factors such as the space or building and the surrounding built environment. Today, humans spend more than 90% of their time indoors; our buildings are crucial to our health and safety [Laurent et al., 2018, Akova et al., 2022]. However, builds often do not consider living with a disability and might increase risk, especially for those living with mobility challenges or mental health issues like schizophrenia [Lee et al., 2023a, Nori-Sarma et al., 2022].

Socio-economic factors influence the indoor experience, such as being low-income or precariously housed, experiencing higher risk in urban areas due to design choices, and being denied access to cooling spaces [Benmarhnia et al., 2018, Kidd et al., 2022, Wong et al., 2013, Memon et al., 2008, English et al., 2022]. In fact, 14% of Canadian households reported that they kept their dwelling at an unsafe or uncomfortable temperature for at least 1 month in the past 12 months because of unaffordable heating or cooling costs, and (26%) of households went without air conditioning or some other type of cooling equipment [Statistics Canada, 2023b]. Those working in low-quality housing, long-term care facilities, prisons, and factories, especially in construction, children and educators working in schools

and summer camps, and patients and healthcare workers working in unconditioned environments are also at increased risk [Children's Environmental Health Collaborative, 2023, McNicol, 2019, Hyndman and Zundans-Fraser, 2021, Loewen, 2020, Acharya et al., 2018, Jackson and Rosenberg, 2010]. Financial constraints and mobility barriers can limit access to cooling spaces, as reaching these facilities often requires reliable access to public transportation [Mazzone et al., 2024, Human Rights Watch, 2021, Smith, 2021].

It is also important to consider factors influencing indoor temperatures during heat waves, including building materials and design, ventilation, and surrounding natural features like green spaces and built infrastructure that contribute to the UHI effect [Health Canada, 2009, Wang et al., 2016]. In Canada, homes are built to withstand cold temperatures and thus have more insulation. While building standards have evolved over the years as insulation technology has improved, R values (the resistance to heat transfer of material) requirements have also increased (see Appendix A for more on R-values), and this thermal barrier could reduce overheating compared to poorly insulated homes [Calama-González et al., 2023].

Several factors, such as the number of windows which increase airflow, the height of the building, and building materials used in construction, can affect a building's heat resilience [Schünemann et al., 2021, Nugroho et al., 2022, Ramakrishnan et al., 2017]. To limit these effects, some mitigation strategies include active or passive cooling mechanisms such as moving cooled air with heat pumps, air conditioners, or fans, opening windows and doors to allow for natural ventilation and cross breezes, and shading to reduce sun exposure through external shutters, awnings, or window film [Gard-Murray et al., 2023, Sarswat and Kamal, 2015, Ahmed et al., 2021].

The impervious nature of dark surfaces of rooftops, roads, and exterior building cladding absorb heat instead of reflecting it away, also known as albedo affects surface temperatures, Mean Radiant Temperature (MRT), and thermal comfort [Salvati and Kolokotroni, 2020, Lopez-Cabeza et al., 2022]. Many low-income earners have to walk or take public transit to work or school along poorly designed stroads with no naturally shaded paths or bus shelters [Milan and Creutzig, 2015, Franck et al., 2013, Stechemesser and Wenz, 2023]. Similarly, in British Columbia (BC) those working in primary industry (e.g., agriculture, forestry); trades, transport, and equipment operators (e.g., construction, transportation); and processing, manufacturing, and utilities (e.g., machine operators) reported experiencing the highest rates of heat-related illnesses during heat waves [Guo et al., 2024, Tetzlaff et al., 2023a, United States Department of Labor, 2022].

Once the sun sets, the nighttime temperatures become critical, as this is the period during which lowering the temperature is possible. Architects, planners, and builders play a role in determining the number, types, and orientation of buildings and operable windows

for natural ventilation [Siu et al., 2023]. Retrofitting existing buildings, designing new ones suitable for a warming climate, and creating green spaces must also occur concurrently with adaptation efforts to reduce indoor heat exposure [McIlroy et al., 2024].

In areas that experience humidity and higher concentrations of vaporized water in the air, ventilation systems assist in creating comfortable conditions [Wolkoff et al., 2021]. Under humid conditions, the evaporation of sweat is reduced, the heat stress threshold is reached at 31.5°C, and prolonged exposure to hot and humid conditions without air conditioning can be fatal [Vecellio et al., 2022]. Dr. Glen Kenny and his team at the University of Ottawa are investigating the physiological limits of the human body, and his work has been critical to the development of safe indoor temperature thresholds [Kenny et al., 2024, Kenny et al., 2019, Kenny et al., 2016]. Indoor environments play a key role in exacerbating or mitigating heat-related health symptoms and illness, and this work seeks to illuminate the actual temperatures experienced.

2.3.2 Outdoor heat exposure

While this thesis focuses on indoor heat exposure, it is equally important to acknowledge the alternative pathway of heat exposure that occurs outdoors. When physically exerting oneself, the body attempts to cool itself through sweating; however, in hot environments, it can heat up faster than it can cool down, leading to heat stress [WorkSafeBC, 2023]. This condition poses significant risks to agricultural workers, construction workers, and athletes, who are frequently exposed to high outdoor temperatures during physically demanding activities [El Khayat et al., 2022, Pierre and Wilson, 2023, Flocks et al., 2013]. Vanos et al. found that observations and actions at the microscale, like on job sites, are beneficial to appropriate decision-making and the health and safety of workers [Vanos et al., 2019]

Outdoor heat exposure also disproportionately impacts precariously housed and unhoused individuals [Kidd et al., 2022]. These individuals may live in temporary housing or makeshift shelters or remain consistently displaced, leaving them vulnerable to prolonged outdoor heat exposure [Leggat et al., 2024]. Individuals can experience dehydration, often unable to access clean water or suffer severe third-degree burns from walking or sleeping on pavement [Griffin, 2022, Sherriff, 2024]. With the addition of mental health and recreational drug use that can inhibit sweating, these individuals are more likely to experience isolation [Page et al., 2012, Sanders and Brown, 2015]. Additionally, they often face barriers when attempting to access cooled indoor spaces, facing challenges with accessing transportation, restricted hours of cooling centres, or social stigma, like aporophobia (i.e. fear of poor people) [Kidd et al., 2022, Poirier, 2024, Bezgrebelna et al., 2021, FEANTSA, 2021].

Strategies to cope during heat events, such as staying indoors or utilizing cooling systems, are often impractical or inaccessible for these populations. They face a unique set of challenges that require tailored interventions. Moreover, traditional methods of communication, such as online alerts or public health campaigns, may fail to effectively reach these groups due to limited access to technology or systemic marginalization. Acknowledging these specific vulnerabilities is crucial for developing equitable heat adaptation strategies and ensuring that public health responses address the needs of all individuals at risk and that the affected communities are included in the solution development process [Harlan et al., 2013, Benmarhnia et al., 2018].

2.4 Protecting against extreme heat

Air conditioning is the most effective life-saving tool to protect against extreme heat illness [Baniassadi et al., 2019, Cardoza et al., 2020, Malik et al., 2022]. Often deemed the obvious solution to heat-related deaths, its carbon emissions footprint cannot be ignored, for significantly increasing the global usage of air conditioners would only exacerbate total GHGs emissions at a time when we must be rapidly transitioning to green energy and decarbonizing [Bloomberg Originals, 2023, Cuff, 2022, Chung, 2023, De Munck et al., 2013].

While being healthy is largely protective, some health conditions, such as Alzheimer's disease, may increase caregiver attention. Researchers believe this is due to caregivers frequently checking in on these individuals regarding their care needs [Xu et al., 2019]. Being high-income is also protective, as individuals can access cooled spaces at work and home, especially in high-income neighbourhoods with large trees or green spaces nearby [Graham et al., 2016, Labbe, 2021].

Further preventive measures and guidelines can be implemented to reduce health risks during heat waves; these include warnings, education, and advice issued by public health authorities via media outlets or mobile applications, public programs in community spaces offering respite from the heat, such as cooling centres which extended opening hours, or telephone chains A method of information dissemination involving Individual A calling Individuals B and C, who in turn each call two additional individuals, creating a branching communication network. Or via door-to-door check-ins on vulnerable individuals [Health Canada, 2011, WHO, 2024]. It is also highly critical that appropriate language is utilized, given that heat waves are challenging to present in the media via images accurately [Tang, 2021, Reclimate, 2024, Tetzlaff et al., 2023b]. Schools, prisons, and long-term care facilities can also reduce time outdoors during extreme heat to reduce exposure. However, this can have detrimental impacts on students' education, and parents must

also be available to care for younger children, which can be challenging on short notice [Okwuofu-Thomas, 2017, Lakhani, 2024, Ng, 2024].

2.5 Awareness and preparation for extreme heat

Some governments have developed plans to protect the population from heat waves. These plans may include integrated measures such as public health interventions, early warning systems, and guidelines for employers, schools, and healthcare facilities [Jay et al., 2021]. Public awareness campaigns and preparation are critical in tackling extreme heat through heat health action plans. They include educating the public about how to stay cool, recognize heat-related illnesses, and protect vulnerable populations during heat waves. Newer strategies, such as naming heat waves in Seville, Spain, aim to raise awareness and recognize the threat of heat waves, as is done with hurricanes and typhoons [Metzger et al., 2024, Beals, 2020, Samenow, 2021]. Appointing Chief Heat Health Resilience Officers, first done in 2021 in Athens, Greece, and now many other cities globally, acknowledges the complex nature of extreme heat and the need for a key point person to coordinate with various stakeholders [WeatherGeeks, 2023, Keith et al., 2021, Arsht-Rock, 2024].

Public health response in Canada to extreme heat requires participation across different sectors of the health care system and also relies on cooperation from other fields and departments [Health Canada, 2012]. Advanced warnings from the Meteorological Service of Canada, Environment and Climate Change Canada (Environment and Climate Change Canada (ECCC)) are vital to all adaptation efforts [Environment and Climate Change Canada, 2010, Gachon et al., 2016]. The dissemination of a forecasted extreme heat event through media channels, such as newspapers, radio, TV, social media, and government health authority websites, warns the public and organizations responsible for protecting high-risk groups. Examples of efforts include alerting the public about higher-than-average temperatures before the event, usually one or two days before. Providing resources via flyers or brochures about strategies to stay safe via television and radio or pushing mobile alerts directly to personal devices via the National Public Alerting System, Alert Ready, for emergencies (e.g. flood warnings, tornado warnings, or Amber Alerts)[Health Canada, 2012]. This includes ensuring the emergency services are adequately staffed and equipped with the necessary operational resources. Poor planning led to several emergency vehicles being out of commission during the BC Heat Dome in 2021, leading to patients needing medical care being transported to the hospital via taxis [Johnstone, 2021]. Additionally, it is crucial to ensure emergency rooms are adequately staffed, particularly in rural areas of Ontario and Alberta, where funding cuts have led to the closure of many

facilities, especially on long weekends [Fletcher, 2023, Miller, 2023].

At the community level, municipal governments can create legislation to protect renters, as well as open cooling centres, provide water cooling trucks, and mobile emergency stations [Kenley, 2022, Health Canada, 2012, McGarr et al., 2023, Yardley et al., 2011, Keith and Meerow, 2022]. Volunteers staff these centres, extend hours, provide signage and provide transportation, as mobility and safety are the biggest barriers for many who need cool rooms. Schools need policies on what to do when temporary trailer classrooms become too hot and must ensure playgrounds are free from heat-absorbing materials that can cause burns [Toronto District School Board, 2023, Vanos et al., 2016, Pfautsch et al., 2022]. Retirement homes must have plans to keep residents comfortable and safe, especially in facilities lacking air conditioning [Loewen, 2020, Rapeli and Mussalo-Rauhamaa, 2022]. Employers must know the risks, provide water breaks and shade shelters, and reduce total working hours in extreme heat [Ontario Government, 2023, Pierre and Wilson, 2023, Liu and Wang, 2017, BWI, 2023].

Figure 2.6 shows how heat risks can be communicated to heat-vulnerable groups and launched in 2024 through a collaboration between the CDC and the National Weather Service (NWS) in the United States. Static risk maps exist in Canada, such as those from the University of Laval, the Prairie Climate Centre, and Climate-Data.ca, and they offer valuable information on vulnerability, exposure, and urban heat islands but lack the immediacy and real-time responsiveness needed to guide timely interventions during heat events [Brousseau et al., 2023, Climate Atlas of Canada, 2023, Government of Canada, 2023a]. Implementing a similar system in Canada would enhance the country's capacity to protect vulnerable populations by providing localized, real-time data to inform public health responses, allocate resources effectively, and prevent heat-related illnesses and deaths.

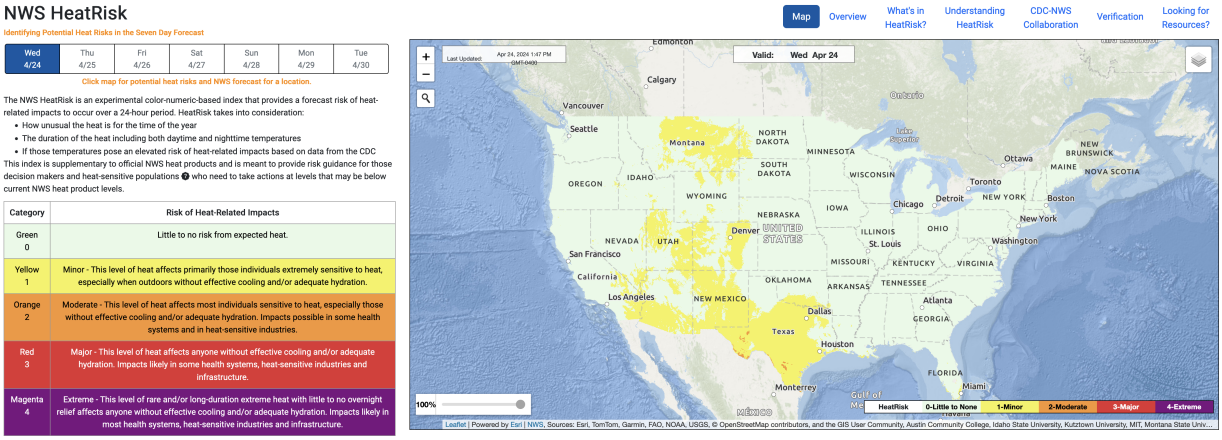


Figure 2.6: NWS Heat Risk interactive colour-numeric-based index that forecasts the risk of heat-related impacts occurring over 24 hours. Source: [NWS, 2024].

Extreme heat is a complex issue that poses a significant barrier to achieving the Sustainable Development Goals (SDGs) by making cities unsafe (SDG 11), hindering economic progress and livelihoods (SDG 8), and straining the provision of health services (SDG 3) [Cool Coalition, 2024]. This connection underscores the importance of raising awareness and enhancing preparation, as addressing extreme heat requires integrated strategies to safeguard urban environments, support economic resilience, and strengthen healthcare systems, all of which are critical for achieving the SDGs.

Established in 2016, the Global Heat Health Information Network (GHHIN), comprised of various experts and practitioners, has also focused on improving awareness and capacity to prevent negative health outcomes due to extreme heat. The network supports efforts to coordinate information and action through the network's 5 Pillars, [Global Heat Health Information Network, 2023]; see Figure 2.7.



Figure 2.7: 5 Pillars of Integrated Heat Health Action. Source: GHHIN.

The international community's concern about the impacts of extreme heat has only increased. In November 2023, the World Health Organization (WHO) and World Meteorological Organization (WMO) released a new report following a rapid assessment in which they identified an urgent need for early warning systems to protect people from the dangers of climate change [World Meteorological Organization, 2023a]. The Early Warnings for All Initiative was also launched, calling that by 2027, early warning systems must cover all people on earth [WMO, 2023].

The UN-Habitat Integrated Planning Approach supports sustainable and inclusive city planning as urbanization accelerates worldwide [UN-Habitat, 2022]. Its principles, such as creating compact and efficient cities, fostering human-nature connections, enhancing livability, and building climate-resilient infrastructure, directly address extreme heat by promoting urban designs that mitigate heat risks, ensure safety, and support vulnerable populations. These strategies align with the focus of this section by highlighting how integrated planning can enhance awareness and preparation for extreme heat events in urban environments.

2.6 Regulatory and policy frameworks

In Canada, existing policies and regulations addressing indoor heat exposure, heat waves, and building standards vary across different levels of government, reflecting the country's diverse climatic conditions, socio-economic contexts, cultural norms, and public health priorities. These policies approach heat mitigation from multiple perspectives, yet gaps remain in ensuring consistent protections nationwide, see Table 2.1. These regulations aim

to protect public health, ensure safe living and working conditions, and maintain comfort levels or reduce the risk of Urban Heat Island and heat-related illnesses during extreme heat events.

Domain	**Examples**
Building codes and standards	Thermal comfort standards
	Energy efficiency regulations
	Green building certifications
Heat health action plans	National, provincial and local heat health action plans
Workplace regulations	Occupational safety and health standards
Urban planning and land use policies	Urban heat island mitigation
Climate adaptation strategies	Building retrofit programs
	Incentives for passive cooling
Public awareness campaigns	Social media messaging
	Information and education
	Weather forecasts and alerts

Table 2.1: Types of policies and regulations related to indoor heat exposure, heat waves, and building standards.

These measures are implemented at different levels of society; in Canada, they typically fall under one of three levels: municipal, provincial, or national. However, most of the regulations related to indoor comfort relate to the workplace rather than living spaces, which is likely an outcome of a society where the individual is prided in their autonomy and ability to control their circumstances. Indoor temperature legislation does not apply to schools, prisons, healthcare facilities such as hospitals, or long-term care facilities, where some of society's most vulnerable individuals spend most of their time.

As heat waves are a symptom of a warming climate, when examined at the macrolevel, governments have a responsibility to protect citizens' health, including adhering to international agreements to reduce emissions. Guidance is provided in-

ternationally through agreements and pledges such as the Paris Agreement, which Canada has signed, committing to reducing greenhouse gas emissions and limiting global temperature increases [Watts et al., 2019, UNFCCC, 2015]. Additionally, Canada has made voluntary commitments under initiatives like the Kigali Amendment to the Montreal Protocol, aiming to phase down hydrofluorocarbons (HFCs) [United Nations Treaty Collection, 2016], and has aligned with the United Nations' Sustainable Development Goals (SDGs) to promote climate resilience, including measures to address heat-related risks [Employment and Social Development Canada, 2024]. See Appendix A for more information on greenhouse gas emissions and who is responsible for reducing them. These commitments, while important, are based on national implementation and are not legally binding, emphasizing the need for stronger enforcement mechanisms and domestic action. The following sections provide an overview of the types of policies and regulations addressing these areas.

2.6.1 In the workplace

Within Canada, several coded guidelines and regulations currently regulate indoor temperature conditions or thermal comfort in workspaces [Canadian Centre for Occupational Health and Safety Government of Canada, 2023b].
Occupational safety and health standards provide regulations that may specify maximum temperature limits for indoor work environments or require employers to provide water, rest breaks, and cooling areas to workers exposed to high temperatures. For example, in the US, OSHA (Occupational Safety and Health Administration) provides employers with guidelines to prevent heat-related illness [Occupational Safety and Health Administration, 2023]. Office spaces in Canada are recommended by theCanadian Standards Association (CSA Group) Z412-17 Office Ergonomics to maintain a temperature of 24.5°C with an acceptable range of $23 - 26$°C during the summer and a temperature of 22°C with an acceptable range of $20 - 23.5$°C during the winter [Canadian Centre for Occupational Health and Safety Government of Canada, 2023a] (CCOHS). These thresholds are based on the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 55-2013, where the relative humidity is 50%, and the average airspeed is less than 0.15 m/s [American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2017].
As previously stated, there is no consensus around indoor temperatures, with some legislation providing acceptable temperature ranges and some having adopted the Threshold Limit Values for heat or cold stress as published by the American Conference of Governmental Industrial Hygienists (ACGIH)

[Canadian Centre for Occupational Health and Safety Government of Canada, 2023a] which summarizes the thermal comfort conditions and the health and safety regulations they fall under. The ASHRAE guidelines are considered acceptable for 80% of individuals; however, given that most research is conducted on young, healthy Caucasian males, it is important to consider other demographics of the populations, as well as factors such as clothing, activity, and radiant heat from equipment, etc. Additionally, workers outside a typical office setting, including factories, mines, construction sites, fields, and forest, are subjected to uncontrollable heat conditions and must also be protected from extreme heat.

2.6.2 In living spaces

The first suggestion that often comes to mind to combat heat indoors is to use air conditioning. For many people, air conditioning is not a reality due to the upfront costs of purchasing, installing, and operating an air conditioner. In Canada, air conditioning is not mandatory by law because it is not considered a "vital" service. Under Section 4 of O. Reg. 516/06 of the Residential Tenancies Act, 2006, SO 2006, c. 17, landlords in Ontario, Canada, are required to provide heating between September 1 and June 15 and maintain a minimum temperature of 20°C [Ontario Government, 2014]. Despite national or provincial-level guidelines, organizations and municipalities have been developing measures to protect those most at risk. In Ajax and Mississauga, Ontario, indoor temperatures have recently been discussed by city councils; proposals include limiting indoor temperatures to below 26°C, which even then would only be applicable if the landlord provides air conditioning [Hamilton ACORN, 2022]. In 2023, the city of Hamilton, Ontario, ratified a motion to implement an indoor max heat bylaw in 2024 [Geenen, 2024, Beattie, 2023]. Meanwhile, the BC Building Code will require all new homes to have a room with temperature control [Woo, 2023].

Not only do the buildings in which we live contribute to our experiences of heat, but nearby spaces also play a role in influencing surrounding temperatures. Some cities, such as Montreal, Toronto and Vancouver, have implemented policies to combat the urban heat island effect, requiring green roofs, urban green spaces, reflective materials for roads and buildings, and increased tree planting efforts [City of Vancouver, 2024, Health Canada, 2020, Wang et al., 2016, Natural Resources Canada, 2014b]. These measures and building code requirements can reduce ambient temperatures, directly and indirectly improving indoor conditions for inhabitants.

Some places have adopted building codes that specify minimum thermal comfort standards, including requirements for ventilation, insulation, and materials to ensure buildings

remain cool during hot weather. As mentioned, ASHRAE Standard 55 in the United States provides guidelines for thermal environmental conditions for human occupancy [American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2017]. A list of temperature guidelines can be found compiled by Canadian Centre for Occupational Health and Safety (CCOHS) on their website, listing applicable legislation in workplace settings [Canadian Centre for Occupational Health and Safety Government of Canada, 2023a]. However, legislation to protect those in schools, prisons, and long-term care homes is lacking, underscoring the urgent need for consistent thermal comfort regulations that address the unique challenges of Canadian climates and diverse building practices.

Other regulations that can benefit indoor heat adaption include Energy Efficiency and Green building certifications that can improve the resilience of living spaces [Roderick et al., 2009]. They may indirectly affect indoor heat exposure by requiring buildings to be more energy-efficient. This can include better insulation and windows, reducing heat gain during the summer months. Or heat pumps that do not contribute hot air to the environment. Similarly, programs like LEED (Leadership in Energy and Environmental Design) and BREEAM (Building Research Establishment Environmental Assessment Method) include criteria for thermal comfort and energy efficiency, encouraging designs that mitigate heat exposure [Lee and Yik, 2004]. The European Union's Energy Performance of Buildings Directive (EPBD) aims to improve a building's energy performance, the co-benefits of which align with net-zero and climate resilience goals [European Union, 2024].

Education is also important to keeping Canadians safe during extreme heat events. This can include advice to stay in shaded areas, plan activities outside the hottest hours of the day, and optimize the use of window coverings and window openings during cooler parts of the day [Prepared BC, 2022].

2.7 Solutions

Addressing the issue of extreme heat requires a multifaceted approach involving collaboration, planning, and innovation across various sectors. Many solutions require preventative finance, which involves funds to prepare countries, provinces, municipalities, organizations, buildings, or individuals for extreme heat. The following sections explore potential areas where indoor heat can be mitigated or adapted to through various solutions and strategies. Around the world, research groups have been investigating the impacts of extreme heat on

the body [Jay and Kenny, 2010, Kenny and Jay, 2013, Meade et al., 2023], studying building envelope responses to extreme heat [Andargie et al., 2019, Stopps and Touchie, 2020, Siu et al., 2023], and studying the impacts of extreme heat on society (such as energy demands on the grid and impacts on infrastructure such as roads and railways) [Brimicombe, 2022, Bastos et al., 2020, D'ulisse, 2019, Dobney et al., 2010].

2.7.1 Building-related

Creating and retrofitting existing living spaces into climate-resilient environments is crucial. A substantial body of research focuses on ensuring indoor comfort, emphasizing the importance of interior climate control in modern architecture [Dounis and Caraiscos, 2009, Zhao et al., 2021b, Sujanová et al., 2019]. However, contemporary architectural trends increasingly incorporate large amounts of glass, introducing new challenges [Galuppi et al., 2023]. High-rise office buildings, which minimize land use amidst declining green spaces, biodiversity, and ecosystems, rely heavily on air conditioning and heating [Medical Officer of Health, 2015]. Safety concerns compound this reliance due to building heights preventing open windows.

Innovative projects like the Bosco Verticale (Vertical Forest) in Milan, Italy, exemplify the integration of plants and buildings. Reaching 116 meters (381 feet) into the air, it represents the equivalent of three hectares of forest with 800 trees and 20,000 plants [Last, 2021]. Similarly, the Trudo Tower Apartment in Eindhoven, Netherlands, was designed as community housing, showcasing that such green building concepts are not limited to affluent developments [Last, 2021].

Buildings in regions that regularly experience below freezing temperatures are designed primarily to retain heat [Lundgren Kownacki et al., 2019]. However, urban heat islands are exacerbated when building materials are selected without considering their heat absorption and storage properties [Health Canada, 2020, Hodder and Parsons, 2008]. As global temperatures rise, traditional North American building practices, such as small windows and high R-value insulation, pose challenges in warmer climates, necessitating mechanical and nature-based cooling solutions [Cuff, 2022].

The discussion extends beyond building materials to design choices and building efficiency features to improve energy performance, such as air tightness. Inspiration can be drawn from historical techniques such as Iranian wind towers, external shading devices such as shutters and awnings common in tropical climates, and the simple ability to open windows [McCabe and Roaf, 2013]. This dialogue is part of a broader conversation on passive survivability, a concept advocated by Dr. Susan Roaf and others [Rempel et al., 2022,

Bayomi et al., 2021]. This concept emphasizes the need for buildings to maintain habitable conditions without active Heating, Ventilation, and Air Conditioning (HVAC) systems. This is particularly advantageous during significant power outages or equipment failures, an inevitability of climate disasters. One option is passive district cooling, currently utilized in Singapore, where 18,000 homes receive cool air without needing individual air conditioning units [SPgroup, 2023]. This approach frees up rooftop space for greenery, helping to mitigate the UHI effect.

2.7.2 Nature-based

Prioritizing low-carbon or carbon-free solutions in building and design practices is essential to preventing increased greenhouse gas emissions (GHGs) [WHO, 2023b, OECD, 2021]. Indigenous, traditional, and ancient building techniques, materials, and architectural designs offer sustainable and eco-friendly options. This includes integrating the environment into the design process and alternatives to mechanical cooling systems that require energy for operation [Jandaghian et al., 2022, Anderson et al., 2022].

In Canada, protecting wetlands and restoring ecosystems can help reduce the impacts of climate change on communities, including extreme temperatures [Shaw, 2024, Hayes et al., 2022]. Green spaces, particularly those including bodies of water, can effectively cool air temperatures in surrounding areas [Turner-Skoff and Cavender, 2019, Graham et al., 2016]. Urban development that includes green and blue spaces—such as parks and water features—provides numerous benefits. Solutions that enhance ambient cooling reduce the reliance on energy-intensive air conditioning systems and make outdoor spaces more enjoyable [Bloomberg Originals, 2023, DW Planet A, 2023]. In Belgium, the 'bouwshift' or 'betonstop' policy restricts the construction of concrete areas. It incentivizes renovating existing built-up areas to include more green spaces, while simultaneously addressing flood risk and heat-island effects [Nalumu et al., 2023]. Meanwhile, the town of Rethymno, Greece, is leveraging bioclimatic designs to reduce the ambient temperatures of its public areas and improve user thermal comfort by 46% through the incorporation of compressed soils, cool pavers, and photocatalytic road paint [Menga, 2024]. These areas can foster community engagement, improve mental health, and support food sovereignty through community gardens, among other advantages. In addition, these spaces contribute to improved air quality, reduced flood risk, and decreased stormwater runoff, and other climate and health-related issues [Moudrak and Feltmate, 2019, Rodrigues and Rocha, 2023, Daalen et al., 2022].

2.7.3 Technology-based

The climate-technology space is rapidly growing. However, there are always challenges and ethical considerations when using technology. For example, monitoring and responding to extreme heat events is not without barriers. The rapid advancement of the IoT space, including sensor and computer technology development, has significantly impacted various sectors, including public health [Shalf, 2020]. Smaller, more sensitive sensors and sophisticated computer algorithms have enabled precise measurements and data collection, enhancing the performance of emergency response systems, environmental surveillance, and health monitoring. Furthermore, as technology becomes increasingly embedded in our everyday lives, challenges such as energy poverty and the wealth gap threaten its potential to equitably protect health, particularly in the context of extreme heat [Riva, 2024]. This disparity aligns with what Dr. Ruha Benjamin describes as the "New Jim Code," where technological advancements risk perpetuating systemic inequities, highlighting the need for inclusive strategies to ensure vulnerable populations benefit from these solutions [Benjamin, 2019, Cong et al., 2022].

Meteorologists and governments use social media, radio, television, newspapers, and other communication channels to inform the public about heat waves. To enhance public awareness and safety, Google has added heat wave warnings directly to its homepage [Google, 2023]. Analyzing social media data, particularly from platforms like Twitter, can offer new insights into public discourse on climate-related events. [Yeo et al., 2017, Al-Saqaf and Berglez, 2019]. Artificial Intelligence (AI) techniques can be applied to large datasets to understand public perception, misinformation, and community resilience during heat waves [Chen et al., 2023]. AI can generate risk scores and predict the most vulnerable homes during extreme heat events. This ensures that the most at-risk homes receive necessary retrofits or assistance (i.e., financial or health support, etc.).

This thesis explores smart thermostat technology chosen for its widespread home use, an off-the-shelf solution that delivers energy-saving potential and real-time monitoring capabilities. This work will illustrate how this technology can enhance the safety of research participants and improve responsiveness and readiness by providing immediate insights during extreme heat situations. The collaboration between research institutions and technology companies can drive innovation in public health monitoring and intervention strategies, as demonstrated by the work with ecobee, Ltd and the Ubiquitous Health Technology Lab [Sahu et al., 2020b].

However, it is crucial to ensure that the data collected via technological solutions is used to respect individuals' privacy and autonomy [Jobin et al., 2019, Hagendorff, 2020]. A participatory approach, where affected individuals are included in the decision-making process,

is essential to creating equitable technical solutions [Asaro, 2000, Harrington et al., 2019]. This strategy of leveraging real-time data collection and advanced computing exemplifies how technological advancements can enhance policy formulation and decision-making processes, ultimately improving public health outcomes.

2.8 Challenges, barriers, and ethical considerations

Tackling extreme heat by implementing heat-related solutions will face several barriers, challenges, and ethical considerations. Economically, the high upfront costs of technologies like heat pumps can deter adoption, especially in low-income communities, despite long-term savings and environmental benefits [Touchie, 2014, The Sustainable Technologies Evaluation Program (STEP), 2024, Gard-Murray et al., 2023, Carbon Brief Staff, 2024]. Infrastructure challenges include ageing or inadequate systems that hinder the deployment of cooling centres and green spaces, which are important for providing respite for individuals during extreme heat events [Meade et al., 2023, Widerynski et al., 2017]. Regulatory hurdles, including inaction by officials or insufficient resources, can result in vulnerable individuals being overlooked and left without adequate protection [Kovacs and Thomson, 2023, Fred Victor, 2024]. Individuals may be unaware of the risks associated with extreme heat or the measures available to protect themselves [Kosatsky et al., 2009, Yoon et al., 2024b]. Ethically, ensuring equitable access to cooling solutions is paramount, as vulnerable populations often lack resources to implement effective heat adaptation strategies [Public Health Ontario, 2023c]. Data privacy concerns are a significant issue with technologies that collect data from the human body or activity, underscoring the need for robust protections for personal information. These challenges highlight the complexities of integrating technology into climate and public health solutions.

While technology offers many advantages for improving public health outcomes, managing the intersection of health, technology, and climate poses unique challenges. Vulnerable communities often face barriers to accessing technologies like IoT devices, necessitating targeted approaches, as this study focused on populations that typically lack access to such tools. To ensure broad benefits, issues such as interoperability, sustainability, energy demands, reliance on rare earth metals, and the associated human rights and health concerns must be addressed [Pardo et al., 2012, Nižetić et al., 2020, Rim, 2016, Brouziotis et al., 2022]. Moreover, these technologies' energy and internet requirements make them inaccessible in many regions most affected by climate change, further emphasizing the need for equitable access.

In parallel, we are living in an "age of the infodemic," as described by the World Health Organization, where misinformation spreads rapidly online, including pervasive climate and health disinformation [Briand et al., 2021, World Health Organization, 2021, WHO, 2023a]. Today, groups previously associated with vaccine misinformation are now shifting focus to climate-related issues. According to the Centre for Countering Digital Hate (CCDH), these actors no longer deny the existence of climate change outright but instead undermine proposed solutions and delay meaningful action [Center for Countering Digital Hate, 2023]. This misinformation obstructs progress and marginalizes voices and perspectives that could drive more effective climate responses.

Amid this backdrop of disinformation, it becomes even more critical to respect Indigenous ways of knowing and actively include Indigenous voices in climate discourse. Indigenous practices and perspectives offer valuable wisdom on environmental stewardship and sustainability, contributing to solving climate challenges [Indigenous Climate Action, 2021, NCCIH, 2022]. Incorporating these views is essential for addressing climate concerns but also represents an important step towards meaningful reconciliation, ensuring integrity and equity in climate solutions [Warren and Lulham, 2021, Sacred Earth Solar et al., 2023]. Carefully considering these challenges, barriers, and ethical implications for any project will yield a better solution.

Addressing these multifaceted challenges requires coordinated efforts across economic, technological, infrastructural, regulatory, and ethical domains to develop effective and equitable heat-related solutions. By tackling barriers like disinformation, ensuring equitable access to technology, and integrating diverse perspectives, we can advance meaningful and inclusive approaches to combat extreme heat and its broader implications.

2.9 Methodologies

The above-discussed remedies to indoor heat are diverse and do not stem from a single field of expertise or field of research. At the individual level, it is possible to investigate how people are exposed to intense heat due to their social position. The Social Ecological Model and the Health Belief Model are helpful tools for analyzing how various societal, interpersonal, organizational, and community levels, as well as policy levels, can protect an individual from suffering an increased risk of extreme heat illness based on factors such as income, type of work, and housing type [Tsoulou, 2021, Akompab et al., 2013]. The latter is employed to comprehend people's actions to protect themselves during periods of excessive heat. Given the intersectional nature of extreme heat, methods and frameworks from other disciplines may also be used to understand how systemic structures create vulnerabilities

and how to address them through policy, such as energy poverty and environmental racism [Jessel et al., 2019, Waldron, 2021, Kleinenberg, 2015].

As cities urbanize globally, more action must be taken to cut emissions from the transportation of people, goods, and services and find ways to use waste heat from manufacturing processes to stem emissions from factories. Combating misinformation and disinformation related to climate solutions and creating a business case for the oil and gas industries to continue to profit will be challenging. While simultaneously designing better cities and buildings and using appropriate materials.

Chapter 3

Study rationale and objectives

3.1 Rationale

3.1.1 Significance of the Topic

The focus of this thesis is on indoor temperature, the intersection with technology (Internet of Things and social media) and how it impacts the ability of public health officials, building owners, and home dwellers to protect individuals and themselves from the dangers of extreme heat. Based on numerous conversations with experts, a review of the literature, including grey literature, and the impacts of climate change, such as the (BC) Heat Dome, it was clear that indoor heat experience had not been researched in depth. Perhaps the most surprising realization was the lack of indoor temperature data from Canadian households. Some datasets have short time scales (less than two months) or data from a single home in a laboratory setting. While the home is intended to be a safe space, many dangers can make it an unsafe and even deadly environment. Indoor air pollution from gas cooking stoves, lead paints, radon gas, and asbestos are just some hazards that have been removed from the home to protect health.

This work is a component of the UbiLab Public Health Surveillance Platform (UPHSP) developed by the Ubiquitous Health Technology Lab (UbiLab), led by Dr. Plinio Morita. It is a complete data ecosystem that collects, analyzes, and displays real-time, aggregated, crowd-sourced IoT data. This is the beginning of the Climate Change - Heat Wave portfolio.

This project was supported by international, national, and local partners, such as Health Canada, the Public Health Agency of Canada, and regional public health authorities. This

project aimed to (1) enhance public understanding, preparedness, and adaptation to the health impacts of climate change and (2) provide governments with tools to access and manipulate large datasets for improved community interventions, real-time data-driven decision-making, and informed policy development.

In the future, this IoT-based indoor heat monitoring platform could be integrated with a system like the Pan-Canadian Real-world Health Data Network (PRHDN) [Guttmann, 2019, PRHDN, 2020] or the Centres for Disease Control and Prevention BioSense Platform (a cloud-based health information system) [Bradley et al., 2005]. Expanding beyond clinical data to include environmental data to improve the surveillance and monitoring activities to protect health and well-being [Howard and Huston, 2019]. This work will position the School of Public Health Sciences at the University of Waterloo at the forefront of continuous and real-time climate-related public health surveillance. It will also address critical gaps in government heat wave monitoring, such as the lack of real-time indoor temperature data and the difficulty in integrating disparate regional datasets, which hinder the ability to build a cohesive national picture of heat impacts. By providing a centralized platform with high-resolution data, this approach can help coroners more accurately attribute deaths to heat exposure and empower government agencies to adopt state-of-the-art monitoring systems, ultimately saving lives. The latest Lancet Countdown 2024 report highlights that the health impacts of the climate crisis have reached record-breaking levels, emphasizing the urgent need to redirect fossil fuel investments and increase lagging funding to protect health and achieve a zero-emissions, health-supporting future [Romanello et al., 2024]. Using technology, such as smart thermostats and temperature sensors, to understand how climate change impacts our environments enables us to monitor conditions in real-time, identify vulnerabilities, and undertake life-saving actions.

3.1.2 Contextual Relevance

Extreme heat is not new in Canada; however, its impacts are more easily measured with today's methods and tools. Older homes and buildings built without mechanical cooling are at a greater risk of experiencing high indoor temperatures today. In certain parts of the country, like British Columbia, there is less air conditioning (AC) use compared with Ontario (32%) vs (85%) [Quick and Tjepkema, 2023]. Another setting where there is less use of air conditioners is among mobile home dwellers, who are also at increased risk, as evidenced by communities and research from the United States [McConville, 2020, Maricopa County Public Health, 2021].

Additionally, increasing rates of social isolation and the shift to nuclear family units away from multi-generation homes puts Canada's ageing older adult

population living alone at greater risk [CCSMH, 2024, Berry and Schnitter, 2022, National Academies of Sciences, Engineering, and Medicine, 2020, Klinenberg, 2016, Taylor et al., 2018]. Heat vulnerability compounds with mental health, chronic illnesses, and age, further highlighting the interconnected nature of our lives, the climate crisis, and the need for social connection as a key piece of the climate solution [Crimmins et al., 2016, Kafeety et al., 2020].

Previous studies have sought to study indoor temperature; however, to our knowledge, no one has used a smart thermostat while providing real-time alerts to stakeholders. Our lab's relationship with ecobee [ecobee, 2021] has given us the unique opportunity to leverage our knowledge of the technology and utilize the smart thermostat for health purposes beyond that of automated home heating and cooling. Through the built-in features of Wi-Fi connectivity and the ubiquity of the thermostat, the ecobee is the ideal technology for studying indoor temperature and providing real-time alerts.

This project will also explore what Canadians know about extreme heat to support public health messaging around heat. We will explore the public discourse around heat waves by building on the successful development of Ubilab's infodemic data extraction pipeline for Twitter (today called X).

3.1.3 Research Gaps

Based on current trends, heat waves are becoming increasingly severe, and cities across Canada expect more heat days. A review of the literature indicates that many heat-related illnesses and deaths occur indoors [Yoon et al., 2024a, Tham et al., 2020, Basu, 2002, WHO, 2018, Abbasi et al., 2019]. During the 2021 North American Heat Dome, 691 deaths occurred, mostly among older adults living alone indoors [BC Coroners Service, 2021, BCCS Death Panel, 2022, BC Housing, 2022]. In the Death Panel report, however, no temperatures were recorded from within the buildings or homes of the individuals who passed away.

Given that nearly 90% of our time is spent indoors [Matz et al., 2014], the lack of data on indoor temperatures and the absence of policies to protect individuals in indoor environments highlight a significant gap in addressing heat-related risks. While air conditioning rates vary across the country, with 64% of households reporting they had at least some kind of air conditioner [Quick and Tjepkema, 2023]. Some provinces, like British Columbia, have less air conditioning usage compared to the national average [Romphf, 2023], and energy costs also prevent people from accessing cooling that could potentially be life-saving [Farbotko and Waitt, 2011]. A limited number of studies have

measured and captured residential indoor temperatures in Canada through the lens of extreme heat [Smargiassi et al., 2008, Teyton et al., 2022, Oetomo et al., 2022]; however, none used IoT devices to support early warnings.

The City of Vancouver partnered with Vancouver Coastal Health and BC CDC to ask residents to track and report indoor temperatures during hot weather in 2021; the survey received over 6000 responses [City of Vancouver et al., 2022]. A team of researchers from CISSS de la Montérégie-Centre ran a study from 2017-2022 using HOBO UX100-003 data loggers, where they suggested older adults should dwell in smaller buildings, on lower floors and outside of urban heat islands where warmer temperatures are experienced [Nour and Tardif, 2022]. In 2023, approximately 50 HOBO data loggers, collecting temperature and humidity sensors at 10-minute intervals, were used by the CBC in five Canadian cities to track the indoor temperatures and found that indoor temperatures peaked around 7 PM [Wong and Carman, 2023, Carman et al., 2023]. More recently, in 2024, Health Canada's Water and Air Quality Bureau also launched an Indoor Environment Quality study, deploying air quality eggs for 18 months with BC Housing to investigate health indicators and energy security.

The studies mentioned above differ from the work in this thesis for several reasons. Firstly, none of the sensor devices used were commercially available, off-the-shelf solutions that would be permanently installed in the home, like a thermostat. Secondly, the longitudinal studies collected/logged empirical temperature data and retroactively analyzed the results, but none were designed for real-time interventions. Thirdly, the proposed and tested system demonstrates the potential for a hyper-local, early warning and prediction system to support advanced extreme heat preparedness through long-term indoor data collection from low-income housing. Fourthly, the shifting media landscape also requires exploring how it is used and what topics and themes are most prevalent surrounding extreme heat to ensure effective heat health messaging.

To the author's knowledge, no study has captured Canadian residential indoor temperature and humidity in real-time, at 5-minute intervals, through smart home technology to provide instant insights via email alerts to stakeholders, enabling an immediate response. Better monitoring of indoor temperatures helps protect vulnerable populations by enabling timely interventions. It informs broader strategies, such as improving energy efficiency, reducing emissions through optimized cooling, and designing heat-resilient homes. These insights can contribute to holistic and multifaceted solutions to extreme heat, including building with nature in mind, retrofitting existing homes, and educating the public. They can also enhance our ability to project vulnerabilities and predict the impact of heat waves. To the best of our knowledge, no other study has explored Canadian tweets related to heat waves. Without addressing the vulnerabilities of our homes, surrounding environments, and

digital spaces, many Canadians will remain at risk of heat-related illnesses and fatalities from heat exposure. While we cannot eliminate all risks from extreme heat, we can take significant steps to reduce them.

3.2 Objectives

3.2.1 Primary Objective

The Canadian Public Health Association executive director, Ian Culbert, stated, "Climate change is an escalating public health emergency, and we need to start treating it that way." [Clark et al., 2021]. The climate crisis's urgency needs no explanation if one examines the record-breaking heat in Lytton, BC, the subsequent fire that destroyed the town, and the lives disrupted and lost [Schmunk, 2021]. This recent tragedy highlights many gaps and shortcomings across society in the face of a warming climate.

Many technologies capture indoor temperatures, and their benefits and drawbacks will be explored. One such device will be validated. We also examine Canadians' narratives and emerging themes on social media about extreme heat to guide public health messaging about it. Then, using the insights gained, this thesis explored the application of smart home technology Smart Home Technology (SHT) to monitor and survey the environment and health at the Canadian household level. Through a partnership with the Canadian-founded smart thermostat company ecobee, this thesis will investigate how indoor temperatures can be monitored via IoT, explore how government officials can leverage this hyper-local real-time data and adaptation purposes, and guide data-informed policy development.

3.3 Research questions

This thesis began with this broad question: "How can we protect Canadians from the dangers of extreme heat and prevent fatalities, particularly in indoor spaces?" Then, the questions emerged through the proposal, literature review, and climate events, see Figure 3.1.

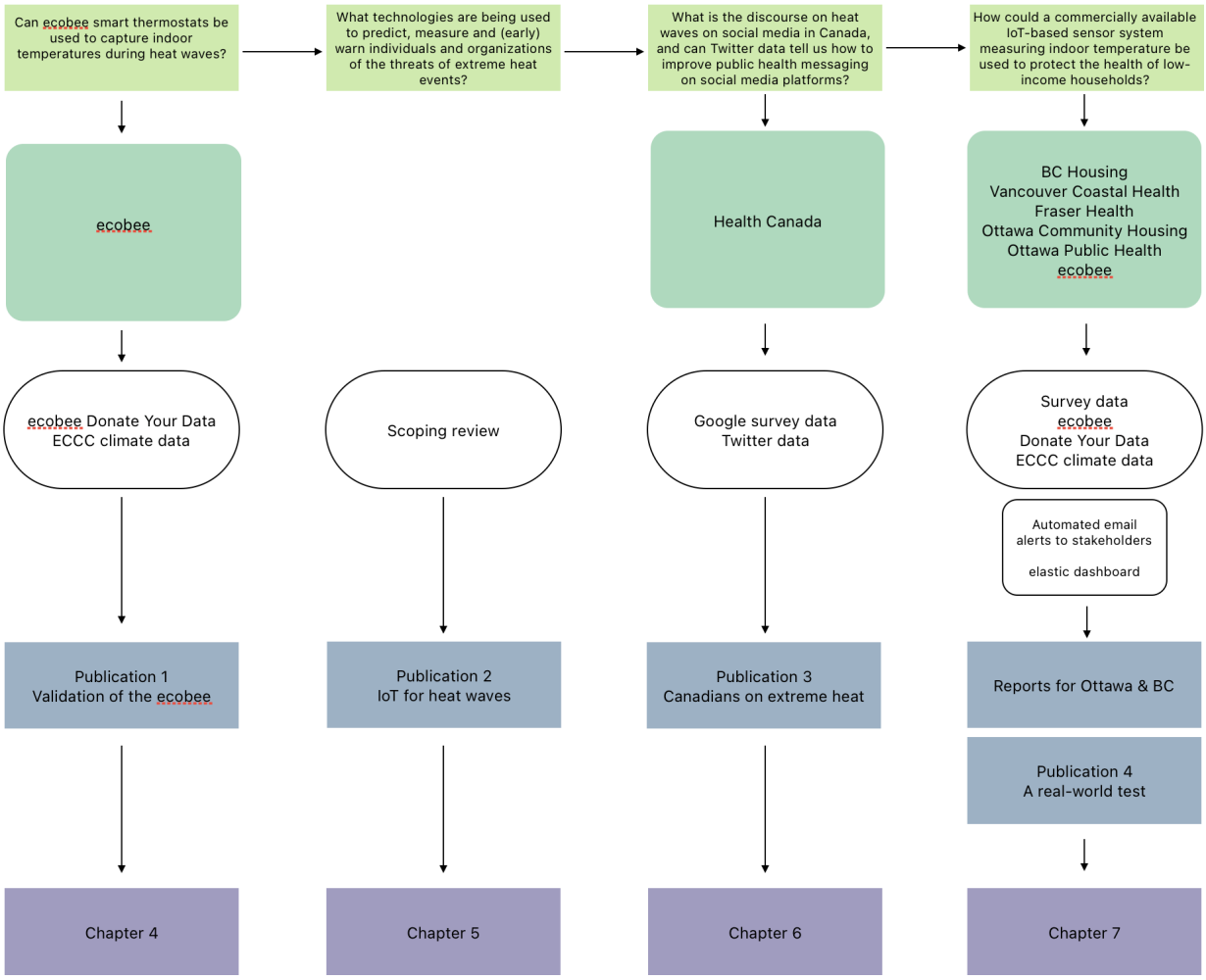


Figure 3.1: Overview of research questions, partners, data sources, and outputs.

- R1: Can ecobee smart thermostats be used to capture indoor temperatures during heat waves?
- R2: What technologies are being used to predict, measure and (early) warn individuals and organizations of the threats of extreme heat events?
- R3: What is the discourse on heat waves on social media in Canada, and can Twitter data tell us how to improve public health messaging on social media platforms?

- R4: How could a commercially available IoT-based sensor system measuring indoor temperature be used to protect the health of low-income communities?

The first study examined how data from smart thermostats revealed that indoor temperatures in homes without air conditioning were significantly higher than those with air conditioning during periods of extreme heat. This second study was a scoping review to explore the technologies used for real-time indoor temperature monitoring and warning during heat waves. The third study employed a mixed-methods approach to identify the media channels most utilized for public health dissemination. It combined survey data and a Twitter data analysis to explore public discourse about heat waves in Canada. The fourth study was a real-time observational study on indoor temperatures conducted via partnerships with local public health organizations and community housing. ecobee smart thermostats and remote sensors were deployed in Vancouver and Ottawa from May to September 2022. During the study, real-time email alerts were provided to stakeholders, along with a dashboard and survey data collected to demonstrate how an IoT-based (smart thermostat) could be used in a HARS).

Chapter 4

Novel approach using IoT data sources

This study uses a novel data source, a nontraditional data-collecting technology consisting of commercially available sensors. These new technologies can overcome challenges associated with traditional data collection methods and provide an additional tool to prepare health systems against the impacts of climate change.

4.1 Relevance of IoT

The IoT space has rapidly evolved since the early 2010s, with the cost of storage and microchips rapidly falling; the ability to create smaller devices has led to an explosion of off-the-shelf technologies able to communicate with each other in the home [Alaa et al., 2017]. IoT aims to create convenience and automation by seamlessly integrating into the home. The ideal smart home devices are easy to use, integrate well with one's mobile device, run automatically, and require minimal maintenance [Vishwanath et al., 2019, Alaa et al., 2017]. The smart thermostat can be easily integrated into the home, especially in North America, where thermostats are heavily featured to control heating and/or cooling systems.

The ecobee smart thermostat, launched in 2008, was developed to deliver financial and energy savings to users by automating the heating and cooling systems in the home to ensure comfort in the home around occupant schedules and time-of-use electric costs [ecobee, 2019]. Without facing typical tech barriers to entry or adoption issues, the thermostat has an advantage over other smart home technologies since it has a permanent place in the home.

ecobee's base model employs temperature sensors and motion sensors, which, from a privacy standpoint, are significantly less invasive compared to other smart home solutions that utilize a combination of microphones and cameras. When paired with its remote room sensors that measure temperature and detect motion, the home's internal temperature can be optimized to lower energy usage, benefiting occupants, the energy grid, and the planet. Unlike many other smart home technology that requires a hub, a proprietary communication device, to function, the smart thermostat, once paired with the home Wi-Fi network, could level up to monitor the environment and health of occupants. The motion sensors provide an opportunity for health monitoring applications, and the built-in screen on the smart thermostat can deliver important information and insights even to those without mobile devices.

Since the UbiLab began working with ecobee in 2017, we have explored how the DYD dataset could be used for next-gen public health surveillance. Then, in 2018, the idea emerged to use the ecobee to monitor indoor temperatures during extreme heat events since this is its core function. With Internet connectivity, the ecobees collect real-time data that can be streamed directly to a dashboard in real-time. With over 1.5 million ecobees sold worldwide and 200,000 users enrolled in DYD, establishing a hyper-local, real-time indoor temperature monitoring network would be possible. With the creation of the DYD program, ecobee has enabled much research and provided access to the thermostat data along with in-kind support that included ecobee thermostats and sensors.

4.2 The path to using IoT

Before completing this work, I worked closely with Dr. Kirti Sundar Sahu, who completed his PhD at the UbiLab in 2022, where his dissertation used ecobee data. The work started by exploring the temperature data provided via the ecobee Donate Your Data dataset. The team was awarded $25,000 through the Healthy Behaviour Challenge, provided by the Canadian Institutes for Health Research (CIHR) and MARs Discovery District, to explore how this motion data from a smart thermostat could be used to monitor physical activity, sleep, and sedentary behaviour or PASS (Physical Activity, Sleep and Sedentary Behaviour) indicators. Initially, we validated the ecobee data as a proxy for indoor activity, and through a pilot study where participants wore Fitbit Charge 2s and logged their activity in a home equipped with a retrofitted ecobee thermostat and approximately ten remote room sensors [Sahu et al., 2020b]. We concluded that the ecobee system could collect movement data indoors and be used to answer questions about sleep patterns, such as the time individuals went to bed and the number of disturbances during the night.

Then, the work on the Ubiquitous Health Technology Lab's NextGen Public Health Environmental Surveillance Platform began for remote patient monitoring of health indicators such as sleep and physical activity [Sahu et al., 2020b, Sahu et al., 2020a, Sahu et al., 2021]. We leveraged the ecobee DYD to answer new questions about sleep, patterns of seasonality, and the impacts of COVID-19. Led by Dr. Niloofar Jalali, we examined the impacts of seasonality on movement patterns [Jalali et al., 2020, Jalali et al., 2022] and currently with Dr. Jasleen Kaur, we are exploring sleep patterns and impacts from Covid-19 policies (including work from home and stay at home orders). Continued applications of this technology will be discussed in Chapter 8.

Having deep knowledge of the ecobee technology and the dataset inspired to use IoTs to address climate change impacts [Bublitz et al., 2019, Jay et al., 2021], using the ecobees to explore indoor temperatures was a logical next step. However, similar to the work on sleep, the ecobee first had to be validated as a tool to capture temperature differences between indoor and outdoor temperatures in homes without air conditioning (AC).

4.3 Validation of ecobee as indoor temperature measurement for extreme heat

Before we could conduct a larger field study (described later in Chapter 7, we first had to assess whether there were discernible temperature differences between homes with and without air conditioning. "Indoor Temperatures in the 2018 Heat Wave in Quebec, Canada: Exploratory Study Using ecobee Smart Thermostats" explores indoor temperature variations during a heat wave, focusing on differences between homes with and without air conditioning. This paper was published in JMIR Frontiers in June 2022, providing the foundation for this research.

Citation: Oetomo, A., Jalali, N., Costa, PDP., Morita, P.P. (2022) Indoor temperatures in the 2018 heat wave in Quebec, Canada: exploratory study using Ecobee smart thermostats. JMIR Formative Research; 6(5):e34104. DOI: 10.2196/34104. PMID: 35550317 https://formative.jmir.org/2022/5/e34104

4.3.1 Abstract

Background: Climate change, driven by human activity, is rapidly changing our environment and posing an increased risk to human health. Local governments must adapt

their cities and prepare for increased periods of extreme heat and ensure that marginalized populations do not suffer detrimental health outcomes. Heat warnings traditionally rely on outdoor temperature data which may not reflect indoor temperatures experienced by individuals. Smart thermostats could be a novel and highly scalable data source for heat wave monitoring.

Objective: The objective of this study was to explore whether smart thermostats can be used to measure indoor temperature during a heat wave and identify houses experiencing indoor temperatures above 26°C. Methods: We used secondary data—indoor temperature data recorded by ecobee smart thermostats during the Quebec heat waves of 2018 that claimed 66 lives, outdoor temperature data from Environment Canada weather stations, and indoor temperature data from 768 Quebec households. We performed descriptive statistical analyses to compare indoor temperatures differences between air conditioned and non–air conditioned houses in Montreal, Gatineau, and surrounding areas from June 1 to August 31, 2018.

Results: There were significant differences in indoor temperature between houses with and without air conditioning on both heat wave and non–heat wave days(P¡.001). Households without air conditioning consistently recorded daily temperatures above common indoor temperature standards. High indoor temperatures persisted for an average of 4 hours per day in non–air conditioned houses.

Conclusions: Our findings were consistent with current literature on building warming and heat retention during heat waves, which contribute to increased risk of heat-related illnesses. Indoor temperatures can be captured continuously using smart thermostats across a large population. When integrated with local heat health action plans, these data could be used to strengthen existing heat alert response systems and enhance emergency medical service responses.

4.3.2 Study Objectives

Background

Our planet is getting warmer, and climate experts report that the frequency of extreme heat days has been increasing—record-setting temperatures have been reported in major cities around the world [Intergovernmental Panel on Climate Change, 2018]. Driven by the output from human activities (such as the greenhouse effect from gas emissions), the frequency and duration of extreme heat events are only expected to increase [Kovats and Hajat, 2008]. In the United States, heat waves kill more people than all other weather-related events

(earthquakes, tornadoes, hurricanes) annually [Luber and McGeehin, 2008]. Periods of extreme heat are dangerous because heat stress occurs when the human body is unable to cool itself [Kenny and Jay, 2013]. Heat waves in Europe in 2003 and Russia in 2010 caused over 100,000 deaths combined [Campbell et al., 2018]. In 2018, Quebec, Canada experienced a severe heat wave that resulted in 66 deaths [D'ulisse, 2019]. Older adults, persons with disabilities, and persons with chronic conditions such as respiratory diseases and heart disease are more vulnerable during extreme heat days due to their impaired ability to regulate body temperature [McMichael et al., 2006, Meade et al., 2020]. Individuals with low sociodemographic status are at a higher risk for suffering the detrimental and even deadly effects of a heat wave [9] because cooling methods may be cost-prohibitive [Williams et al., 2019] or they may live in older buildings without air conditioning units. Those living in urban areas are at greater risk for extreme heat events. Urban areas are often several degrees hotter than rural areas [McMichael, 2000]. Densely populated urban areas experience heat domes, wherein the built environment absorbs and traps heat instead of reflecting it into the atmosphere [Memon et al., 2008, Health Canada, 2020, National Oceanic and Atmospheric Administration, 2021, Mohajerani et al., 2017]. Even at night, the temperatures remain high because building materials (such as concrete and asphalt) continue to radiate heat [Laaidi et al., 2012, McGregor et al., 2015, Hajat et al., 2010, Toloo et al., 2013]. To prevent heat-related deaths, many governments have adopted heat health action plans that include ensuring residents are appropriately informed, providing resources such as cooling centers, and door-to-door checks by emergency services [McGregor et al., 2015]. Heat health action plans are localized and specific to each municipality, tailored to local needs [Kovats and Hajat, 2008, Hajat et al., 2010, Health Canada, 2016]. These action plans rely upon heat alert and response systems [Health Canada, 2012] or heat health warning systems. Weather forecasts, based on outdoor meteorological data, are used to predict weather conditions that could be potentially hazardous to health [Environment and Climate Change Canada, 2010]. There are no universal criteria used for issuing a heat wave warning [Mayrhuber et al., 2018]. Environment and Climate Change Canada issues heat warnings for each province. For example, in Quebec, a heat warning is issued when (1) the temperature is 30°C or higher, with a humidex value of 40 or higher for at least one hour, or (2) when the temperature is 40°C or higher [Environment and Climate Change Canada, 2010]. Local health departments also issue extreme heat alerts and often use different criteria. Santé Montréal [Santé Montéal, 2020] a local health department, defines an extreme heat episode as either 3 consecutive days when the average maximum temperature reaches 33°C and the average minimum temperature does not drop below 20°C or when the temperature does not drop below 25°C for 2 consecutive nights. Current heat alert and response systems rely upon outdoor meteorological data, yet individuals now spend most of their time

indoors [Mirzaei et al., 2012]. Indoor temperatures during heat waves can be significantly higher than outdoor temperatures [Lee and Lee, 2015]. There are discrepancies between temperature data being used to make decisions about heat waves and temperatures actually experienced indoors by individuals. Our understanding of indoor temperature trends is relatively limited because studies on indoor environments can be challenging, time-consuming, and cost-prohibitive due to factors such as sensor costs, cost of study deployment and duration, resources, and disturbances to home life. Traditional studies on heat waves and urban heat islands typically use satellite imagery data [Mirzaei, 2015, Buscail et al., 2012], local or airport weather stations [Henderson and Kosatsky, 2012], or emergency room visit, mortality, and ambulance call data [Huang et al., 2013] to set thresholds or examine outdoor heat exposure risk. Only a few studies have investigated indoor temperature related to mortality and morbidity [O'Lenick et al., 2020] or indoor temperature exposure [Vant-Hull et al., 2018, Van Der Hoeven and Wandl, 2018]. The advent of smart home technology (ie, indoor temperature sensors) coupled with the Internet of Things (IoT) offers a unique opportunity to monitor residential indoor environments across a large population. IoT sensors have been successfully used to monitor indoor health behaviors including sleep [Sahu et al., 2020b, Jalali et al., 2020], gait [Boroomand et al., 2018], breathing, and heart rate [Alizadeh et al., 2019]. Smart thermostat adoption has been driven by government incentives, such as the Ontario Government's Green Ontario Fund, and a desire save on heating and cooling costs [Lu et al., 2010, Canadian Press, 2017]. We searched Scopus and Google Scholar, with no language restrictions, for publications since database inception until December 31, 2020, using the search string ("smart home thermostat" OR "smart thermostat") AND ("heatwave" OR "heat wave") OR ("public health"). We identified 2 studies [Sahu et al., 2020b, Jalali et al., 2020] that used smart thermostats for public health surveillance, with focuses on healthy behaviors such as sleep, physical activity and sedentary behavior. One study [Sahu et al., 2020b]validated the use of smart thermostats for measuring sleep, physical activity, and sedentary behavior and found results to be highly comparable with results captured through traditional survey methods used by the Public Health Agency of Canada. The other study [Jalali et al., 2020] found that using smart thermostats allowed for insights into differences (which were significant) in time spent indoors during the weekend versus during weekdays. Both studies [Sahu et al., 2020b, Jalali et al., 2020] demonstrated that smart thermostats and remote motion sensors can be used with minimal interference to individual to monitor activity levels routine in real-world settings (ie, in the home). To the best of our knowledge, this is one of the first studies to use smart home thermostat data to investigate the effects of heat waves. As heat waves increase in frequency, intensity, and duration, the use of indoor cooling methods such as air conditioning will increase. The use of smart thermostats to capture indoor temperature data has several benefits, such as minimal disturbance to study participants, and overcomes barriers associated with

many environmental data collection studies (ie, high overhead costs, equipment costs, small sample sizes, short study durations). In many cases, temperature, motion, and humidity data are already being collected. This overlooked source of indoor temperature can be used to strengthen public health response and climate mitigation efforts for decision-making during extreme heat events.

Objective

We aimed to compare indoor temperatures during heat wave and non–heat wave periods between air conditioned and non–air conditioned houses with ecobee smart thermostats and identify extreme indoor temperatures posing a health risk.

4.3.3 Methods

Data Collection

We used smart home thermostat data (collected by ecobee and made available to researchers through the Donate Your Data program [ecobee, 2021]) and Environment and Climate Change Canada [Poitras, 2020, Abreu, 2020] data from in Quebec, Canada between June 1 and August 31, 2018, which included a multiday heat wave event. Outdoor temperatures at weather stations were obtained from Environment and Climate using an amended Python3 script [Abreu, 2020, Tremblay, 2018]. Indoor temperature and occupancy data had been collected via the smart thermostat and remote motion sensors at 5-minute intervals.

Smart Thermostat Data Processing

Thermostat metadata (number of sensors in a home, HVair conditioning mode setting, and household ID) and indoor temperature timeseries data were available from a total of 768 households. The metadata file also contained information used to associate the house with the nearest weather station. We calculated the mean indoor temperature for each house each hour and each day. For each day in the period from June 1 to August 31, houses were labeled as non–air conditioned if the cooling stage status was 0 and cool was not recorded for HVair conditioning mode in the metadata, and houses were labeled as air conditioned if the cooling stage status was 1, 2, 3, or 4 and HVair conditioning mode was cool at any point during the day. Data from days for which a given house was unoccupied were removed. To determine whether non–air conditioned houses were more likely than air conditioned houses to have elevated indoor temperatures, we focused on a subset of 82

non–air conditioned households and 96 air conditioned households in the areas of greater Montreal and Outaouais. This was done after data cleaning, remove of incomplete data and filtering for occupancy (determined by activation of motion sensors).

Mapping Indoor to Outdoor Data

Each house was assigned to the nearest Environment Canada weather station using thermostat metadata. Houses with incomplete data were removed. Three weather stations—Ottawa Gatineau, Montreal/St Hubert, Montreal Intl A—were selected for further study based on having a minimum of 30 houses with data within their associated region and being within a region for which a heat wave had been declared C. Montreal and Outaouais (Gatineau and surrounding areas) experienced a 6-day heat wave (from June 30 to July 5, 2018) [Poitras, 2020].

Data Analysis

We developed and used an app (RShiny) to visualize and compare indoor and outdoor temperature trends. We compared the indoor temperatures of non–air conditioned houses during heat wave and non–heat wave days. After combining all the daily records from each group, we used t values to examine temperature differences between air conditioned and non–air conditioned houses. A 1-tailed t test (with unknown variance) was performed to comparing the indoor temperatures of all houses in the same region, with the assumption that they experienced the same outdoor temperature during extreme heat events and that the indoor temperatures for non–air conditioned households was consistent. Literature indicates that 26°C (72°F) is the threshold for a safe indoor temperature (ASHRAE 55 indoor temperature standard [Tham et al., 2020]). Exposure to indoor temperatures greater than 26°C has been associated with increased premature mortality and emergency medical service calls [British Columbia and BC Housing, 2019] We sought to determine whether above-threshold indoor temperatures were recorded during the heat wave in regions of Quebec (Montreal and Gatineau) for which heat waves had been recorded on specific dates [Poitras, 2020, Lebel et al., 2019]. Remaining households were further filtered to remove those not in areas where heat waves were officially declared so that analysis contained only houses that experienced the heat wave. Thus 47 non–air conditioned homes from Montreal, Laval, Montérégie, and Outaouais health regions of Quebec remained after removing households that used air conditioning between June 1 and August 31, 2018 and houses with no occupancy on heat wave days (who may have turned off air conditioning while away). To examine which time of day the highest indoor temperatures occurred, we created a heat map of the non–air conditioned home temperatures for each hour on each official heat wave day.

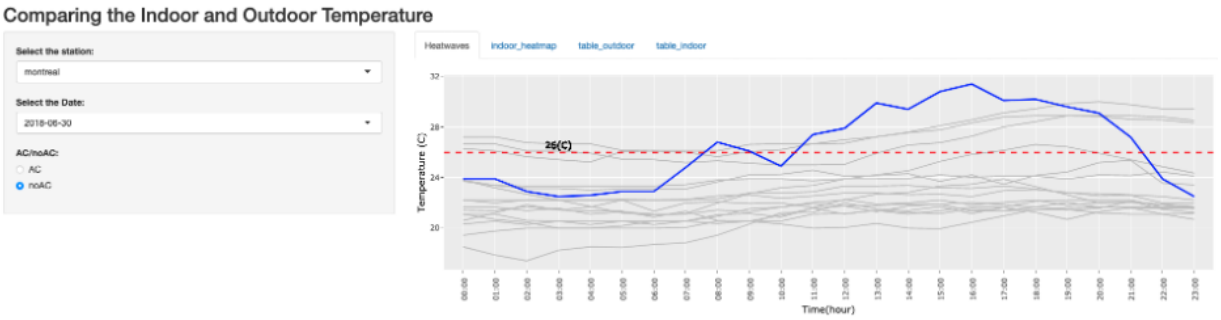


Figure 4.1: Screenshot from the RShiny app, which shows a comparison of indoor (gray lines) and outdoor (blue line) temperatures for non–air conditioned houses in the Montreal/St. Hubert weather station region on June 30, 2018.

4.3.4 Results

On certain days, some non–air conditioned homes recorded indoor temperatures similar to, or even exceeding, the outdoor temperature on heat wave dates (Figure 4.1). These results demonstrate that using IoT devices such as the ecobee smart home thermostats are a logical means of monitoring indoor residential temperatures, especially during extreme heat events.

Indoor Temperature Differences Between Air Conditioned and Non–air conditioned Houses

There is a significant difference of indoor temperature between the houses with air conditioning and without air conditioning in heat wave and non–heat wave days ($P < .001$). On heat wave days, the average daily indoor temperature was lower (mean 1.3°C) for air conditioned homes than that for non–air conditioned homes. This difference is lower in non–heat wave days (mean 0.5°C) Table 4.1.

Indoor temperatures of houses with air conditioning during the heat wave days and non–heat wave days remained relatively stable, with mean temperatures 22.3°C and 22.4°C for non–heat wave and heat wave days, respectively. For houses without air conditioning, there was a statistically significant difference ($P< .001$) between indoor temperatures on heat wave days (mean 23.7°C) and non–heat wave days (mean 22.8°C), which were, on average, 0.90°C hotter, Figure 4.1. There were significant differences in indoor temperatures between houses with and without air conditioning for all 3 regions (all $P< .001$).

Non–air conditioned Houses With Indoor Temperatures Above Safe Thresholds in Health Regions With Heat Waves

Table 4.1: Indoor temperature comparisons.

	Mean difference (°C)	Standard difference (lower, upper) or 99% CI	P value
Air conditioned vs non–air conditioned houses			
During heat wave days[a]	–1.320	–0.730 (–1.90, –0.73)	< .001
During non–heat wave days[b]	–0.500	–0.021 (–0.615, –0.40)	< .001
Non–air conditioned houses only			
Heat wave vs no heat wave[c]	0.906	0.784 (0.350, 1.45)	< .001

[a]Air conditioned: n=465; non–airconditioned: n=151.
[b]Air conditioned: n=6045; non–airconditioned: n=2713.
[c]Non–air conditioned–during heat wave: n=151; non–heat wave: n=2713.

Figure 4.2 shows the number of non–air conditioned houses, out of 47 located in regions with recorded heat waves, that experienced a daily temperature of or above 26°C between June 1 and August 31. There were consistently a number of non–air conditioned households with temperatures of or above 26°C, on heat wave days as well as non–heat wave days, especially during July and August.

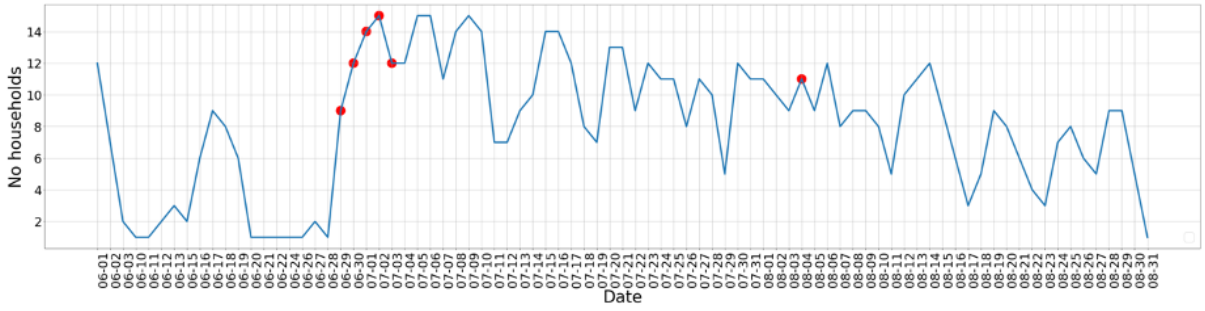


Figure 4.2: The number of households that experienced indoor temperatures equal to or greater than 26°C for each date. Official heat wave days indicated by a red dot.

Figure 4.3 illustrates the average duration (in hours) that the 47 non–air conditioned households recorded indoor temperatures to equal to or greater than 26°C from June 1 to August 31. Indoor temperatures were highest during the afternoon, evening, and night-time periods of the day (Figure 4.4); the hottest time of the day was between 4 PM and 7 PM on heat wave days.

During the 5-day heat wave from June 29 to July 3, it is possible to see the accumulation of residual heat later into the evening and into the early hours of the day.

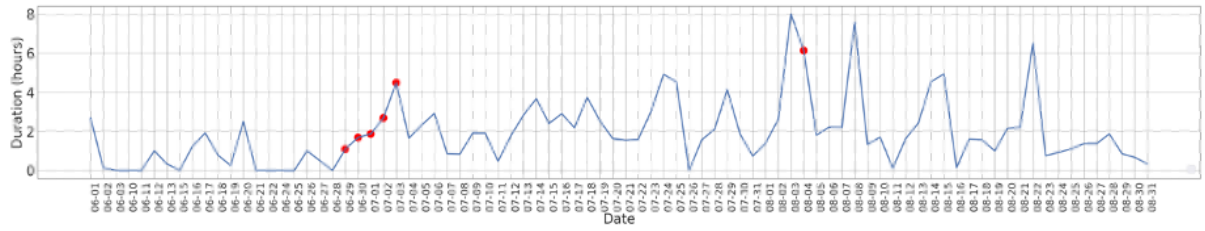


Figure 4.3: The average duration (in hours) with indoor temperature equal to or greater than 26 ^{o}C for houses without air conditioning. Official heat wave days indicated by a red dot.

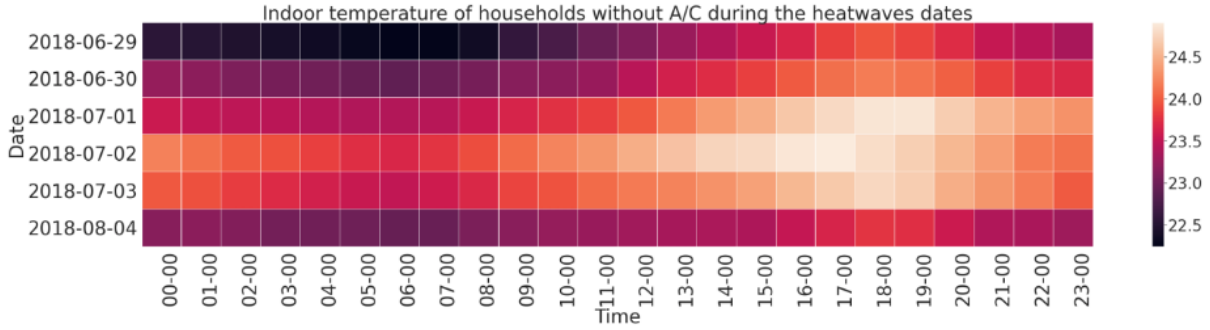


Figure 4.4: Average indoor temperatures for 47 households on heat wave days over time.

4.3.5 Discussion

Principal Findings

There were high indoor temperatures for prolonged periods of time that may put people at risk; indoor temperatures may be important to consider in policies and heat mitigation strategies. In Quebec, current heat alert and response systems rely upon outdoor meteorological data, which do not reflect actual indoor temperatures experienced by individuals. There were statically significant differences between air conditioned and non–air conditioned houses: non–air conditioned homes experienced a greater than 1°C difference in temperature between heat wave and non–heat wave days. Because there were only 6 official heat wave dates during the summer of 2018, comparison dates were limited. We also found a statistically significant difference between indoor temperatures for non–air conditioned houses and air conditioned homes during a heat wave ($P < .001$). Additionally, we found that there were significant differences between indoor and outdoor temperatures across all

households (P< .001).

During the summer of 2018, there were numerous non–air conditioned houses that experienced indoor temperatures greater than the ASHRAE 55 standard of 26°C for extended periods of time. This indoor temperature standard [Kenny et al., 2019], which is used widely in spaces such as office buildings, does not take into account factors such as age or health. The threshold was exceeded both on official heat wave days and on non–heat wave days. We also observed that the hottest time of the day indoors was between 4 PM and 7 PM, with increases in temperature over the 5-day heat wave. We were specifically interested in indoor temperatures recorded during the official heat wave from June 30 to July 5, 2018. Unsurprisingly, the indoor temperatures of homes with air conditioning remained relatively stable (mean 22.3°C or approximately 72°F) with no dramatic temperature spikes. Some air conditioned homes did record higher indoor temperatures. This may be due to homeowners having programmed the thermostat to maintain a higher indoor temperature to save on energy costs. Several non–air conditioned dwellings with ecobee thermostats had indoor temperature readings between 27°C (81°F) and 32°C (90°F), which is above the safe indoor threshold of 26°C (79°F) that is recommended by numerous health policy documents [Tham et al., 2020, British Columbia and BC Housing, 2019, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2017].
Smart home technology was able to capture continuous temperature data, which allowed the identification of houses that had experienced higher than ideal indoor temperatures. This technology could allow local governments to develop hyperlocal, real-time heat alert and response systems to protect health [Nguyen and Dockery, 2016]. On official heat wave days, many homes recorded indoor temperatures reaching 26°C. Temperatures as high as 32.7°C were recorded over multiple hours in several households on heat wave days. This information is important considering that spending more than a few hours indoors in a hot room can be hazardous to health [Kenny et al., 2019]. Non–air conditioned homes experienced indoor temperatures above 26°C for an average of 4 hours; there was an upward trend in duration as the heat wave persisted. A second official heat wave event was declared on August 4 in the Outaouais health region. In this region, homes without air conditioning experienced indoor temperatures for more than 9 hours above 26°C. Prolonged periods with indoor temperatures above 26°C were also experienced by non–air conditioned dwellings on unofficial heat wave days (July 14, July 23, July 31 to August 3, August 7, August 11 to August 15). In fact, houses in the Montreal and Outaouais areas consistently recorded indoor temperatures above 26°C throughout the summer of 2018. While definitions of extreme heat vary by region, heat warnings are issued in Canada when temperatures of 30°C or higher are expected for at least one hour [Government of Quebec, 2020] [50]. Consistent with the findings of previous literature

[Watkins et al., 2007, Soltani and Sharifi, 2017], our findings showed that higher indoor temperatures were reached in the late afternoon, and the coolest temperatures typically occurred in the early morning. Our results emphasize that outdoor temperature is not always a good indicator of safe indoor temperature; thus, there is a need to include indoor temperature monitoring capacity in our public health units. We plan to explore indoor humidity data in the future. While the humidex is not widely used and critiqued by many, indoor humidity plays a role in human comfort especially during extreme heat events [Lee and Lee, 2015, Nguyen and Dockery, 2016, Quinn and Shaman, 2017]. There is still relatively little known about indoor temperatures; the ability to study a large number of dwellings is both costly and time-consuming. This study is one of the first to use indoor smart thermostat data to investigate extreme heat events in Canada.

Strengths and Limitations

Our ability to identify at-risk households has implications for the delivery of emergency services. While in this study, data were not collected in real time, the technology can be used for real-time alerts. For example, the data can be integrated directly with real-time temperature updates to ensure caregivers, community care organizations, emergency medical response, paramedic, or hospital teams can reach at-risk populations. These data can also be used to dispatch emergency medical services to respond to calls and improve the safety of those aging in place or vulnerable individuals who may require alternate care levels. Furthermore, smart thermostats can be used to replace existing thermostats and bring energy and cost savings to home owners while meeting moral, pro-environment values and low-carbon targets [Balta-Ozkan et al., 2014]. Leveraging smart thermostats instead of introducing new technology could mean less barriers to adoption and easier integration to support heat health warning systems. The volume of data available is another strength of this technology. Although we focused on a short timeframe in a single province, there are still hundreds of datapoints available from location across Canada. There are currently several limitations to the use of ecobee data to study indoor temperatures. The number of occupants is unknown. In addition, the location of the residence is limited to the city level. This made grouping and matching homes with outdoor weather stations a challenge. This limitation protects anonymity and encourages voluntary enrollment in ecobee's Donate Your Data program [ecobee, 2021]. We were unable to account for technology malfunctions, such as a dead battery in a remote sensor, internet disconnection, or a power outage, that may have resulted in missing data. The location of the smart thermostat is entered in a text fieldby the user during setup, thus, could be inaccurate. Another limitation is that we do not know if other cooling methods, such as a fan or window air conditioning

unit, were used in the home. This could explain why some non–air conditioned dwellings experienced stable indoor temperatures. Furthermore, smart thermostats are more likely to be in higher socioeconomic status households, in detached homes that are owned by the resident [Opinion Dynamics, 2019].

Implications

A greater understanding of indoor temperature is necessary, given the risks of high temperature to human health [Tham et al., 2020] and the rise in extreme heat events over recent decades [Horton et al., 2016]. Many factors can contribute to increased indoor temperatures, including the surrounding environment and building materials [White-Newsome et al., 2012, Mavrogianni et al., 2012]. Canada has put in place some policies to address urban heat, such as planning that include green urban areas with trees and living roofs, encouraging the use of materials that reflect heat into the atmosphere, and retrofitting old buildings with smart, energy-efficient technologies [13]. These results also have implications for schools, hospitals, and long-term care facilities looking to prepare for future decades of warmer temperatures [McGregor et al., 2015, Environment, Climate Change and Health, 2020, Salthammer et al., 2016]. We must consider and ensure safe indoor temperatures, particularly for at-risk populations [Kenny et al., 2019, Giridharan et al., 2007, Mavrogianni et al., 2010, Mavrogianni et al., 2015]. Preparation for extreme challenges is vital (ie, lockdowns due to a pandemic). During the COVID-19 pandemic, many public spaces traditionally used for cooling centers (ie, libraries and community centers) were closed, and previous strategies (ie, visiting an indoor mall) were not feasible when public gathering was prohibited due to social distancing measures [Martinez et al., 2020, Salas et al., 2020]. Our study demonstrates the use of smart thermostat data for heat wave monitoring. The adoption of smart home devices, such as smart thermostats, can be used for a greater purpose and have public health benefits. This technology can be used to build on existing public health heat adaptation interventions and programs; for example, the strategic placement of sensors across neighborhoods can help cities understand how heat affects their citizens. The use of secondary data overcomes some of the challenges associated with a traditionally environmental study. Further research is needed to understand better indoor temperatures in low-income housing or in institutions, such as long-term care and hospitals, that house individuals who are less able to cope with extreme heat and more vulnerable to its effects.

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Data Availability Readers may contact the authors for more information on the RShiny app [Jalali, 2020]. The code used for the app is available upon request to the corresponding author. The ecobee data are available by reaching out to ecobee directly to become an affiliated researcher.

Conflicts of Interest None declared.

Appendix C Weather stations in Quebec 2018 and number of associated houses with ecobee smart thermostats.

Chapter 5

Leveraging IoT technologies for indoor climate change mitigation: A scoping review

Status: Prepared for submission to an open-access journal.

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5.1 Introduction

Addressing climate change requires both mitigation and adaptation efforts. While mitigating climate change focuses on tackling its root causes, adaptation addresses its immediate impacts that disproportionately affect vulnerable populations, particularly the urban poor [McMichael et al., 2006]. As global temperatures continue to rise, the threats posed by climate change will worsen, creating new vulnerabilities, such as the increasing risk of extreme heat indoors [Head et al., 2018]. There is a growing recognition of the importance of indoor air quality, especially following the COVID-19 pandemic, which emphasizes the need for adequate ventilation and air filtration [Morawska et al., 2021, Morawska et al., 2024]. HVAC systems in various settings, including concert halls, hospitals, and universities, were upgraded to ensure proper air exchange cycles to mitigate airborne risks. In addition,

individuals began purchasing consumer-grade air quality sensors, like the ARANET4 [aranet, 2024], to monitor particulate matter (PM2.5) levels in indoor environments, such as airplanes or other enclosed spaces. Simultaneously, there has been increased awareness of the dangers posed by wildfire smoke, particularly its risks to individuals working or exercising outdoors in affected regions [Coker et al., 2024].

5.1.1 Smart home technology

Given that people spend most of their time indoors, especially during extreme weather events such as heat waves, creating safe and healthy indoor environments cannot be overstated [Boyd, 2020]. Smart home technologies provide a powerful opportunity to monitor and improve indoor conditions, ensuring that vulnerable populations—who are often most at risk from environmental hazards—are protected [Bublitz et al., 2019, Jay et al., 2021]. By leveraging IoT technologies for climate adaptation and public health, we can move beyond convenience and comfort to create spaces that actively contribute to health and safety during climate-related events. Smart home technology is increasingly growing for convenience, comfort, and safety, with devices like smart thermostats, air filtration systems, and leak detection sensors becoming more common [Tirado Herrero et al., 2018]. As the cost of sensor technologies and data storage decreases, these technologies can provide valuable insights into environments that are not typically studied, including vulnerable communities that cannot afford gold-standard sensors [Sahu et al., 2019]. Currently, the Internet of Things (IoT) is predominantly used for entertainment and convenience and is a billion-dollar market expected to grow to USD $4.5 billion by 2028 [Statista, 2024a]. Still, there is a critical need to shift the focus toward addressing climate adaptation and improving public health outcomes.

Smart home automation is largely used for many mundane daily tasks, such as turning on lights and appliances, but its applications can extend beyond these physical functions. In the health sector, smart home technologies can be applied to monitor air quality, providing crucial information in cases such as allergy seasons or wildfires [Morita et al., 2023b]. There is also a significant data gap regarding indoor environments during extreme heat, which could be addressed through the widespread use of IoT technology, with important public health implications. In agriculture, IoT devices optimize crop irrigation and growing conditions [Maraveas et al., 2022], while in urban environments, they monitor localized air pollution and street-level particulate matter [Shete and Agrawal, 2016, Pantelic et al., 2022]. These technologies also have the potential to address issues related to indoor overheating, promote sustainability, and enhance climate resilience [Saeed et al., 2020, El-Mawla et al., 2019]. Wearables are another large field of technologies that can provide insights for measuring

the health impacts of climate change [Koch et al., 2022] and were thus excluded from this review. Furthermore, smart home technologies could play a critical role in filling gaps in public health responses to climate-induced disasters, such as by providing real-time monitoring and early warning systems to mitigate risks.

Smart home technologies, distinct from wearable devices, can also collect various health-related data, such as indoor environmental conditions or activity level [Ojo et al., 2018, Verma et al., 2019]. However, wearables like fitness trackers, which capture detailed physiological data such as heart rate and other vital signs, were excluded from this review to maintain a focus on non-wearable, home-based technologies.

5.1.2 Benefits and challenges

Smart home technologies have the capability to collect a wide variety of health-related data, such as heart rate, movement patterns, and other vital signs [Sahu et al., 2021]. These data streams can be critical for monitoring the health and well-being of individuals, especially during periods of extreme heat or other climate-related events when vulnerable populations are at heightened risk. In addition to health data, smart home devices can also capture essential environmental data, including indoor temperature, humidity, and air quality levels. This information is valuable for assessing indoor environments' safety and comfort, particularly during heat waves or poor-air-quality events caused by wildfires or pollution [Coker et al., 2024, Dahlbeck, 2024]. Despite the potential benefits, there is a significant gap in empirical evidence regarding the effectiveness of these data streams in mitigating the health impacts of extreme heat or improving indoor environmental conditions during climate events. While these technologies are promising tools, more rigorous research is needed to determine how effectively they can prevent heat-related illnesses or improve air quality in real-world settings. Additionally, there is limited understanding of how these data can be integrated into public health interventions or emergency responses to better protect vulnerable populations [Rathore et al., 2016]. Without robust evidence, it remains unclear whether these technologies can reliably contribute to climate resilience or address public health disparities, especially in low-income communities where access to high-quality sensors may be limited. Expanding research in these areas is essential to fully harness the potential of smart home technologies in addressing the public health challenges associated with climate change.

Smart home technologies face several challenges related to accuracy, standardization, and data interoperability. While low-cost devices often trade precision for affordability [Government of Canada, 2024], the ecobee thermostats used in this study are designed to

provide reliable temperature and humidity data, minimizing concerns about data quality. However, as with many smart devices, ensuring compatibility with broader systems and maintaining data accuracy across various contexts remains important. This can be particularly problematic in climate and public health applications where high data accuracy is critical for effective interventions [Clements et al., 2022]. Additionally, there are significant geographic gaps in deploying smart technologies, as much of the research and technology development has been concentrated in high-income countries. This focus leaves underserved populations, particularly in low- and middle-income regions, vulnerable and less equipped to benefit from these advancements. 42% of smart home technology adopters and 52% of non-adopters reported a financial barrier in the 2024 survey, a significant increase in lower-income respondents, who tend to have lower adoption rates [ASHB, 2024]. Energy poverty and inequity present further barriers to adopting smart home technologies, as many communities lack access to reliable electricity or stable internet infrastructure [Canadian Urban Sustainability Practitioners, 2019, Cong et al., 2022]. As a result, a growing divide is emerging between communities that can access and afford smart technology solutions and those that cannot. Energy poverty, in particular, is a significant obstacle in low-resource settings, limiting the reach and effectiveness of smart technologies in enhancing climate resilience [Jessel et al., 2019]. Moreover, the environmental impact of developing and deploying these technologies warrants critical evaluation. The extraction of precious metals for electronics, increasing energy demands of data centres, and using artificial intelligence (AI) all have substantial environmental footprints [Allan-Blitz et al., 2022]. These processes contribute to greenhouse gas emissions and environmental degradation, raising ethical concerns about the long-term sustainability of relying on technology to solve climate-related issues [Masson-Delmotte et al., 2018]. Addressing these challenges requires a balanced approach that considers both the benefits and the unintended consequences of smart home technology on the environment and society.

5.1.3 Gaps and relevance

There is a significant gap in research on the effectiveness of smart home technologies in reducing heat-related health risks. While these tools have the potential to improve indoor environments, empirical evidence on their role in mitigating heat-related illnesses and other climate-related impacts is scarce. The lack of real-world studies makes it unclear how effectively these technologies work, particularly during extreme heat events affecting vulnerable populations. Moreover, current research often overlooks marginalized communities, focusing predominantly on high-income households [University of Oslo and Sahay, 2016]. This under-representation highlights the need for future studies to be more inclusive and

address the unique challenges faced by low-income groups who are disproportionately exposed to climate risks.

Another challenge is the lag in policy frameworks for integrating smart home technologies into broader climate adaptation strategies. While their potential is recognized, these tools have not yet been incorporated into official climate resilience planning, partly due to uncertainties about their long-term effectiveness. Policymakers, however, have an opportunity to adopt a cautious but proactive approach by developing pilot programs and phased regulations to test, scale, and standardize smart technologies. This would allow for evidence-based adjustments while addressing climate risks and protecting public health [Salam, 2024], especially as the frequency and severity of heat waves and other climate-induced disasters continue to increase.

5.1.4 Objectives and research question

This research aims to explore and map the current literature on using low-cost and consumer-grade smart home technologies to monitor and address climate change-related risks, such as indoor air quality, flooding, and extreme heat. By conducting a comprehensive review of existing studies and applications, the goal is to identify the key technologies utilized in this space and assess their potential impact on mitigating climate-related health risks. Additionally, this research seeks to uncover gaps in the current body of knowledge, particularly regarding the effectiveness and accessibility of these technologies in various settings. The ultimate aim is to understand how these smart home solutions can improve public health outcomes, especially for vulnerable populations most at risk from the impacts of climate change.

What low-cost or consumer-grade smart home technologies are currently being utilized to monitor and address the risks and impacts of climate change-related disasters (e.g., extreme heat), and what gaps exist in the current research and application of these technologies?

5.2 Methods

5.2.1 Search strategy

Following the scoping methods of Arksey and O'Malley, the [Arksey and O'Malley, 2005] comprehensive search strategy was developed by identifying relevant keywords, terms, and phrases (see Appendix D). The search string used was: ("indoor comfort" OR "thermal

comfort") OR ("temperature" OR "heat stress") AND ("sensor" OR "technology*" OR "early warning system" OR "real-time") AND ("extreme heat event" OR "heatwave").

The search term "climate change" was deliberately excluded because it made the search too narrow and returned limited results. The search was carried out on multiple databases, including PubMed, Scopus, CINAHL, Web of Science, and Google Scholar (the first 200 results were extracted using Publish or Perish) on January 4, 2024. In addition, a search was performed in Google's search engine, the first 10 pages of results were viewed, and 2 additional articles were added.

Together, these searches yielded approximately 1,000 results for review.

5.2.2 Data extraction

The search results were imported into Covidence, a software tool used for systematic review management, where titles and abstracts were initially screened according to predefined inclusion and exclusion criteria. See Figure 5.1 for the PRISMA flow diagram outlining the study selection process. Only studies aligned with the focus on smarthome or low-cost technologies addressing climate-related risks were selected during the title and abstract screening phase.

Full-text articles of the potentially relevant studies were then downloaded and reviewed to ensure they met the specific inclusion criteria, see Table 5.1. Studies were excluded if they were not peer-reviewed journal articles, involved non-human study populations, were written in a language other than English, or were review-type articles. Additionally, articles were excluded if they did not specifically mention the use of low-cost or Internet of Things (IoT) technologies and if they did not address climate change as an impact or factor.

After this thorough screening process, eight studies met all the criteria and were selected for inclusion in the analysis. The characteristics of these eight studies, including key details such as the technologies used, study settings, and measured outcomes, were tabulated in a spreadsheet for further analysis. This data will form the basis for a deeper evaluation of the effectiveness of smart home technologies in mitigating climate change-related health risks.

Table 5.1: Inclusion and exclusion criteria

Inclusion criteria
Full text available
Publications

Continued on next page

Table 5.1 – continued from previous page

Inclusion criteria	
IoT sensor	Published in English
	Published between January 2010 and December 2023
	Study type = Randomized control trials (RCTs), non-RCTs, observational studies, case studies
	Low-cost and commercially available electronic devices
	Low cost
	Noninvasive and nonobtrusive
	Measuring at least one individual exposure (e.g. ambient temperature)
Climate hazard focus	Related to extreme heat or exacerbated by it
Setting	Real-world settings such as inside a home, hospital, or office/workplace
Outcomes	The individual effect of climate change-related environmental conditions is measured.
Exclusion criteria	
Publications	Non-human study population (e.g. animal, agriculture, ecosystem)
	Reviews, books, book chapters, editorials, opinions, commentaries, conference papers, reports
IoT sensor	Not commercially available (e.g. prototype, design study)
	Smartphones or wearables used as IoT
	IoT or sensors not implemented (e.g. theoretical paper)
Data	Synthetic
Study setting	Climatic chamber or laboratory
Outcomes	No mention of climate change impacts
	No measurement of variables occurred

5.3 Results

Following the initial search, 1,071 records were identified, with two additional records added through a manual search. After removing 80 duplicate records, the remaining titles and abstracts were screened based on the inclusion and exclusion criteria. Studies that passed the initial screening moved on to the full-text review phase, where the articles were

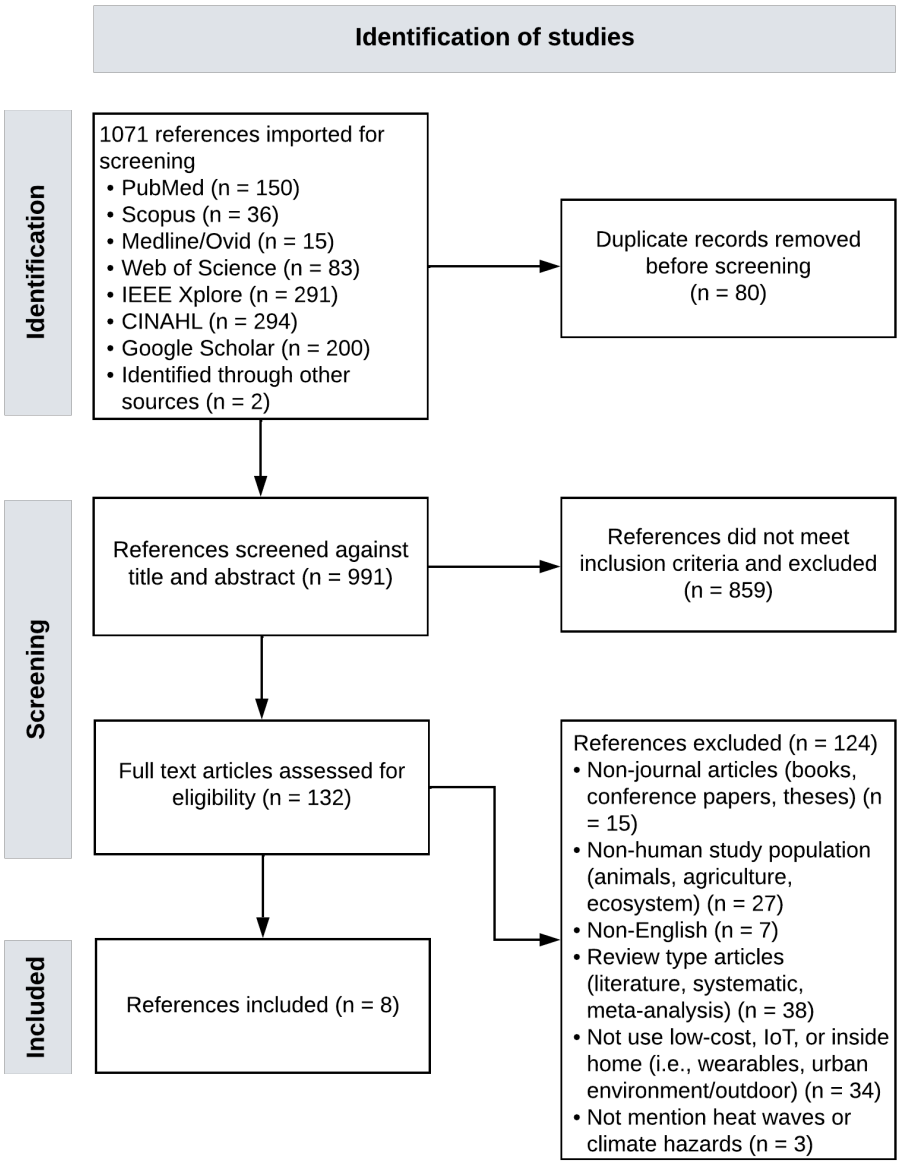


Figure 5.1: PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart

thoroughly examined to ensure they met the predefined screening criteria. Only studies specifically addressing low-cost or Internet of Things (IoT) technologies concerning climate change impacts were retained for further analysis.

5.3.1 Study characteristics

The studies included in this review were published between 2017 and 2023, with half (four) published in 2022. This range reflects the increasing focus on smart home technologies and their potential applications for climate resilience and public health during this period. The publications appeared in a wide array of journals, reflecting the interdisciplinary nature of the research, which spans environmental sciences, building sciences, health, and technology. These journals include Atmospheric Environment, Energy and Buildings, Buildings and Environment, Environmental Research and Public Health, Journal of Hospital Management and Health Policy, JMIR Formative Research, Scientific Data, and Sensors (Basel). The majority of the studies were conducted in upper-middle-income countries. However, one was based in lower-middle-income countries, illustrating a global interest in IoT and smart home technology applications across diverse economic contexts. Geographically, the research spanned across North America, Europe, and Asia. For example, studies were conducted in Vancouver, Canada, by Dickson et al. 2023, Montreal, Canada ([Oetomo et al., 2022]) and Elizabeth, New Jersey, United States ([He et al., 2023]), as well as London, UK ([Gustin et al., 2020]) and [Pathan et al., 2017]) and Budapest, Hungary ([Szagri et al., 2022]). In Asia, significant research was carried out in Maharashtra and Delhi, India, Dhaka, Bangladesh, and Faisalabad, Pakistan (as seen in [Tasgaonkar et al., 2022]), with additional work in Seoul, Korea by Yun et al. in 2020 [Yun et al., 2020]. The types of studies included were predominantly observational, with six studies classified as cross-sectional or observational, such as [Gustin et al., 2020] and [He et al., 2023]. One study was retrospective ([Oetomo et al., 2022]), while another employed a longitudinal cohort design. The duration of the studies varied, with most lasting less than six months. However, two studies spanned between one year, up to nearly two years providing long-term insights including [Yun et al., 2020] and [Tasgaonkar et al., 2022]. In terms of study settings, eight of the studies focused on residential homes, emphasizing the domestic application of smart home technologies to monitor indoor air quality, heat exposure, and environmental conditions. One study by [He et al., 2023] extended beyond homes and was conducted in a hospital/workplace environment, demonstrating the adaptability of IoT devices across different environments. Sample sizes also varied significantly, with small cohorts like the 24 seniors in Budapest in the study by [Pathan et al., 2017], contrasted with larger-scale studies involving 871 participants across South Asian cities [He et al., 2023]. This variability

highlights smart home technologies' broad scope and potential scalability of smart home technologies in small and large populations across diverse regions.

Table 5.2: Study characteristics

Study characteristics	Studies (N=8)	Participants / Number of studies
Regions and countries		
North America	Vancouver, BC, Canada	n/a
	Quebec, Canada	n/a
	Elizabeth, NJ, United States	24 seniors
Europe	London, UK	111 participants
	London, UK	n/a
	Budapest, Hungary	n/a
Asia	Maharashtra, India; Dhaka, Bangladesh; Delhi, India; Faisalabad, Pakistan	871 participants
	Seoul, Korea	n/a
Type of Study	Observational, cross-sectional study	1
	Observational	4
	Retrospective	1
	Observational longitudinal cohort	1
Duration	<1 month	3
	<6 months	5
	<2 years	1
Study setting	Home	8
	Hospital/workplace	1

Table 5.3: Study methods and objectives

Study methods and objectives		Studies (N=8)
Study Objective	Explore indoor temperature range, heat exposure, thermal environment, or overheating inside and outside	5
	Investigate temperature prediction deployment for iH-HWS.	1
	Impact of heat waves on PM 2.5 levels in apartments.	1
	Develop a wireless monitoring system for indoor air quality.	1
Sensors per site	1	4
	2	1
	>3	3
Sensor models (company)	HOBO U12-012 (Onset Corporation, USA)	1
	HOBO UX 100-001, HOBO UX100-011, AWS (Wireless Vantage Pro2 Plus or equivalent, Davis Instruments, USA)	1
	AQ-0115V (Coway Co. Ltd., Korea)	
	Testo 480 (Testo Co. Ltd., Germany)	1
	WGT-10 (Hario SCI, Japan)	
	ecobee smart (Generac, Canada)	
	AirVisual Node (IQAir, Goldach, Switzerland)	1
	ESP32-WROOM-32E (Expressif Systems, China)	
	Air Quality Egg sensors (EGGs) (Wicked Device, New York), temperature sensors (Sensirion SHT35)	1
Variable(s) measured* Indoor	Temperature (Maximum)	6
	Dry Bulb Temperature (DBT)	2
	ODH26 indicator	1
	Air temperature	2

Continued on next page

Study methods and objectives		Studies (N=8)
Outdoor	Relative humidity (RH)	6
	PM2.5, PM10	1
	CO2	3
	Air temperature	6
	Humidity	2
	Wind direction and speed (anemometer)	1
	Global (solar) radiation and evaporation	1
	Global Horizontal Irradiance (GHI)	1
Other	Occupants' socioeconomic status, use of appliances, summertime ventilation habits, construction age, form/type	1
	Window opening and shutter position	1
	Rainfall	1
Location of indoor sensor	Basement (near elevator, hallway), ground floor (therapy room, lobby), 4th floor (near elevator, patient room, office)	1
	Living room, kitchen, bedrooms (centre of room, 1.2m from floor, away from heat sources)	1
	Living room and bedroom	1
	Living room, dining room, large bedroom, small bedroom	1
	Sleeping corner or where most time was spent (wall or furniture, 1.3m from floor)	3
	Not determined by study - Apartment - location, height, and proximity to windows differed	2
Data storage capability	Internal on device	2
	Remote, uploaded to a server	1
	Both (internal and remote)	3
	Not specified	2
Frequency (indoor temp)*	10 seconds	2

Continued on next page

Study methods and objectives		Studies (N=8)
	1 minute	1
	5 minute	1
	10 mins	3
Comparison data (environmental data)	Temperature	1
	Humidity	
	Other	
	Sensors on-site	3
Location of environmental data*	Nearby weather station	3
	None	2
Methods of analysis (statistical test)	Two-sample t-test and analysis of variance (ANOVA) with follow-up Tukey posthoc test	1
	Backward stepwise regression, Rolling window approach, Boxplots for forecasting accuracy	1
	Shapiro-Wilk normality test, non-parametric Mann-Whitney test, non-parametric Kruskal-Wallis test	1
	Descriptive statistical analyses and t-tests to compare indoor temperatures between air-conditioned and non-air-conditioned homes on both heat wave and non-heat wave days	1
	Descriptive and 1-tailed t-test	1
	No statistical techniques were mentioned in the paper for analyzing the results of the study	1
	Descriptive	1
	Levene tests, one-way ANOVA, Scheffe's posthoc tests, Student's t-test, Pearson correlation coefficients, regression analysis using R	1

The study methods and objectives varied significantly across the eight studies reviewed, each exploring different aspects of indoor environmental monitoring in the context of heat and air quality. For instance, Dickson et al., [Dickson et al., 2023] studied the indoor temperatures of a healthcare facility during the 2021 Heat Dome. Tasgaonkar et al. [Tasgaonkar et al., 2022] looked at indoor heat exposure and health outcomes in South Asia. Similarly, Yun et al. [Yun et al., 2020] looked at indoor temperatures in apartments in Seoul, Korea. Oetomo et al. [Oetomo et al., 2022] studied the effects of heat waves on indoor temperatures in homes in Quebec, while Pathan et al. [Pathan et al., 2017] focused on monitoring indoor overheating in residential buildings. Gustin et al. [Gustin et al., 2020] aimed to develop a temperature prediction deployment system for an indoor Heat Health Warning System (iHHWS), and Szagri et al. [Szagri et al., 2022] developed a wireless monitoring system to investigate residential overheating. Meanwhile, He et al. [He et al., 2023] investigated the impact of heat waves on PM2.5 levels inside apartments.

The number of sensors deployed at each study site varied, with some deploying sensors indoors and outdoors for comparison. One study used a single sensor [Oetomo et al., 2022], four studies deployed two sensors ([He et al., 2023, Gustin et al., 2020, Dickson et al., 2023, Pathan et al., 2017], and three studies used more than three sensors per site [Szagri et al., 2022, Yun et al., 2020, Tasgaonkar et al., 2022].

The studies used various sensors, including the HOBO UX100 100 001 (air temperature), UX100-011 (relative humidity) and HOBO U12-012 (Dry Bulb Temperature and relative humidity) sensors from Onset Corporation [Tasgaonkar et al., 2022, Pathan et al., 2017], the ecobee (temperature and humidity) from Generac (Canada) [Oetomo et al., 2022], the AirVisual Node (PM2.5, PM10) IQAir (Switzerland) [He et al., 2023], the Air Quality Egg sensors from Wicked Device (New York) [Dickson et al., 2023], SHT85 (temperature and relative humidity) and SCD3 (CO2) (Sensirion AG, Switzerland) and HC-SR501 PIR (motion) (TruSens, China) [Szagri et al., 2022] and sensors from Testo 480 (temperature) Testo (Germany), AQ-0115V (temperature and relative humidity) Coway Co. Ltd. (Korea), and WGT-10 (airflow rate) (Hario SCI, Japan) [Yun et al., 2020].

The variables measured across the studies were predominantly indoor air temperature and relative humidity, with six studies capturing maximum temperature and five monitoring relative humidity. Other studies measured variables like PM2.5 and PM10 levels [He et al., 2023], CO2 concentrations [Szagri et al., 2022], and external environmental data, such as wind direction, speed, and global radiation. Some studies also included socioeconomic variables, such as the occupants' status, ventilation habits, and the age or type of building construction, which were important factors influencing indoor temperatures, as reported by Oetomo et al. [Oetomo et al., 2022].

Indoor sensors were typically placed in key living areas, including living rooms, bedrooms, kitchens, and dining rooms. Specific placement strategies were often mentioned, with sensors positioned 1.2 to 1.3 meters from the floor and away from heat sources, as noted by Pathan et al. [Pathan et al., 2017]. However, some studies, such as Oetomo et al. [Oetomo et al., 2022], did not specify exact sensor placement. Data storage approaches also varied. Two studies relied on internal device storage [Szagri et al., 2022, Pathan et al., 2017], one on remote storage [Oetomo et al., 2022], three used internal and remote data storage [He et al., 2023, Szagri et al., 2022, Yun et al., 2020] and two did not specify their data storage methods [Dickson et al., 2023, Gustin et al., 2020]. The frequency of data collection ranged from 10-second intervals in two studies to 10-minute intervals in three studies.

Three studies used on-site weather stations for comparison with environmental data, while two did not utilize external environmental data. The statistical methods employed for data analysis were diverse. They included two-sample t-tests, analysis of variance (ANOVA), and post-hoc Tukey tests, as used in Gustin et al. [Gustin et al., 2020], as well as regression analysis and non-parametric tests like the Shapiro-Wilk normality test. Some studies, such as He et al. [He et al., 2023], conducted descriptive statistical analyses, while Pathan et al. [Pathan et al., 2017] did not specify the statistical techniques used.

In summary, the studies employed a wide range of methods to analyze indoor environmental conditions and the impact of heat on air quality and indoor temperatures. These studies used different sensor deployment strategies, data collection methods, and statistical analyses, underscoring the need for a standardized approach to improve the comparability and reliability of findings across different environments.

5.3.2 Findings

Population of study

The studies included in this review primarily focused on urban populations in the middle- to high-income regions, with some measuring temperature at the household or room [Dickson et al., 2023, Oetomo et al., 2022] level and others measuring both temperatures while also collecting data on behaviours and heat-related symptoms [Pathan et al., 2017, Tasgaonkar et al., 2022]. For example, Pathan et al. [Pathan et al., 2017] studied residents of London, UK. In contrast, Oetomo et al. [Oetomo et al., 2022] examined households in Quebec, Canada. He et al. studied 24 seniors in Elizabeth, New Jersey, USA and Tagoankar et al. [Tasgaonkar et al., 2022] examined homes in Dhaka, Bangladesh; Delhi and

Maharashtra, India, and Faisalabad, Pakistan. These populations were primarily affected by extreme heat and indoor air quality issues, highlighting the need for technologies to provide real-time monitoring and preventive measures in such environments. However, lower-income populations, countries in the Global South, and rural areas remain underrepresented in this area of research.

Technology Used

The technologies used in these studies primarily relied on low-cost, commercially available sensors. For example, He et al. [He et al., 2023] used AirVisual Node (IQAir) sensors to monitor PM2.5 and PM10 levels, while Gustin et al. [Gustin et al., 2020] employed HOBO U12-012 sensors (Onset Corporation) to track temperature and humidity. Some were selected for their accuracy and availability, making them accessible to both researchers and everyday users [Oetomo et al., 2022].

Common environmental variables measured included temperature, humidity, and air quality (PM2.5), with He et al. [He et al., 2023] specifically focusing on PM2.5 and PM10 levels to assess the indoor air quality during heat waves. These variables are key to understanding how home conditions affect health, especially during extreme heat.

All the devices used have the potential for integration into existing HARS or related initiatives. Variations in study designs, including time frames and device types, provided valuable temperature data to inform decision-making processes.

Szargi et al. [Szagri et al., 2022] developed a custom sensor platform, while others used off-the-shelf sensors, many with real-time or near-real-time capabilities. This shift supports moving heat-health responses from being reactive to more proactive and immediate. While the ecobee platform can be used similarly according to [Oetomo et al., 2022]

These systems can also leverage large databases historical data for predictions, as seen with devices like ecobee [Oetomo et al., 2022], or integrate into broader platforms, such as the HOBOlink Remote Monitoring Software [Onset's HOBO Data Loggers, 2024], for comprehensive monitoring and response.

Storage and power requirements

Storage capabilities varied across the studies. Pathan et al. [Pathan et al., 2017] and He et al. [He et al., 2023] highlighted that most sensors stored data internally, with some devices offering the option to upload data to a remote server. Power and internet

requirements were also crucial for ensuring continuous monitoring. For example, Gustin et al. [Gustin et al., 2020] emphasized the need for a stable internet connection to transmit real-time temperature data, while Oetomo et al. [Oetomo et al., 2022] noted that smart thermostats relied on both electricity and Wi-Fi for full functionality. However, the studies did not extensively discuss cost per unit or operating costs, though He et al. [He et al., 2023] referred to the relatively low cost of deployment for AirVisual Node sensors in urban apartments.

Interoperability and standards

Interoperability was a common challenge across the studies, as different IoT devices often used proprietary systems. Gustin et al. [Gustin et al., 2020] noted issues with integrating multiple sensors from different manufacturers due to the lack of universal communication standards. The absence of a unified standard for sensor communication and data storage led to data silos, which inhibited the sharing of data across platforms. This fragmentation limited the ability to apply FAIR (Findable, Accessible, Interoperable, Reusable) data principles to the collected data, as noted by Pathan et al. [Wilkinson et al., 2016, Boeckhout et al., 2018, Pathan et al., 2017]. A more concerted effort toward standardization would be required to improve data sharing and enhance the interoperability of IoT devices used in climate resilience and public health applications.

End user and information sharing

Researchers and government agencies were the primary end users of the information generated by these IoT systems. For instance, He et al. [He et al., 2020], and Oetomo et al. [He et al., 2023, Oetomo et al., 2022] noted that collected data was primarily shared with researchers to understand environmental conditions better. In contrast, Gustin et al. [Gustin et al., 2020] emphasized the role of government agencies in using the data for policymaking. While some smart home technologies offered dashboard interfaces or mobile apps for individual users [Oetomo et al., 2022], offering benefits to the participants, and the broader public health and climate resilience planning, such as amendments to the building code [Szagri et al., 2022].

Ethical considerations and knowledge translation

Ethical considerations surrounding the use of IoT technologies were addressed in some of the studies. Pathan et al. [Pathan et al., 2017] highlighted concerns related to data

privacy, particularly regarding how indoor environmental data was collected, stored, and used. Collecting sensitive data, such as indoor conditions and air quality, raises concerns about potential misuse or unauthorized access. Oetomo et al. [Oetomo et al., 2022]. He et al. [He et al., 2023] also acknowledged the importance of informed consent from participants, ensuring that users knew what data was being collected and how it would be used, especially with the surge in AI use for predictions [Gustin et al., 2020, Yun et al., 2020, Hagendorff, 2020].

Knowledge translation efforts were mainly targeted at government agencies and public health organizations, as seen in Gustin et al. [Gustin et al., 2020] and Oetomo et al. [Oetomo et al., 2022], where research findings were used to inform climate adaptation policies. However, there remains a gap in how effectively this data reaches the general public. Improved communication through mobile apps or real-time dashboards could enhance the public's ability to engage with and act on the data generated by these systems, particularly in the face of climate-related health risks. Simultaneously, retroactive studies must translate into evidence-informed policies to protect the most vulnerable to extreme heat events.

5.4 Discussion

5.4.1 Key Findings

This review identified several low-cost and consumer-grade smart home technologies that effectively monitor and mitigate climate change-related risks. These included temperature and humidity sensors (e.g., ecobee smart thermostats) and air quality monitors (e.g., AirVisual Node). Notably, these technologies were predominantly implemented in high-income regions, with limited representation in low-income or rural settings. The findings emphasize the critical role of real-time monitoring in identifying and addressing indoor environmental hazards during extreme heat events.

Outliers included studies where sensor placement significantly impacted data accuracy [Oetomo et al., 2022] and where low-cost sensors, while affordable, introduced variability in measurements [He et al., 2023]. These results highlight the need for standardized methodologies to ensure reliability across diverse settings.

5.4.2 Study Characteristics

The studies reviewed were diverse in design, geographic location, and objectives, revealing how environmental factors and local challenges influenced the outcomes. Most of the studies employed observational designs, with variations in the duration of data collection and the number of sensors deployed. Some, like Dickson et al. [Dickson et al., 2023], focused on short-term monitoring, while others, like Oetomo et al. [Oetomo et al., 2022], incorporated longer-term monitoring of indoor environments during heat waves. The differences in study duration played a role in the robustness of the data. Short-term studies captured immediate responses to heat events, while longitudinal designs allowed for identifying trends and seasonal variations in indoor temperature or air quality. These designs reflect a growing emphasis on real-time environmental monitoring to identify patterns in indoor temperature and air quality.

Geographically, the studies were concentrated in high-income regions, such as North America and Europe. This geographic bias reflects the challenges in studying IoT solutions in lower-income regions facing energy poverty and poor infrastructure. For instance, extreme weather events like heat waves in North America and Europe provided opportunities to investigate the deployment of smart sensors in real-world scenarios [Dickson et al., 2023, Oetomo et al., 2022]. However, the absence of studies in low-income countries, where the effects of climate change are often more severe, suggests a research gap that must be addressed to improve global resilience.

5.4.3 Study methods and objectives

The studies employed various methods to monitor environmental conditions, including temperature, humidity, and air quality (PM2.5). Many relied on commercially available low-cost sensors, such as the HOBO U12-012 or AirVisual Node, which made deployment easier but introduced trade-offs in terms of data precision. For example, He et al. [He et al., 2023] found that low-cost PM2.5 sensors could accurately track indoor particulate matter during heat waves. Still, they noted that external factors like ventilation and sensor placement impacted the readings' accuracy.

The trade-offs between sensor types and technologies were apparent across studies. Higher-cost, precise sensors provided more reliable data but were often infeasible for larger-scale home deployment due to cost. Low-cost devices were more accessible but tended to introduce variability in data accuracy, especially compared to lab-calibrated systems. The choice of sensors influenced the findings and the potential scalability of the solutions, particularly in vulnerable communities where cost remains a critical barrier to adoption.

The objectives of the studies often addressed real-world needs, such as understanding indoor heat exposure [Dickson et al., 2023], predicting indoor temperature fluctuations [Gustin et al., 2020], or monitoring air quality [He et al., 2023]. These objectives align with pressing public health challenges exacerbated by climate change, particularly in urban and vulnerable communities, where extreme heat events disproportionately affect health.

Backward / forward searching (where additional texts are found through those references in or citing texts in the initial sample) was not used and could have potentially resulted in a greater number of articles that met the inclusion and exclusion criteria.

5.4.4 Outcomes

The studies consistently demonstrated the effectiveness of smart home technologies in monitoring indoor environmental conditions, but their role in directly reducing health risks or impacts remains unclear. While these technologies provide valuable data to inform actions during heat events, few studies have specifically linked their use to measurable reductions in heat-related morbidity or mortality, such as fewer deaths or illnesses in homes equipped with smart devices after a heat wave. This distinction underscores the need for further research to evaluate the direct health benefits of these technologies in mitigating climate-related health impacts.

Both Yun et al. [Yun et al., 2020] and Oetomo et al. [Oetomo et al., 2022] showed that homes equipped with IoT devices could better maintain safe indoor temperatures during heat waves, reducing the risk of heat-related illnesses. Dickson et al.[Dickson et al., 2023] found that while indoor temperatures were lower than outside, there was still variation within the healthcare facility. Similarly, Szagri et al. [Szagri et al., 2022] and Pathan et al. [Pathan et al., 2017] highlighted how continuous monitoring of indoor conditions in London, UK revealed significant overheating, which could be mitigated through a cost-effective monitoring system and smart ventilation systems. He et al. also demonstrated that heat waves worsened air pollution by smoking [He et al., 2023].

However, significant gaps still need to be addressed, particularly in representing low-income or climate-vulnerable regions [Tasgaonkar et al., 2022]. The studies focused predominantly on developed countries, and few addressed the unique challenges faced by regions with limited infrastructure. Moreover, while smart home technologies showed promise in public health applications, scaling these solutions to larger populations, especially those without access to consistent energy or the Internet, remains challenging.

The potential for scaling IoT applications is evident, particularly in public health monitoring and prediction [Gustin et al., 2020]. For instance, Sahu et al. [Sahu et al., 2020b]

and Jalali et al. [Jalali et al., 2022] emphasized the role of thermostats in North American homes, providing a unique opportunity for monitoring indoor environments and potentially related health factors, such as sleep and movement. Sleep and movement are important in the context of protecting health from indoor heating, as disrupted sleep due to high temperatures and limited mobility in overheated spaces can exacerbate heat-related illnesses. While these technologies currently focus on environmental monitoring, their integration with additional sensors (fridge door contact, water usage, light meters, etc.) could provide insights into behaviours such as fan usage, water intake, lowering blinds, or preparing cool meals. These capabilities would be particularly beneficial for care providers supporting vulnerable individuals, enabling real-time assessments and interventions to ensure safety during extreme heat events.

5.4.5 Measuring other indoor hazards

Beyond temperature and air quality, smart home technologies have significant potential to monitor a broader range of hazards within homes. For instance, radon detection is where IoT devices could provide real-time monitoring, particularly in regions where radon exposure is a known risk. Radon, a naturally occurring radioactive gas, can accumulate in poorly ventilated homes and poses serious health risks, including lung cancer [Chen et al., 2012, Ruano-Ravina et al., 2023]. Although none of the reviewed studies specifically focused on radon, similar technologies used to monitor indoor air quality, such as those detailed by He et al. [He et al., 2023] and Pathan et al. [Pathan et al., 2017] for monitoring PM2.5 and humidity, can be adapted.

Additionally, smart systems could be employed to track indoor pollutants such as volatile organic compounds (VOCs), which are released from everyday household products like paints, cleaning supplies, and furnishings [Chin et al., 2014, David and Niculescu, 2021]. VOCs pose significant health risks over long-term exposure, contributing to respiratory issues and other illnesses. Oetomo et al. [Oetomo et al., 2022] demonstrated how smart technologies monitor indoor environments during heat waves, providing a model for expanding IoT applications to include VOC detection. Expanding the scope of these technologies to address a wider array of airborne toxins could greatly improve indoor air safety, particularly in vulnerable populations exposed to environmental pollutants.

In addition to physical hazards, smart home technologies can also be utilized to monitor non-environmental factors like mental health and mental workload [de la Torre Díez et al., 2018, Pütz et al., 2022]. IoT devices equipped with behavioural data analysis capabilities can track sleep patterns, stress indicators, and daily routines,

offering insights into an individual's mental well-being [Jalali et al., 2022, Kim et al., 2021, Saleem et al., 2020]. By analyzing changes in behaviour—such as disrupted sleep or increased stress—these devices could help identify mental health issues early, prompting timely interventions. Studies such as those by Oetomo et al. [Oetomo et al., 2022] focused primarily on the physical environment but underscored the potential of IoT systems to go beyond environmental monitoring with the addition of additional sensors or by leveraging existing functionality. Given the growing prevalence of climate-related stress and anxiety, particularly in vulnerable populations affected by extreme weather events, the potential for IoT technologies to contribute to mental health monitoring has broad public health implications. By integrating the monitoring of physical and mental health risks, smart home technologies could provide a comprehensive tool for health management in the face of climate change, further expanding their role in public health and climate resilience.

5.4.6 Policy and Program Implications

The findings suggest that integrating smart home technologies into public health initiatives could significantly enhance climate resilience. Policymakers should prioritize subsidies for low-income households to increase accessibility and address inequities in technology adoption. Additionally, standardizing data collection and storage methodologies would facilitate broader integration into national and regional heat health action plans. For example, incorporating real-time temperature monitoring from devices like ecobee thermostats could enable targeted interventions during extreme heat events [Oetomo et al., 2022].

However, the accuracy of these devices can vary depending on the model and environmental conditions. While many ecobee smart thermostats are highly reliable for monitoring temperature [ecobee, 2023], their ability to track more complex metrics, such as air quality [ecobee, 2024b] or infer activity patterns, may be less precise and require integration with additional sensors. Studies by Sahu et al. [Sahu, 2022] and Kaur et al. [Kaur et al., 2022] further reinforce the potential for using these systems to monitor individual and population health indicators in real-time.

Given the increasing threats from climate change—ranging from wildfire smoke to extreme heat—IoT systems are uniquely positioned to fill data gaps in public health surveillance. These devices allow the monitoring of health risks granularly, enabling timely interventions to protect vulnerable populations. However, it is important to recognize that IoT devices should not be viewed as a one-size-fits-all solution. For example, while air conditioning (AC) effectively mitigates heat, it is not a universal solution. Similarly, IoT devices are most effective when integrated into broader policy frameworks that protect health and well-being.

The potential of smart home technologies to inform policy development is significant. Data from these devices can provide real-time insights that help shape public health responses, ensuring that evidence-informed policies are enacted to address the health impacts of climate change [Sahu et al., 2021]. By monitoring environmental conditions in homes, these technologies offer an invaluable tool for developing policies responsive to the evolving threats posed by climate change, particularly in protecting at-risk populations.

5.4.7 Challenges

Despite the rapid growth and adoption of IoT technologies, many fundamental challenges persist, hindering their full potential and perpetuating inequities in access and usage. One of the primary challenges is the lack of standardization across devices and systems. The proliferation of different communication standards, proprietary software, and incompatible platforms has led to the creation of data silos, where valuable data remains isolated within specific systems and cannot be easily shared or integrated across platforms. This fragmentation limits the ability to harness IoT technology for public health and climate adaptation, resulting in inefficiencies and wasted data, as seen in multiple studies. For example, Dickson et al. [Dickson et al., 2023] highlighted that the lack of a unified framework in sensor technology and data collection restricts the use of IoT in monitoring heat exposure. In contrast, Gustin et al. [Gustin et al., 2020] noted the limitations of proprietary systems in their high-resolution temperature prediction models.

Although progress has been made in areas such as wireless network standards and cloud computing, including the development of edge devices and networks, the lack of interoperability between devices continues to pose significant barriers. Without universal communication standards, the data generated by IoT devices remains locked within proprietary ecosystems, limiting the scope for collaboration and hindering the development of more comprehensive solutions. This challenge disproportionately affects lower-income and underserved regions, where the cost of adopting proprietary systems can be prohibitive. In Canada, while access to smart home technologies may be higher than in some global regions, disparities exist, particularly in rural and remote areas with limited infrastructure. As Oetomo et al. [Oetomo et al., 2022] point out, inequitable access to IoT innovations, such as real-time indoor temperature and air quality monitoring, can prevent vulnerable populations from benefiting during extreme weather events. This is a critical issue, including in Canada, as addressing these disparities is essential to ensuring that all communities, especially those at higher risk, are equipped to cope with climate-related challenges [Gray, 2022, WHO, 2022].

The European Union has taken significant steps to address these challenges by pushing manufacturers toward adopting universal standards, such as their efforts to mandate

common charging standards for electronic devices [European Parliament, 2022]. This move is intended to reduce environmental waste and eliminate proprietary market holds, creating a more open and interoperable ecosystem. These efforts set a precedent that other governments and regulatory bodies should follow. Similar policies can help overcome technical barriers, making IoT technologies more accessible and collaborative across sectors. Universal standards simplify the user experience, allow broader data integration, and promote cooperation between manufacturers, researchers, and public health systems, which is critical for maximizing the impact of IoT in addressing climate-related challenges [El-Mawla et al., 2019].

A shift toward open-source solutions and more affordable IoT technologies is essential to further reduce technological barriers, especially in low-income and underserved regions. Open-source platforms foster innovation by enabling developers and communities to build on existing technologies without being restricted by proprietary systems. As demonstrated in He et al. [He et al., 2023], deploying low-cost sensors for air quality monitoring in urban homes allows for the collection of critical data that informs public health responses, even in resource-constrained environments. However, this potential can only be fully realized with governmental and international investment in infrastructure that supports the expansion of IoT networks, such as affordable internet access and reliable renewable sources of electricity, both critical components for enabling widespread use in marginalized communities [Bracher, 2023].

Moreover, policies encouraging IoT adoption must be designed with inclusivity at their core, ensuring that solutions are both accessible and affordable to all. This includes providing subsidies for low-income households, offering incentives for manufacturers to produce affordable IoT devices, and launching initiatives that prioritize deploying IoT technologies in underserved regions. Addressing these persistent challenges through policy interventions, industry collaboration, and infrastructure investment can significantly reduce the barriers to widespread IoT adoption. This would enable the technology to realize its full potential in improving public health, enhancing climate resilience, and promoting sustainability on a global scale. The potential for real-time, evidence-based decision-making—as discussed in studies like those by Pathan et al. [Pathan et al., 2017] and Oetomo et al. [Oetomo et al., 2022] —illustrates the vast opportunities that remain untapped if these challenges can be overcome.

5.4.8 Ethics of IoT technologies

The rapid proliferation of Internet of Things (IoT) technologies brings significant ethical challenges that need to be addressed, particularly concerning global equity, resource extrac-

tion, and the digital divide. As seen in the studies by Oetomo et al. [Oetomo et al., 2022] and Gustin et al. [Gustin et al., 2020], smart home technologies have predominantly been adopted by middle- and higher-income individuals, reflecting a long-standing trend where new technologies tend to benefit wealthier populations while marginalizing lower-income and rural communities. This pattern is especially concerning in the context of climate change, where the populations most vulnerable to its impacts—often in low-income and Indigenous communities—are least likely to benefit from these innovations. The research by Dickson et al. [Dickson et al., 2023] highlights how IoT systems could offer vital data for monitoring heat exposure, yet their adoption in vulnerable regions remains limited, reinforcing existing inequalities. Additionally, data is incredibly valuable within capitalism, and the use of IoT may potentially contribute to surveillance capitalism [Zuboff, 2015].

A decolonial framework provides an important lens for addressing these disparities. The unequal access to IoT technologies is not solely a technological issue but also a continuation of colonial structures that concentrate resources and power in certain regions while excluding others. For instance, in places like Canada, where basic necessities such as clean drinking water and reliable internet remain inconsistent, particularly for Indigenous populations, the introduction of IoT systems could deepen inequities if not designed with inclusivity in mind [Klasing, 2016, Karanicolas, 2012]. It is crucial to ensure that marginalized groups are not left behind in the IoT revolution and that their specific needs and challenges are addressed. A decolonial approach would prioritize the voices of Indigenous and marginalized communities, ensuring that the benefits of IoT are equitably distributed and that these groups are given agency in the development and implementation of new systems [Indigenous Climate Action, 2021].

In addition to access issues, ethical considerations around transparency and data privacy are paramount. As IoT systems become more integrated into everyday life, individuals must understand how these devices function, what data is being collected, and how it is processed and stored. As He et al. [He et al., 2023] notes, while low-cost sensors can track vital environmental factors such as PM2.5 levels, consumers often remain unaware of the full scope of data gathered, including sensitive information related to personal habits and health conditions. IoT companies need transparency and accountability to ensure that data privacy is maintained and users are empowered to control their data [Guhr et al., 2020].

Moreover, the resource extraction required to produce IoT devices raises ethical concerns about the environmental and human impact. The mining of precious metals, such as cobalt and lithium, which are critical in manufacturing electronic components, often occurs in regions with poor labour standards, environmental degradation, and human rights abuses [Rehman et al., 2018, McKinsey Global Institute, 2017, Amnesty International, 2016]. This is particularly concerning given that the demand for

these materials is increasing as IoT technologies become more widespread. The global demand for these metals, driven by the rise of smart home devices, places immense pressure on natural resources, perpetuating a cycle of exploitation that disproportionately affects vulnerable populations in the Global South.

As IoT technologies become more integral to modern life, the ethical implications of this resource extraction must be critically examined. Efforts should be made to develop more sustainable production methods, including using recycled materials and long-lasting, alternative technologies that reduce the need for finite resources [Gerlach, 2019, Tirado Herrero et al., 2018]. Companies must also be held accountable for ensuring that their supply chains are transparent and ethically sourced, with strict regulations to prevent human rights violations and environmental harm, as raised in the context of IoT sensor deployment in He et al. [He et al., 2023].

Finally, the increasing reliance on internet access for IoT technologies further highlights the digital divide and the ethical issue of global inequality in digital infrastructure. In many regions, particularly low-income and rural areas, access to reliable and affordable Internet remains a significant barrier, preventing these communities from benefiting from IoT innovations. The studies by Oetomo et al. [Oetomo et al., 2022] and Pathan et al. [Pathan et al., 2017] emphasize how access to smart home devices and internet infrastructure can improve public health and climate resilience. Yet, many populations are excluded from these benefits. Tasgaonkar et al., [Tasgaonkar et al., 2022] was the only study undertaken in the Global South. This digital divide perpetuates existing inequities, leaving those without access to the necessary infrastructure vulnerable to climate risks [Hart and Martinez, 2015]. Governments and international organizations must prioritize expanding internet access as a fundamental right, ensuring that the benefits of IoT technologies are available to all and not confined to the privileged few as recognized by the United Nations [Karanicolas, 2012, Grey, 2020].

The ethical implications of IoT technologies are wide-ranging and multifaceted, touching on decolonization, global access, resource extraction, and data transparency [van Wynsberghe, 2021, Climate Transparency, 2022]. Addressing these challenges requires a concerted effort to ensure that the benefits of IoT are equitably distributed, that resource extraction is conducted sustainably and ethically, and that individuals are empowered to control their data. Only by addressing these ethical concerns can IoT technologies contribute to a more just, equitable, and sustainable future, as envisioned in the frameworks proposed by Oetomo et al. [Oetomo et al., 2022] and Gustin et al. [Gustin et al., 2020].

5.4.9 Energy demands and sustainability

The expansion of the Internet of Things (IoT) and artificial intelligence (AI) technologies presents a critical tension between their growing energy demands and the global imperative to reduce carbon emissions. This highlights a significant gap, particularly in the way research, practice, and researchers consistently integrate the principles of sustainability and environmental justice throughout their projects. Studies such as Oetomo et al. [Oetomo et al., 2022] and Gustin et al. [Gustin et al., 2020] discuss the vital role of smart home technologies in improving climate resilience and public health, particularly in the management of indoor environments during extreme heat events. However, these technologies also contribute to increased energy consumption, especially as AI-powered devices become more widespread in homes, where they manage essential tasks like heating, cooling, and security. This point was not assessed in any of the studies. Increasing analysis and prediction algorithms for understanding heat risks also demand higher energy consumptions [Boudreault et al., 2023, Luccioni et al., 2024]. While these technologies offer significant benefits in terms of efficiency, convenience, and climate adaptation, the energy required to support these systems cannot be overlooked, raising concerns about their long-term sustainability [van Wynsberghe, 2021, Crawford, 2024, Christoforaki and Beyan, 2022, Ren and Wierman, 2024].

The global energy demand has surged alongside the proliferation of AI-driven devices [International Energy Agency, 2024]. From smart home assistants to complex AI algorithms that power smart grids and environmental monitoring systems, the world's energy consumption has tripled due to the increased computational power required for these technologies. This rise in energy demand raises critical ethical questions about the sustainability of such energy-intensive processes. As Pathan et al. [Pathan et al., 2017] suggest, while air conditioning provides essential cooling, widespread adoption will exacerbate climate change if no other adaptation actions are taken.

Integrating renewables into the power supply for IoT systems and AI-driven platforms is essential to mitigate these concerns. Renewable energy solutions, such as solar, wind, and geothermal energy, offer a promising way to offset the carbon footprint of these technologies. For example, Wei et al. [Wei et al., 2019] demonstrated using solar-powered sensors to monitor outdoor air quality, ensuring these systems operate without further contributing to greenhouse gas emissions. Offshore wind farms also present a viable pathway to supporting the computational power required for AI applications while reducing dependence on fossil fuels [Masoumi, 2023]. In this way, renewable energy supports the energy demands of IoT and AI and aligns with the broader transition to a low-carbon future. Several examples illustrate the successful integration of renewable energy with IoT applications in improving

climate resilience. In regions experiencing frequent extreme heat or poor air quality, solar-powered air quality sensors and weather stations are being deployed to monitor and respond to climate-related risks [Adoghe et al., 2017, Malozyomov et al., 2023]. These IoT devices, powered entirely by renewable energy, align with sustainability goals by reducing operational emissions [Huchuk et al., 2021]. Similarly, smart grids optimized by AI have been utilized to balance energy loads and enhance the efficiency of renewable energy systems, demonstrating how technology and sustainability can co-exist to support climate adaptation efforts [Rehman et al., 2021].

However, technocentrism, the belief that technological solutions alone can solve complex social and environmental issues—must be critically examined [Bailey and Wilson, 2009, Lanzini and Stocchetti, 2021]. As Gustin et al. [Gustin et al., 2020] highlight, unchecked development of IoT and AI technologies without consideration of their environmental impacts risks contributing to the growing greenhouse gas emissions that threaten planetary boundaries. Developers, researchers, and policymakers must collaborate to ensure that the expansion of these technologies aligns with sustainability principles. This requires leveraging renewable energy, developing energy-efficient designs, promoting circular economies for technology components, and reducing the environmental burden of data centres that power IoT and AI networks.

In conclusion, while smart home technologies and AI hold the potential to play a pivotal role in climate resilience, their growing energy demands present a significant challenge to global sustainability goals [Crawford, 2024]. By integrating renewable energy sources and prioritizing energy-efficient designs, IoT and AI technologies can contribute to climate adaptation without undermining the broader goal of reducing carbon emissions. To ensure that these technologies remain part of the solution rather than contributing to the problem, a balance must be struck between their utility and environmental impact [all tech is human, 2024]. This responsible development and deployment will ensure that IoT and AI technologies fulfill their promise of promoting climate resilience and environmental sustainability [Responsible AI Working Group, 2023].

5.4.10 Strengths and limitations

Smart home devices, such as advanced thermostats, offer multifaceted benefits beyond their primary functions. These devices, equipped with sensors capable of monitoring environmental parameters such as temperature, humidity, and air quality play a crucial role in managing indoor environments. Oetomo et al. [Oetomo et al., 2022] highlights the role of these technologies in monitoring indoor temperatures during extreme heat events, providing

critical data to inform interventions. While these technologies do not directly maintain safe indoor temperatures in homes without air conditioning, they enable occupants and caregivers to take timely actions, such as using fans, closing blinds, or seeking cooler spaces, to mitigate heat risks. Additionally, the data collected can guide longer-term strategies, such as retrofitting homes or improving ventilation, to enhance resilience to extreme heat. Meanwhile, He et al. [He et al., 2023] demonstrate their potential for monitoring PM2.5 levels during heat waves, helping individuals make informed decisions about their health and indoor environment. Integrating smart home technologies into daily life goes beyond convenience; it enables proactive health management. For example, continuous air quality monitoring can alert residents to allergens or pollutants, prompting timely interventions to maintain a healthy environment. Studies like Gustin et al. [Gustin et al., 2020] showed that real-time data from smart devices can also inform public health policies by providing insights into environmental factors that affect community health, particularly in response to extreme heat events and indoor air quality issues.

One notable strength of smart home technologies is their accessibility. Many modern homes are already equipped with basic versions of these devices, such as programmable thermostats, which lowers the barrier to entry. This accessibility makes it easier for many households to adopt and benefit from these innovations. Oetomo et al. [Oetomo et al., 2022] emphasize that the widespread adoption of such technologies creates opportunities for evidence-informed decision-making at both the individual and governmental levels. This collective data can be used to promote strategies that safeguard public health and well-being, particularly in the context of climate resilience.

Additionally, the versatility of smart home devices allows for their application across various domains. Beyond environmental monitoring, these devices can improve energy efficiency, enhance security, and contribute to overall quality of life. As seen in the work by Pathan et al. [Pathan et al., 2017], smart home technologies offer multifunctional benefits, reinforcing their value in contemporary living by helping mitigate the risks posed by indoor overheating, which is becoming more frequent due to climate change.

This review has several limitations that must be acknowledged. First, the search was restricted to articles and reports published in English, which may have inadvertently excluded important research from non-English-speaking regions. Many studies and innovations, particularly from emerging markets or low-income countries, may be published in local languages and not readily available in English-language databases. Consequently, key developments in smart home technologies and climate adaptation strategies in these regions may have been overlooked, as suggested by the regional concentration of studies by Oetomo et al. [Oetomo et al., 2022] and Pathan et al. [Pathan et al., 2017].

Furthermore, excluding non-peer-reviewed journal publications may have filtered out early-stage or experimental technologies still in development. Innovations in IoT and smart home technology often first appear in conference proceedings or industry reports, which are not subjected to peer review. By focusing solely on peer-reviewed literature, this review may have missed cutting-edge developments that have not yet matured enough to reach journal publication, particularly in the rapidly evolving field of IoT.

The focus on studies predominantly conducted in high—or upper-middle-income countries also introduces a potential bias. Many of the articles included in this review are based on research conducted in regions with advanced infrastructure and higher access to smart home technologies, as seen in the work by Dickson et al. [Dickson et al., 2023]. This focus limits the generalizability of the findings to global contexts, especially in regions where energy poverty, limited internet access, and insufficient technological infrastructure may hinder the adoption and effectiveness of smart home technologies.

This geographic bias also raises concerns about equity in technology deployment. Vulnerable populations in low-resource settings, who are more likely to face severe impacts from climate change, may have less access to smart home technologies that could help mitigate health risks. Consequently, the findings of this review may not fully capture the unique challenges these populations face. Future research should aim to include a broader range of geographic regions and socioeconomic contexts to provide a more comprehensive understanding of how smart home technologies can contribute to climate resilience and public health on a global scale.

Finally, the scope of this review was limited to specific types of studies, which may have excluded interdisciplinary or cross-sectoral approaches that integrate smart home technology with other areas of public health or environmental science. This narrow focus may have prevented a fuller exploration of how smart home technologies interact with broader climate adaptation strategies, potentially missing opportunities for more holistic, system-wide solutions that address climate change's multifaceted impacts on health and the environment.

5.4.11 Recommendations

The policy recommendations from these papers emphasize the importance of actively monitoring indoor temperatures in healthcare facilities and homes, particularly during extreme heat events. They advocate for adopting passive cooling measures, such as building design improvements, before resorting to active cooling like air conditioning [Gustin et al., 2020]. To reduce heat-related health risks, it is recommended that indoor

temperature data from smart thermostats be integrated into local heat health action plans [Oetomo et al., 2022]. Additionally, the papers highlight the need to include climate adaptation strategies in building regulations, designing resilient buildings, and evaluating summertime indoor overheating [Gustin et al., 2020, Pathan et al., 2017, Szagri et al., 2022]. The potential of IoT-based devices for real-time monitoring and time series forecasting is underscored, enabling timely interventions to protect vulnerable populations from heat exposure [Dickson et al., 2023, Yun et al., 2020].

5.5 Conclusion

This study demonstrates that while smart home technologies are promising tools for climate resilience, their potential remains underutilized in public health strategies. The reliance on low-cost sensors provides an accessible entry point, yet challenges persist in data standardization, equity of access, and interoperability. Moving forward, targeted investments in infrastructure and policy adjustments are essential to ensure these technologies benefit all populations, particularly those most vulnerable to climate risks.

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Chapter 6

Perceptions of extreme heat in Canada: A study of social media discourse and survey insights

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6.1 Introduction

Misinformation and disinformation represent significant challenges in the modern information ecosystem [Eysenbach, 2009, Jin et al., 2024]. Misinformation refers to the unintentional spread of false information, while disinformation involves deliberately disseminating falsehoods to mislead [WHO and UNICEF, 2023]. Rapid proliferation of the Internet and the design of social media networks, which encourage quick sharing and reaction, exacerbate the spread of both types of false information [Bolsover and Tokitsu Tizon, 2020]. This shift has increased the volume of noise on the Internet and changed the landscape of information dissemination, particularly with the advent of Artificial Intelligence (AI) [Raman et al., 2024, Kolo et al., 2022]. People increasingly rely on chatbots for information, bypassing traditional search engines and opting to use large social media platforms such as

Facebook [Lee et al., 2023b]. The development of chatbots, often with minimal regulation and oversight, underscores the growing need for public inoculation against misinformation [Morita et al., 2024]. This involves educating the public, flagging false information, and marking reliable sources. For example, YouTube's initiative to label doctors as credible sources of health information is a step in the right direction [Nassetta and Gross, 2020].

The spread of misinformation and disinformation poses serious threats to public health efforts. The World Health Organization (WHO) has increased efforts to train public health professionals to monitor and combat these threats, as they undermine crucial public health initiatives such as vaccination programmes [WHO, 2023a]. For example, the reemergence of measles in previously eradicated areas is correlated with the decline in vaccination rates fuelled by misinformation [Loomba et al., 2021]. Similarly, disinformation campaigns questioning the validity of climate science or public health measures can erode support for Heat Alert and Response Systems (HARS) and other heat mitigation efforts. Addressing these issues is critical to ensure clear, accurate, and effective communication that protects the public during extreme heat events.

The way people consume information has changed dramatically, with a decline in traditional media (e.g. TV, radio, newspapers) as the most trusted sources and a move towards mobile devices and social media applications [Twenge et al., 2019, Fotopoulos, 2023]. During the COVID-19 pandemic, social media platforms such as Facebook and Twitter played a crucial role in the dissemination of information in a rapidly evolving crisis [Bolsover and Tokitsu Tizon, 2020, Tsao et al., 2021]. However, these platforms were also used by bad actors, such as the "Dirty Dozen," to spread misinformation and promote unproven "treatments" [CCDH, 2021]. Research on social media analysis of public health topics, such as water fluoridation and vaccine hesitancy, has enabled rapid evaluations and informed the development of targeted communication strategies [Lotto et al., 2023, DeVerna et al., 2021, Allen et al., 2024].

Social media networks are increasingly used to communicate forecasts, health advice, and information on public health interventions during heat waves [Zottarelli et al., 2022]. However, climate denial and misinformation can downplay the dangers of extreme heat and the severity of the climate crisis, leading to poorer health outcomes [Russill, 2023]. The reliance on social media for communication during heat waves highlights the need for social inoculation against misinformation [Jung and Uejio, 2017]. Using a systems approach could save lives by ensuring that accurate information reaches the public [Lee et al., 2024]. However, the decline in trust in public institutions globally, such as the CDC, presents a significant challenge, particularly during elections, when voters' choices can impact climate resilience policies and funding for climate mitigation and adaptation [Pollard and Davis, 2022, Herati et al., 2023, Kitt et al., 2021, Siegrist and Bearth, 2021].

The lessons learnt from the COVID-19 pandemic can be applied to other public health challenges, such as climate change and acute extreme weather events such as heat waves. Public health progress has contributed to longer life expectancy, including lower rates of child and maternal mortality and the elimination of many diseases through immunisations and education [Lindsay et al., 2014, Buxbaum et al., 2020]. During the COVID-19 pandemic, it has also suffered setbacks due to attacks from science deniers, governments, and instances of poor communication [Fraser et al., 2021, Björnberg et al., 2017, Capurro et al., 2021, Jylhä et al., 2023]. Reliant on high levels of trust for its success, experts have raised concerns about decreasing levels of public trust and the loss of progress in health and well-being [Mainous et al., 2024, Kruk et al., 2018]. This has been largely facilitated by the Internet and social media platforms, where individuals can accumulate large followers and profit from spreading false information for personal gain [Paddison, 2024, Center for Countering Digital Hate, 2023, van Zoonen et al., 2024].

6.2 Background

The advent of the Internet has brought knowledge to billions of people around the world. However, it has also enabled the nefarious creation and the spread of misinformation and disinformation. In 2020, WHO declared that we were in an infodemic and that this would seriously undermine public health efforts and progress made to date [World Health Organization, 2021]. During the past two centuries, public health progress has contributed to longer life expectancies in some parts of the world through hygiene practices such as food safety, water sanitation, and preventive actions such as cancer screenings [Wit et al., 2024, Shih et al., 2022]. The development of vaccination and screening programmes has reduced the rates of child and maternal mortality and helped to eliminate many diseases through vaccination campaigns and education [Shattock et al., 2024].

Reliant on high levels of trust for public health success, experts have raised concerns about decreasing public trust and the loss of progress in health and well-being. Emerging technologies have changed how society communicates, including the speed at which information can be disseminated. This has led to the development of the field known as infodemiology, which provides decision makers and people with tools to tackle misinformation and disinformation on social media networks [Calleja et al., 2021]. The research of Statistics Canada found that 44% of Canadians obtain news from social media accounts that were not official government, scientific, or new organizations [Statistics Canada, 2024b]. 43% of the respondents reported finding it increasingly difficult to distinguish between true and false information online, underscoring a growing challenge in navigating digital

content[Statistics Canada, 2024b].

Twitter (officially known as X at the time of writing), one of the largest social media networks, had more than 368 million monthly users in December 2022 [Statista, 2022], and Canada had almost 8 million users in 2022 [Statista, 2024b]. Online discourse moves quickly and researchers found in 2018 that false news spreads faster than true information on Twitter, fuelled by its novelty and the emotionally charged nature of content [Vosoughi et al., 2018]. The COVID-19 pandemic highlighted how rapidly evolving information can be beneficial and confusing as rules, mandates, and advice on the use of personal protective equipment (PPE) (i.e., masks) changed to meet changing supply demands and evolving scientific discoveries [Capurro et al., 2021].

Monitoring the virtual world is challenging due to its vastness and the attention economy driven by algorithms that create echo chambers, exploiting confirmation bias, shock-and-awe tactics, and the Dunning–Kruger effect [Dunning, 2011, Mahmood, 2016]. In addition, bots contribute to the noise on social media platforms, causing confusion and influencing public sentiment for political gain [Lee et al., 2023b]. As the world faces an increasingly hot climate, where extreme weather events become daily events, the ability of governments to quickly analyse data to understand a situation, from the causes of a situation to discourses on social media networks, to guide timely responses and interventions has become critical [Jung and Uejio, 2017, Philip et al., 2021]. The spread of information can simultaneously alter risk perception and prevent or cause harm, especially during prolonged periods of extreme heat [Madrigano et al., 2018, Varghese et al., 2020, Tetzlaff et al., 2023b]. Misinformation could lead people to engage in activities that negatively impact their health, and bad actors could cause distrust, leading the public to ignore and ignore official warnings or advice. It can also delay the transition to clean and renewable energy and the adoption of technologies such as heat pumps or electric vehicles [CCDH, 2024, Lamb et al., 2020]. Individuals may ignore warnings about the dangers of extreme heat and do not seek medical care if they believe the danger is low. For example, during the 2021 Heat Dome in British Columbia, social media posts downplayed the impact of climate change on extreme heat events [AFP, 2024].

Thus, it is essential to be aware of the themes and narratives in the discourse to address or correct them swiftly. The WHO provides guidance on these techniques through toolkits, training modules, and additional resources available on their website, specifically designed for infodemiology managers [Zarocostas, 2020, Purnat et al., 2023]. The field of infodemiology has been applied to combat the increase in vaccine misinformation after COVID-19 by identifying health beliefs associated with antivaccine and antiscience movements. However, these tools can also be applied to acute public health events or larger public health disinformation campaigns, such as water fluoridation, the mental health and climate crisis,

or public perception of lockdowns [Lotto et al., 2023, Crank, 2024, Tsao et al., 2022].

To understand themes from social media data, researchers have used machine learning techniques such as VADER (Valence Aware Dictionary for sEntiment Reasoning) or the RoBERTa (Robustly Optimized BERT Approach) models to explore sentiments in tweets [Hutto and Gilbert, 2014]. VADER, a rule-based, lexico-based model, requires no pretraining, runs quickly, and requires less computational power, as it was designed for the analysis of social media platforms and handling informal language, emoticons, and platform-specific patterns such as capitalisation and exclamations [Elbagir and Yang, 2019]. This contrasts with RoBERTa, which uses deep learning, as it is a transformer-based, pre-trained model that is more adaptable to capturing context and nuances in language. Thus, it is better at detecting more complex texts and nuance, which is also important in tweets that often contain ambiguous language, such as sarcasm and irony [Tan et al., 2022].

As the number of days of extreme heat increases, awareness of extreme heat also increases [Kovats and Kristie, 2006, Mayrhuber et al., 2018]. Research and expert consensus on the media portrayal of heat waves through images found they were incompatible and contradictory to public health advice [Tetzlaff et al., 2024, Harrisson, 2019]. Cecinati et al. leveraged tweets to complement climatic data [Cecinati et al., 2019], while Jung and Uejio [Jung and Uejio, 2017] studied the link between heat exposure and the number of related tweets over time, and Grasso et al. found that tweets increased during extreme heat and could be a local level indicator in urban settings [Grasso et al., 2017]. Tetzlaff et al. also examined the media coverage of the 2021 Heat Dome, finding that only 23% of the media articles included heat-health messaging aligned with government memos [Tetzlaff et al., 2023b]. These highlight just some of the gaps that must be addressed to protect health and safety as they relate to extreme heat events.

Google search trends in Canada reveal increased searches for the term "heat wave" since tracking began in 2004, reflecting the growing frequency of extreme heat events.

The largest increase has occurred in the last five years, corresponding to heat waves in Quebec and British Columbia and the release of the Death Panel Report on the (BC) Heat Dome in 2022 [BCCS Death Panel, 2022]. This increasing trend is positive and requires investigation to understand what is being discussed online.

As heat waves increase in frequency worldwide, public awareness of the dangers of extreme heat is also increasing [ENBL, 2023, Anderson, 2024]. Educating and early warning systems play an important role, and similar lessons from the COVID-19 pandemic can be learnt and applied here, especially in public trust. If the public does not trust the warnings or advice issued, this could result in mass injuries or casualties. CCDH experts found that YouTube misinformation about climate changed from outright denial to a delay

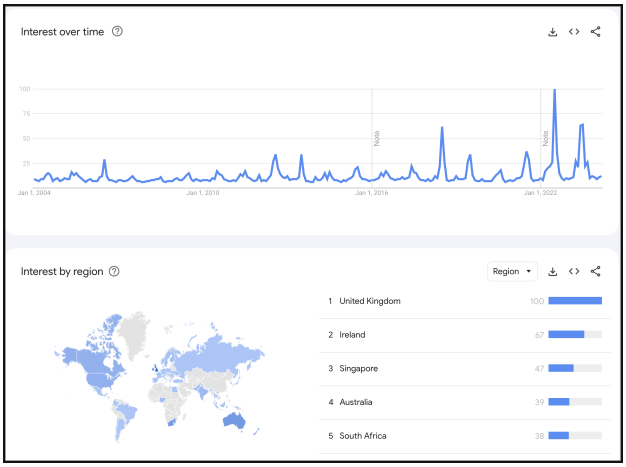


Figure 6.1: Heat wave search term popularity from 2004 to 2024. Numbers represent search interest relative to the highest point on the chart for the given region and time. A value of 100 is the peak popularity for the term. A value of 50 means that the term is half as popular. A score of 0 means there was not enough data for this term. Source: Google Trends

strategy [Center for Countering Digital Hate, 2023]. As companies like Google, X (formerly Twitter), and YouTube profit from the spread of misinformation, public health professionals must effectively identify and counter false narratives that could undermine public health efforts[Bolsover and Tokitsu Tizon, 2020, Lofft, 2020].

6.2.1 Motivation

By surveying Canadians, the study seeks to understand their experiences and perceptions of extreme heat and their preferred methods of receiving communications about such events. This understanding will support public health efforts to mitigate the impact of extreme heat and improve communication strategies. This research addresses a critical gap in the literature by focussing on the Canadian context and the intersection of social media networks, public health communication, and climate change. The findings are expected to inform the development of more effective communication strategies, ultimately contributing to better public health outcomes and greater resilience to climate change. In addition, the study will consider the implications of using social media and AI for public health communication, discussing issues such as access, representation, and sustainability.

6.2.2 Objectives

By surveying Canadians and analysing Twitter discourse, the study seeks to:

- Understand Canadians' perceptions of extreme heat as a threat and their preferred methods of receiving communications about such events.
- Analyse Twitter discourse through a Canadian lens to identify prominent themes or topics related to extreme heat.

This understanding will support public health communication efforts. The findings are expected to inform the development of more effective communication strategies, ultimately contributing to better public health outcomes and greater resilience to climate change.

6.2.3 Research questions

To fulfil the objectives, the study will address the following research questions:

1. What are the perceptions of Canadians of extreme heat?
2. What are the preferred methods by which Canadians receive communications about extreme heat events?
3. What keywords are used in the Twitter discourse on extreme heat events/ heat waves?
4. What are the main themes and topics most discussed with respect to extreme heat events?

By answering these questions, the study aims to extract insights from public discourse to inform regional health authorities and public health practitioners in crafting effective messaging before, during and after heat waves to protect the health of the population.

6.3 Methods

6.3.1 Google Survey

The Google Surveys platform collected the survey from August 10-18, 2022. The platform was retired on November 1, 2022. Only ten questions could be asked and one question was allocated to collect income data. The ten questions were developed, revised and uploaded to the Google Surveys platform. Although questions could not be skipped within the platform interface, an open text field was given for the 'Other' option or 'Prefer not to answer' option when possible. The list of questions can be found in Appendix E. Participants' ages were already precollected by Google, and geolocation was predetermined for representative sampling of the desired local area; for this survey, we requested that survey participants be located in Canada. For this study, 200 completed surveys were requested and 201 were received, with over 400 incomplete surveys. Each participant received CAD $2 for their time. Ethics approval was obtained from the Research Ethics Office of the University of Waterloo (ORE # 43777).

6.3.2 Twitter data

Data collection and subsequent computer-aided analysis of the data were implemented using the internal infodemic data ecosystem and pipeline of the Ubiquitous Health Technology Lab (University of Waterloo) or the Misinformation Analysis System (MAS) [Morita et al., 2023a, Zakir Hussain et al., 2023]. U-MAS is a novel and in use pipeline and data ecosystem that uses the previously available 'academic researcher' level of access to the Twitter V2 API to collect real-time and filtered data. It then preprocesses the data and applies pre-developed natural language processing models like Latent Dirichlet Allocation (Latent Dirichlet Allocation (LDA)) topic modelling. The front end of U-MAS is a comprehensive but intuitive dashboard that displays insightful, pre-developed visualisations and metrics.

The research team identified a list of keywords to extract geotagged tweets from Canada related to extreme heat events or heat waves. Experts from Health Canada were consulted and additional words and phrases were included after two review rounds (see the Appendix E). This search strategy returned approximately 1,500 tweets; however, multiple reviews were required to filter out non-English tweets (although French hashtags were included) and tweets that did not match the topic of interest. As Twitter data are considered public domain, no ethics approval from a research review board was required. Five hundred tweets published in English from 2013 to 2022 were extracted from Twitter's API, following the data extraction framework described by Lotto et al. [Lotto et al., 2022].

Preprocessing

To prepare the data set for the LDA topic modelling, the U-MAS system performed various preprocessing techniques [Morita et al., 2023a]. First, a performance metric that equally weighs each public interaction was calculated for each tweet. Then, the dataset was combed for duplicate tweets; often, due to automated bot accounts on Twitter, seemingly different users authored tweets with the same text. In such a case, the tweet with the highest performance associated with it was retained while its duplicates were removed. The text of each tweet was then standardised to be universally lowercase and then tokenised into individual words using the Spacy Python package. Further preprocessing of these tokens was also performed, including removing tokens that were articles, conjunctions, prepositions, verbs, non-English characters, digits, punctuation marks, symbols, and special characters, as they are irrelevant to the analysis done by IZH and AO. Finally, the specified tokens within the search strategy were removed to aid in the analysis.

The term 'heat' is widely used in sports, such as the name of a basketball team in Florida called the Miami Heat or a hockey team called the Stockton Heat. Many expressions use the word "heat", for example, to describe situations, TV characters, politicians or athletes, and sports teams, i.e., "throwing heat", "heat is on", "taking heat", "feeling the heat", etc. It is a common word in music, used as the name of albums and song titles (Heat Wave by Glass Animals and Heatwave by Martha and the Vandellas), bands (H.E.A.T. and Heat), and lyrics such as the 1933 song "Heat Wave" by Irving Berlin and Ethel Waters. It is also found in the titles of books and films, such as the 1995 film 'Heat.' Even spicy foods, such as potato chips or sauces, are often marketed with the word 'heat'. Furthermore, heat also applies when discussing desired heat in the home and other technologies such as heat pumps or heat pump water heaters, heating bills, heating and cooling systems, etc., further adding to the noisy results. Radio stations tweet their recently played song lists, and bots or specific users generate many tweets. Thus, a careful manual review of terms and resulting tweets was necessary to arrive at a data set suitable for analysis.

Thematic analysis

With the 500 tweets geotagged to Canada, AO manually assessed a random sample of 100 tweets to determine their types and manually categorized them based on the main message. The analysis of tweets related to heat waves in Canada employed an inductive approach, allowing themes to emerge directly from the data without the constraints of predefined categories. An open coding process was performed, in which individual tweets were read line by line and descriptive labels were assigned to capture their content and

intent. Initially, a codebook was not used, as the inductive approach sought to allow themes to arise organically from the data. However, as the analysis progressed, an informal codebook was developed to define emerging themes and ensure consistent application of the codes. The decision on whether a tweet met the criteria for a theme was based on the researcher's interpretation of its content in alignment with these emerging definitions. For example, tweets were classified as "Mentions" if they acknowledged the presence of a heat wave without elaboration or as "Statements" if they expressed personal experiences or reactions to heat. The iterative refinement of these criteria ensured that the tweets were consistently coded.

This process resulted in the iterative development of five themes: *Mentions* refer to tweets that acknowledge the area experiencing the heat wave but do not directly discuss the weather (e.g., "I'm in town during the heatwave"). Second, *Statements* capture individuals' experiences or reactions to heat, such as comments on high temperatures or how they cope (e.g., eating ice cream). Third, *Strategies* highlights tweets where users mention specific actions to stay cool, such as visiting pools or staying indoors. Fourth, *Advice* includes tweets that share guidance from public health authorities or healthcare professionals, such as reminders to drink water or wear sunscreen. Finally, *Warnings/predictions* consist of posts that warn about upcoming heat waves or relay weather forecasts to alert people to prepare for extreme temperatures. These categories help to understand how people engage with heat waves on social media.

The analysis was carried out by a single researcher to maintain methodological uniformity and coherence in the interpretation and application of codes, especially given the manageable size of the data set. Although parallel coding might have enhanced inter-coder reliability, working alone allowed for a consistent analytical perspective crucial for exploratory research. If discrepancies or ambiguities arose during the coding, the researcher revisited the broader dataset and the definitions of the theme to refine or adapt the criteria, ensuring clarity and consistency in categorisation.

Topic modelling

LDA topic models are probabilistic generative natural language processing models that enable the unsupervised discovery of latent thematic structures within a collection or corpus of text documents [Asmussen and Møller, 2019]. LDA is grounded in the premise that each document in a corpus can be conceptualised as a mixture of latent topics, where a topic is defined as a probability distribution over words [Xue et al., 2020]. The primary objective of LDA is to estimate the latent topic structure within the corpus by iteratively refining its parameters based on observed word co-occurrence patterns. The LDA algorithm starts

by randomly assigning words to topics for all documents. It then iteratively refines these allocations through a Bayesian inference process to discover the latent topics and their associated word distributions. The algorithm repeats this process until it converges to a stable solution.

The U-MAS' predeveloped LDA modelling framework was applied [Morita et al., 2023a]. First, the best range of K topics was determined by computing the coherence values of the LDA models ranging from K=2 to K=50. The best range was determined to be K=2 to K=12. A higher coherence value can indicate a better quality topic model, allowing for easier interpretation of the results. An independent investigator validated the models that had the highest coherence scores. To do this, the investigator evaluated the relevance of the generated topics, assessed how semantically similar tweets were within the same topics, and measured the degree of semantic distinction between tweets belonging to different topics. An intertopic distance map was constructed to vizualize the similarity of the topics, representing the topics as two-dimensional bubbles whose sizes correspond to the number of tweets associated with each topic. The mapping of topics to the two axes of the intertopic distance map was achieved through principal component analysis, reducing the multidimensional vectors to the coordinates [x, y]. The spatial separation between the topic bubbles on the map indicated the level of similarity among the tweets within those topics.

Subsequently, the tweets were categorized using the validated topic model. An independent investigator manually analysed a subset of tweets from each topic to identify the specific theme(s) within each topic. Finally, visualisations portraying key analyses, such as the total number of tweets within each topic in the data set and the temporal relevance of the topics, were generated and presented using the dashboard capabilities of U-MAS's Elastic Cloud deployment.

Sentiment analysis

Sentiment analysis was performed in Google Colab using Python's Natural Language Processing (Natural Language Processing (NLP)) with the Natural Language Tool Kit (NLTK) with VADER and Huggingface RoBERTa Transformers. The HuggingFace SensitivityIntensityAnalyzer and Cardiffnlp / Twitter-Roberta-base-sentiment models were used [Loureiro et al., 2022, Lou et al., 2024]. VADER (Valence Aware Dictionary and sEntiment Reasoner) employs a bag-of-words approach [Hutto and Gilbert, 2014] and was also used by Young et al. [Young et al., 2021]. Using the NLTK 'Sentiment Intensity Analyser', a negative, neutral, and positive score is assigned to the text. The stop words (e.g., 'and' and 'the') are eliminated, and all the words are scored and combined for a final score. RoBERTa

is a pre-trained transformer model trained on a large corpus of Twitter data. This model also accounts for the words and the context related to other words.

6.4 Results

6.4.1 Google survey

201 complete surveys were collected, Table 6.1 and the demographic characteristics can be seen here.

Characteristics		n	%
Gender	Female	71	35
	Male	99	50
	Unknown	31	15
Age	18-24	24	12
	25-34	27	13
	35-44	42	21
	45-54	23	11
	55-64	29	14
	65+	25	12
	Unknown	31	15
Geography	New Brunswick	5	2
	Newfoundland and Labrador	5	2
	Nova Scotia	10	5
	British Columbia	43	21
	Ontario	72	36
	Alberta	18	9
	Manitoba	4	2
	Saskatchewan	8	4
	Quebec	36	18
Income	Less than $20,000	20	10
	$20,000 - $39,999	14	7
	$40,000 - $59,999	23	11
	$60,000 - $79,999	21	10
	$80,000 - $99,999	10	5
	$100,000+	28	14
	Prefer not to answer	85	42

Table 6.1: Google Survey sample characteristics (n=201)

The survey responses are in Table 6.1.

Question	n (%)
Have you heard about a heat wave (extreme heat event) happening in Canada in the last 5 years (between 2016 and 2021)?	
Yes	145 (72)
No	41 (20)
I'm not sure	15 (7)
Have you experienced a heat wave in the last 5 years (between 2016 and 2021)?	
Yes	151 (75)
No	25 (12)
I'm not sure	25 (12)
How did you hear about the heat wave?	
TV (Weather channel, news broadcast)	90 (45)
Radio (AM/FM)	38 (19)
Newspaper (printed)	19 (9)
Online (mobile app, weather website, etc.)	107 (53)
Social media (Twitter, Facebook, etc.)	40 (20)
I did not hear about the heat wave	21 (10)
Is hearing about heat waves important to you or your dependents? Scale from 1 to 7 (1 being not at all important to very important at 7)	
1 (not at all important)	27 (13)
2	8 (4)
3	11 (5)
4	43 (21)
5	34 (17)
6	35 (17)
7 (very important)	43 (21)
How would you like information about heat waves to be shared with you? Please select up to 3 choices	
TV (Weather channel, news broadcast)	97 (24)
Radio (AM or FM)	69 (17)
Newspaper (printed or online)	23 (6)
Online (mobile app, weather website, etc.)	138 (34)
Alert Ready (like the Amber Alerts)	34 (8)
Other (please specify)	-
Is Canada prepared for a future of more frequent, intense, and longer heat waves? Scale from 1 to 7 (1 being not at all prepared to very prepared at 7).	
1 (not at all prepared)	17 (8)
2	13 (6)
3	26 (13)
4	70 (35)
5	32 (16)
6	22 (11)
7 (very prepared)	21 (10)

Table 6.2: Responses to questions related to heat waves in Canada.

Figures 6.2a and 6.2b illustrate the most common words in the free text answers to Question 8, "Why do heat waves pose a risk?" from the Google Survey and the resulting word cloud of the 500 tweets.



(a) From Google Survey

(b) From Tweets

Figure 6.2: Word clouds from the Google Survey Question 8 - "Why do you think heat waves pose a risk to your health?" on the left and word cloud from 500 tweets on the right.

6.4.2 Twitter data

The 500 tweets spanned 2013 - 2022, with the majority from the last two years likely due to the 2021 Pacific Heat Dome and subsequent fallout, including news and reports in the aftermath; see Figure 6.3. This follows a similar pattern to the Google Trends graph shown above.

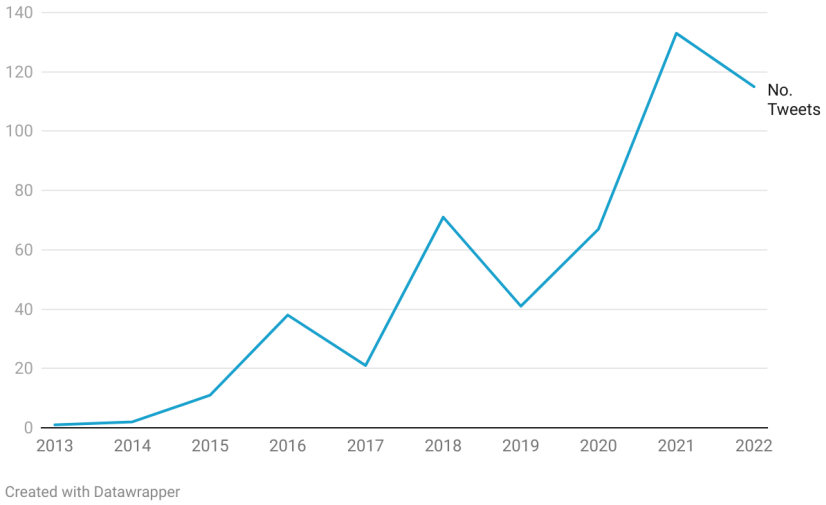


Figure 6.3: Number of relevant tweets by year

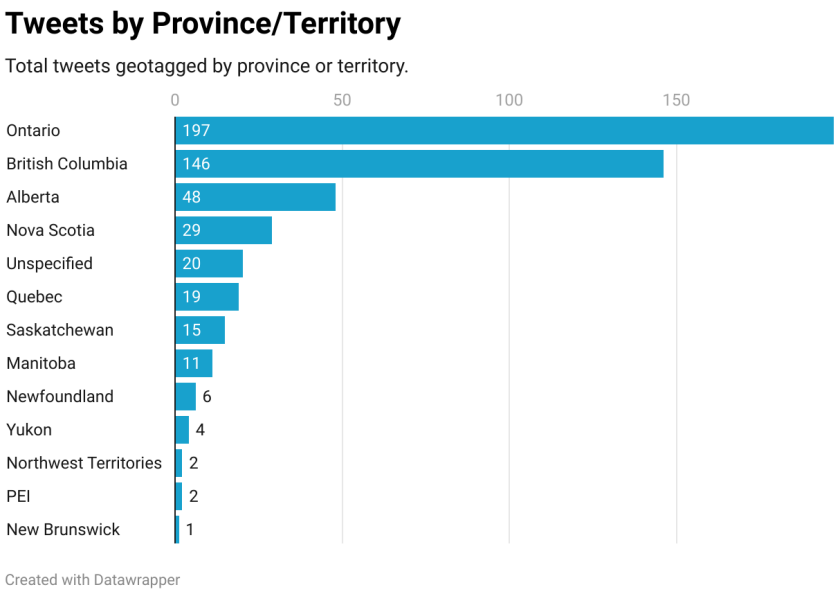


Figure 6.4: Tweets by province or territory

A manual review of the 500 tweets was conducted to classify them according to their purpose. AO reviewed all tweets and grouped them into five categories.

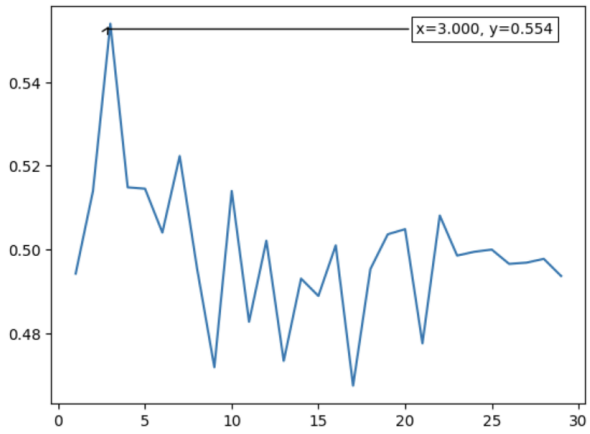


Figure 6.5: The coherence scores for distinct topics with the extracted tweets.



Figure 6.6: The Intertopic distance map generated using multidimensional scaling (MDS). The map visualizes the relationships between topics based on their similarity, with closer proximity indicating greater overlap in content. The three blue areas represent specific topic categories, grouping closely related topics. Principal components (PC) are used to position topics in a two-dimensional space for interpretability.

The Intertopic Distance Map reveals the semantic distance between the three main topics identified through topic modelling.

Topic	Most frequent words	Themes	Examples
1	Cool, week, good, beach, new, monday, place, night, friend, pet, dog, way, fan, beautiful, bad	Statement about conditions	We sure live in a beautiful place. With yet another heatwave upon us, we can feel lucky that Vancouver has so many beautiful beaches where we can cool off!
2	Day, today, summer, time, deg C, pool, major, record, little, degree, good, 10, pet, water, friend	Mention of weather conditions	10 weather stories that made 2021 a year like no other #bcstorm #records 2021 was year of EF-2 tornado, deadly BC heat dome, wildfire records ... #heatdome #heatwave #bcwildfires #bcfloods #BCTornado ...
3	Water, people, right, ice, climate, year, cold, weekend, temperature, pnw, fan, bad, summer, record, great	Strategy shared to stay safe	You know what ... cool? These places they ... cool. Literally. Go cool off in one of these places, #Saskatoon. #HeatWave #YXE #Saskatooning ...

Table 6.3: Stratification of heat wave-related salient topics by most frequent words, themes, and examples.

The pair plot matrix, Figure 6.7, provides a comparative visualisation of sentiment scores from two models, VADER and RoBERTa, applied to tweets about heat and extreme heat events from 2013 to 2022. Social media sentiment analysis shows an even distribution of negative, neutral and positive sentiments, indicating a balanced mix of alarm, resilience, and acceptance among the population. Negative sentiments likely reflect concerns about health risks and the broader implications of climate change. In contrast, neutral and positive sentiments can highlight discussions about adaptation strategies, public awareness campaigns, and proactive measures to address extreme heat. This balance suggests that, while there is apprehension, there is also recognition of the need for action and adaptation.

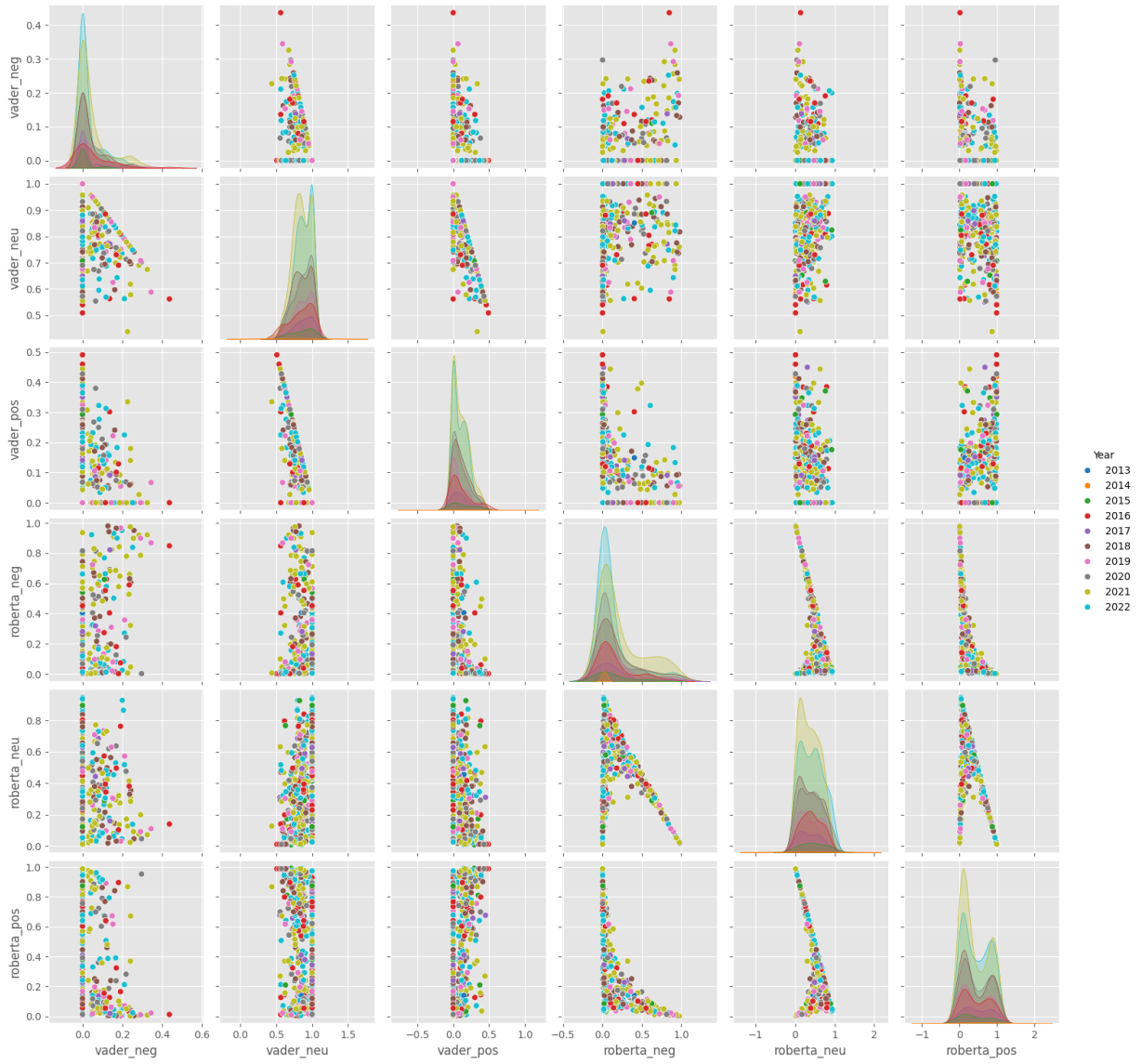


Figure 6.7: Pair plot matrix visualizing the relationships between sentiment analysis scores derived from two models: VADER and RoBERTa. Each plot shows how the sentiment scores correlate across the dataset, with data points colour-coded by year (2013 to 2022) for temporal analysis. The diagonal plots represent the distribution of individual sentiment scores, while the off-diagonal plots illustrate pairwise relationships between different sentiment metrics across time.

6.5 Discussion

6.5.1 Survey insights

The analysis of weather information access in Canada highlights several key trends and insights. Most (68%) of Canadians access weather information at least once a day, indicating a high level of involvement and reliance on weather updates for planning and daily activities. Online platforms are the most popular method, used by 58.49% of respondents. This preference spans all age and income groups, although younger individuals and higher-income brackets show the highest usage rates. Traditional media, such as TV (19%) and radio (10%), remain important, particularly among older age groups. For example, 36% of people aged 65+ rely on television for weather information.

Younger age groups (18-24) have a notable segment (16%) that does not access weather information, which may indicate differing interests or needs for weather updates compared to older demographics. Income levels influence the method of access, with higher-income groups ($80,000 - $99,999) favouring online sources significantly (69%), while lower income groups (less than $20,000) also prefer online access but at a lower rate (44%). Regional differences in frequency and access methods were observed, and the CA-PRAIRIES region showed a higher tendency for frequent access. This may be due to more variable weather conditions that require frequent updates.

The perceived preparedness for heat waves is moderate, with an average rating of 4.18 out of 7. This indicates a general acknowledgement of preparedness efforts and highlights room for improvement. Awareness of heat waves varies by region, with areas like Alberta (CA-PRAIRIES) showing high awareness (70%), while Newfoundland and Labrador (CA-ATLANTIC) have higher unawareness rates (20%).

The survey's finding of moderate perceived preparedness for heat waves aligns with results from other Canadian studies assessing public readiness for climate-related events. For example, a 2023 Leger survey reported that 76% of Canadians felt somewhat prepared to handle future heat waves, while a 2022 Health Canada study found that 72% of Canadians viewed climate change as at least a moderate health risk, with 32% considering it a major risk. Similarly, the longitudinal study of the Program for Applied Research on Climate Action in Canada (PARCA) revealed that only half of Canadians strongly agreed that climate change posed an urgent threat requiring immediate action [Leger, 2023a, Health Canada, 2022, Impact Canada, 2022]. These findings suggest that while Canadians recognise the risks associated with heat waves and climate change, there is still significant room for improvement in public preparedness.

These insights underscore the importance of using multiple communication channels effectively to distribute weather information and preparedness measures. Tailoring communication strategies to regional preferences and demographic differences can improve public awareness and safety during extreme weather events. The role of education about extreme heat and the media's role in educating the public and accurately portraying the dangers of extreme heat was highlighted by responses that indicated a lack of understanding or denial of potential risks to the individual and others within society. One participant wrote in response to Question 1 about experiencing an extreme heat event, *"No, but the government says it was extreme... fearmongering.*"

When asked if heat waves posed a risk, approximately 25% of the responses ranged from direct denial to uncertainty, "*They literally don't."* and *"NO."* and *"It does not as it isn't that hot in Nova Scotia ever."* to "*I have no idea."* and "*maybe.*" This aligns with findings from experts at the CCDH, that YouTube misinformation on climate shifted from outright denial to a strategy of delay [Center for Countering Digital Hate, 2023]. As companies such as Google, X (formerly Twitter), and YouTube profit from misinformation, public health practitioners must know which false narratives to debunk and address that may impede or hinder public health efforts [Kotch, 2022]. In addition, geography and experience of extreme heat events also played a role.

However, the remaining answers indicated that Canadians are aware of higher-risk populations, "More for elderly and pets," and belong to an at-risk group, "Because I am elderly, and I sometimes find *it hard to breathe deeply."* They also connected to larger societal impacts like *"Air quality."* and *"Can affect food chains."* and symptoms and heat-related illnesses, including *"Heat stroke."* and *"death."* This aligns with research suggesting that older adults or those with health conditions (such as heart disease) may be protected due to having received advice from a medical professional about extreme heat [Henderson et al., 2022]. This aligns with the research by Re.Climate, where the survey respondents overwhelmingly agreed that climate change was real and occurring throughout society [Hatch et al., 2024]. This analysis suggests that income levels and preferences for receiving heat wave information need to be carefully considered. Although online platforms dominate, the importance of traditional media and other channels varies significantly by income, highlighting the need for a multifaceted approach to ensure effective communication of heat wave warnings and information to all segments of society [Gruzd et al., 2018].

The sample was representative of the Canadian population and captured a balanced distribution between age groups and regions. However, it is important to acknowledge that Canada's vast geography significantly influences extreme heat experiences. The survey results indicate a high level of awareness and personal experience with heat waves in Canada, with 72% of the respondents having heard about them in the past five years

and 75% having experienced them. The most common sources of information are online platforms (53%) and television (45%), highlighting the importance of digital and broadcast media in disseminating information about extreme weather events. While 34% prefer to receive information online, 24% prefers television and 17% prefers radio. Only 13% of the respondents rated the importance of hearing about heat waves as "not at all important," suggesting that most people find it relevant. Opinions on Canada's preparedness for future heat waves are mixed, with the majority rating it neutral (35%) and only 10% saying the country is very prepared. These insights underscore the need for improved public communication and preparedness measures to address extreme heat events.

Most of the participants checked weather information daily, with 37% accessing it once per day and 31% accessing it 2 - 4 times per day, 13% reported monthly, rarely or never checking, 11% indicated that they checked weekly, and 8% said that they checked five or more times per day. Online platforms are the predominant source, with 59% of respondents using mobile apps or weather websites. TV was next at 19%, followed by radio at 10%, social media was 6%, and 3% reported reading the printed news, with 5% reporting not having access to weather information.

Regarding methods for accessing weather information by age group, online sources are highly preferred across all age groups, especially among the 45-54 age group with 79%. Traditional media, such as TV (36%) of those 65+, was highest among all groups, and access to online sources for this group was lowest 46%. The radio was reportedly used by groups 25 - 34 (5%) and 55 - 64 (15%). Social media were specifically reported only by 18 - 24 at 8%, 25-34 at 14%, and 35 - 44 at 9%, respectively. The two age groups that indicated no access were 18 - 24 at 16% and 45 - 54 at 4%. A 2022 survey conducted by Environics for Health Canada found that when seeking information about heat illness, 41% of the respondents relied on the Internet, 3% on TV or radio, 2% on social media, and 9% did not know or did not answer [Health Canada, 2022]. Although these sources differ from those used for accessing general weather information, staying informed about the weather is crucial in preventing heat-related illnesses by enabling individuals to take timely precautions and adapt to changing conditions. When comparing the methods of accessing weather information based on income levels. Higher-income groups ($80,000 - $99,999) predominantly use online sources (69%), while lower-income groups (less than $20,000) also show a significant preference for online sources (44%).

Key Insights

The survey revealed that while 68% of Canadians access weather information daily, significant disparities exist in preferences and access methods across demographics. Online platforms

(58%) are the most preferred, particularly among younger and higher-income groups, while older adults rely more on traditional media such as television (36% for 65+). Notably, 16% of 18–24-year-olds reported not accessing weather information, a surprising outlier that suggests differing priorities or needs within this age group.

Awareness of heat waves also varied regionally; for instance, residents in Alberta (CA-PRAIRIES) demonstrated high awareness (70%), whereas 20% of respondents in Newfoundland and Labrador (CA-ATLANTIC) were unaware of heat risks. Perceived preparedness for heat waves averaged 4.18 out of 7, aligning with findings from a 2023 Leger survey that noted moderate preparedness levels among Canadians [Leger, 2023a]. These findings highlight the need for region-specific and demographic-sensitive communication strategies.

The open-text responses revealed notable outliers. Approximately 25% of participants expressed uncertainty or outright denial of heat wave risks, such as *"They literally don't [pose a risk]."* or *"It isn't that hot in Nova Scotia ever."* In contrast, others connected heat waves to broader societal and health impacts, citing concerns such as *"Air quality"* and *"Heat stroke."* These polarized perspectives underscore the importance of addressing misinformation and improving public understanding of extreme heat risks.

6.5.2 Heat wave-related salient topics

The tweets analysed provided information on public sentiment and institutional communication strategies during extreme heat events. Distinguishing between public and official tweets is important to understand how people perceive and respond to heat risks versus how organizations communicate essential information. Public tweets often reflect personal experiences, emotional reactions, and coping strategies, while official tweets focus on disseminating timely warnings, advice, and resources. These distinctions highlight the gaps and opportunities to improve the alignment between public perceptions and institutional messaging to enhance protective behaviours and public engagement. The word clouds seen in Figure 6.2 show that Canadians can name symptoms of heat illness and tend to use the word "heat wave" and describe the context of heat waves through words such as "summer", "water", "day" and "weather".

The most tweets were from Ontario and British Columbia, with 203 and 146 tweets, respectively.

- Mentions - The tweet is not explicitly about a heat wave; rather, it mentioned being in the area during a heat wave (e.g., at a concert during a heat wave).

- Statements - This type of tweet directly stated that the weather was hot or what they were doing while it was hot (eating ice cream, drinking a cold beverage, etc.).
- Strategies - A strategy tweet named or describes a method to stay cool. Actions taken include going to the pool or beach, etc.
- Advice - These were official tweets from authorities/healthcare professionals encouraging safe sun practices or ways to stay safe (e.g., drink water, wear a hat, apply sunscreen regularly, etc.).
- Warning/predictions - These tweets were statements of forecasted weather from official meteorological accounts, news, or private individuals about incoming/approaching hot weather.

The topic modelling analysis, as shown in Table 6.3, reveals three main themes in the data set. The first topic, comprising 265 tweets, is centred on environmental observations, with frequent terms like "cool," "beach," and "night," indicating that users often comment on their surroundings during heat waves, particularly highlighting natural cooling locations such as beaches. The second topic, consisting of 122 tweets, focuses on extreme weather conditions, with common terms like "day," "pool," "record," and "degree," reflecting discussions about record-breaking temperatures or specific weather events (e.g., a new heat record set in Lethbridge). The third topic, which includes 113 tweets, emaphazises safety and response strategies, with keywords such as "water," "ice," and "fan," as users share advice on staying hydrated, keeping cool, and caring for pets and wildlife. Although these topics capture what is currently at the top of the public's mind during heat waves, other critical aspects, such as long-term climate resilience, infrastructure vulnerabilities, and the effects on marginalized populations, deserve further research and communication.

As illustrated in Figure 6.5, the trend of the coherence score in the topic modelling process highlights the evolution of topic consistency in iterations. Coherence scores measure how semantically interpretable the identified topics are. An early peak in coherence (0.554) occurs around the third iteration, suggesting that the initial topics generated were clearer and more meaningful. After this peak, coherence fluctuates between 0.48 and 0.52, indicating variability in topic quality as the model continued to refine its results. The coherence score stabilises around 0.50 in later iterations, demonstrating moderate consistency across topics. This pattern implies that, while the initial topics were strong, further iterations did not significantly improve topic quality, suggesting that additional tuning of model parameters might be required for further optimisation.

The Intertopic Distance Map (Figure 6.6) vizualizes the relationships between the three main topics, revealing clear separations with minimal semantic overlap. Topic 3 dominates the discourse, covering a significant portion of the dataset, while Topics 1 and 2 are smaller, but still distinct in their thematic focus. The map confirms that the topics are well divided, each representing a unique aspect of public engagement with heat waves. This visualisation not only clarifies the structure of the data set, but also highlights the distinctiveness of the identified themes, contributing to a better understanding of how the public interacts with extreme heat events on social media.

In addition to the need for further research on long-term climate adaptation and impacts on vulnerable populations, it is important to acknowledge the limitations of manual classification and LDA topic modelling in fully capturing the nuances of public discourse on heat waves. Although necessary for refining noisy data, the manual review process may introduce subjective bias. In contrast, LDA relies on algorithmic patterns that might overlook subtle but important contextual information, such as sarcasm, cultural references, or regional variations in extreme heat experiences. Future studies could benefit from employing mixed-method approaches, combining quantitative topic modelling with qualitative analyses to better interpret the underlying sentiments and concerns.

Studying perceptions and experiences of heat provides valuable information on how individuals and communities understand, react to, and cope with extreme heat events. These insights are critical for designing effective communication strategies, tailoring public health interventions, and informing policy decisions that address the needs of vulnerable populations. In addition, understanding lived experiences can reveal barriers to adaptation, such as inequities in access to cooling resources, while also highlighting community-driven solutions and resilience strategies. By incorporating these perspectives, policy makers and researchers can develop more inclusive and impactful responses to the growing threat of extreme heat.

Compared to studies that analyse social media behaviour during heat waves, many discussions have focused on climate-related aspects of extreme heat. For example, Zander et al. examined global Twitter data during heat waves and found that 66% of tweets discussed climate-related extreme heat and heat waves, indicating a substantial public engagement in the topic [Zander et al., 2023]. The spread of climate misinformation on social media is a growing concern in the Canadian context. Far-right influencers have been found to exploit social media platforms to disseminate misleading information about climate change policies, in order to generate distrust and anger [Re.Climate, 2024]. Although social media networks serve as a platform for the dissemination of information and public discourse on heat waves and climate change in Canada, they also facilitate the spread of misinformation, which can undermine public understanding and response to these critical issues.

In addition, expanding the data set to include a wider range of social media platforms and incorporating temporal analysis could provide information on how public concerns evolve, especially in response to repeated heat wave events or official public health interventions. Understanding these dynamics could help policymakers tailor more effective and targeted public health messaging. Furthermore, integrating sentiment analysis could shed light on emotional responses to extreme heat, further informing strategies to improve public awareness and encourage behavioural changes.

Finally, future research should also examine the role of misinformation in the context of extreme heat events. As seen during the COVID-19 pandemic, misinformation can erode public trust in health authorities and lead to harmful behaviours [Mainous et al., 2024]. A deeper exploration of how misinformation about climate change and extreme heat is spread and the public's response to it could be crucial in ensuring that health interventions are trusted and effective.

Within Figure 6.7, the diagonal density plots reveal that VADER tends to classify tweets predominantly as neutral, with negative and positive sentiment scores skewed toward lower values, indicating limited sensitivity to extreme sentiment in either direction. In contrast, RoBERTa exhibits a wider range of sentiment scores, particularly for negative and positive sentiments, suggesting a greater ability to capture nuanced emotional responses in tweets related to extreme heat. The scatter plots indicate weak correlations between the sentiment models for the detection of negative and positive sentiment, although both models agree more closely on neutral sentiment. This divergence in sentiment analysis suggests that VADER may underestimate the emotional intensity of tweets during extreme heat events. In contrast, RoBERTa's broader sentiment distribution could reflect increased public concern or distress during these periods. Over time, no clear trend indicates a shift in sentiment detection, suggesting that public sentiment around heat events has remained consistent. However, RoBERTa's more nuanced sentiment detection may be useful for capturing public reactions during severe heat waves, particularly in identifying spikes in negative or positive sentiment linked to health risks, warnings, or community resilience efforts.

Takeaways

Twitter discourse during heat events provided critical insights into public sentiment and communication patterns. Topics fell into three main categories: environmental observations (e.g., "cool," "beach"), extreme weather conditions (e.g., "record," "pool"), and safety strategies (e.g., "water," "fan"). While these topics reflect general awareness of coping mechanisms, key outliers included dismissive or misinformation-laden tweets, such as

"Climate change is a scam" or *"Heat warnings are just fearmongering."* These findings mirror broader trends identified by the CCDH, where misinformation campaigns increasingly delay action rather than outright deny climate issues [Center for Countering Digital Hate, 2023].

Analysis of institutional tweets revealed a disconnect between public sentiment and official messaging. While organizations focused on providing actionable advice, public tweets often highlighted emotional reactions or community-based solutions, such as sharing local cooling centre locations. This gap emphasizes the need for tailored messaging that resonates with public experiences and leverages the emotional and community-driven aspects of discourse.

6.5.3 Monitoring emerging trends

The survey and Twitter analysis provide critical insights into public perceptions and behaviours regarding extreme heat, which are essential for effectively deploying and accepting Internet of Things (IoT) technologies to protect health from unsafe indoor temperatures.

The survey reveals how people perceive the risks associated with extreme heat and their current preferences about receiving information about it. Understanding which channels are used is necessary to reach the populous, especially to identify segments of the population who may not have access to digital methods (such as the Internet). For example, older adults and people who are low-income or precariously housed may lack consistent internet access to receive weather alerts. This underscores the need for alternative methods of communicating risks, particularly for those who may not use technology or are socially isolated, as learnt during the 2003 European heat wave [IFRC, 2012].

Analysing Twitter data offers near-real-time insights into public discourse on extreme heat events. This information can be used to distribute timely alerts and fact-based content through social media, improving public awareness and safety. In addition, understanding the spread of information and potential misinformation on social media platforms enables the development of strategies to counteract false narratives, ensuring that accurate information about heat health safety reaches the public, and ensures that responsible parties act accordingly to protect the health and safety of individuals. This is particularly important because social media networks can influence how constituents and elected politicians respond to climate change, shape the adoption of solutions, and impact their potential implications, potentially endangering public health and safety [Wood, 2021, McCright et al., 2016].

Social media platforms have played a dual role in the modern information ecosystem, acting as conduits for accurate information and dangerous misinformation. Governments have often lagged in implementing regulations to control this flow [Hagendorff, 2020,

Jobin et al., 2019]. A notable example is the spread of the "Blue Whale Challenge," a dangerous phenomenon that targets vulnerable teenagers on social media, which proved difficult to effectively ban due to the decentralised nature of its dissemination [Lupariello et al., 2019, Mukhra et al., 2019]. This situation raises important ethical questions on the extent of policies protecting health and safety and when they infringe upon free speech and freedom of expression. Access to the Internet is not possible for all individuals and usage varies greatly depending on factors such as sex and age. In 2024, Twitter users were 60% male and 39% female [Statista, 2022] and where the use of social media networks in the last three months is greater than 92% between the ages of 15 and 65 and decreases to 71% for those 65 and older [Schimmele et al., 2021].

Influential individuals, particularly in alternative health, often exploit their social capital to drive traffic to products or ideas, leveraging their fame or the trust built through para-social relationships [Paddison, 2024]. This has been particularly problematic in the health sector, where misinformation about treatments can have real-world consequences; an example is the promotion of false COVID-19 treatments by a former president of the United States, including suggestions to use bleach and other disinfectants [Lofft, 2020]. Such incidents highlight the power of social media networks to amplify harmful narratives and the urgent need for regulatory measures to curb misinformation, especially in the context of public health.

In Canada, there is an increasing need for careful and realistic legislation similar to the frameworks being implemented in the UK and Europe to combat misinformation and protect public health and safety [European Commission, 2024, Bateman and Jackson, 2024, Trengove et al., 2022]. The intersection of health and climate change messaging is important for decision makers to address effectively [Lange and Rand, 2022]. As climate denial tactics have evolved, moving from outright denial to delaying action and downplaying the consequences or effectiveness of solutions, public health communication must rise to meet this challenge [Kotch, 2022, Corsi, 2021]. Disinformation campaigns that weakened public trust in governments and health authorities during the COVID-19 pandemic serve as a warning [Limaye et al., 2020, Siegrist and Bearth, 2021]. In extreme heat events, misinformation can have deadly consequences, as it can cause people to underestimate the risks to their health [France 24, 2024].

More recently, rampant misinformation surrounding the causes and evacuations during Hurricanes Helene and Milton has highlighted the serious dangers it poses, particularly to vulnerable populations, such as women [Gollom, 2024]. With increasing rhetoric about climate change and widespread antiscience narratives that climate change is a hoax [Bellamy, 2020, Williams and Conlan, 2024], there is increasing denial and skepticism about the realities of climate change and its impacts, such as heat waves [CAAD, 2023]. Although

misinformation poses challenges in public health communications, understanding whether social media platforms effectively promote protective behaviours during extreme heat events is perhaps more critical. However, as platforms become increasingly siloed into echo chambers through the evolution of algorithms, making users more susceptible to consuming, accepting, and spreading misinformation, public health authorities will face significant challenges in effectively disseminating credible information [Treen et al., 2020].

Regarding misinformation, while denial of climate change and general misinformation on environmental issues are prevalent, there is limited evidence to suggest a significant amount of misinformation, specifically around extreme heat and health [van der Linden et al., 2017]. However, misinformation can undermine public trust in heat warnings and reduce the effectiveness of public health interventions [Bode and Vraga, 2018]. Therefore, leveraging social media effectively requires not only disseminating accurate information but also actively countering misinformation to ensure that the public adopts protective behaviours.

During these crises, false narratives and inaccurate information confuse the public and undermine emergency response efforts, putting lives at risk by delaying or preventing people from taking necessary precautions [Jung et al., 2014]. Often disproportionately affected in disaster scenarios, women face increased risk when misinformation complicates evacuation procedures or obscures critical safety guidelines [Shamsuddoha et al., 2024, Leahy, 2024]. This underscores the urgent need for stronger strategies to combat misinformation during extreme weather events to protect public health and safety.

Frameworks like the Center for Countering Digital Hate (CCDH) STAR Framework focus on Safety by Design, Transparency, Accountability, and Responsibility and offer a structured approach to regulating social media in a way that protects both public health and individual rights [CCDH, 2022]. Ethical considerations also arise from the use of artificial intelligence in public health communication, particularly with respect to access, representation, and sustainability [Christoforaki and Beyan, 2022]. Although AI has the potential to help decision makers manage and quickly assess disinformation narratives, it also presents challenges. AI systems are prone to hallucinations (generating false or misleading information) and may reflect biases embedded in training data, further eroding public trust in the information being distributed [Norori et al., 2021].

Public health communicators must stay attuned to social media trends in real time to effectively counter misinformation and ensure that their messaging resonate with the public. Social inoculation efforts, which aim to educate individuals about misinformation tactics in a preventive way, are crucial in this environment. Adopting a Health in All Policies approach (HiAP), Planetary Health, or One Health lens can help frame the discussion so that the outcomes consider more than capital gains of shareholders [Stephen, 2022, Canning, 2020].

With the right tools and regulatory frameworks, governments and public health authorities can regain public trust and protect their health in the face of increasing challenges such as extreme heat and climate-related health risks.

In summary, the survey and Twitter analysis inform us how heat health safety messaging can be or is being shaped. Although evidence of direct impacts of misinformation on heat and the resulting impacts is less concrete, disinformation about the severity of climate change and denial is prevalent [Braun, 2023]. Further research and adoption of IoT devices to improve household efficiency face significant barriers from organised climate denial, which undermines public trust in climate solutions and delays policy and technological advancements.

6.5.4 Implications

These findings emphasize the necessity of a multifaceted approach to heat-health communication. While online platforms dominate as the primary source of weather information, the reliance on traditional media by older and lower-income groups necessitates parallel communication strategies to ensure equitable access. Social media analysis further underscores the role of community-driven narratives in shaping public sentiment and behaviours during heat events.

Counteracting misinformation remains critical, as public denial or misconceptions about heat risks can hinder protective behaviours. For instance, tweets dismissing heat warnings as *"fearmongering"* reflect a broader skepticism that aligns with misinformation trends identified in prior studies on climate denial [Kotch, 2022]. Public health authorities must proactively address these narratives by providing transparent, evidence-based information through trusted channels.

By tailoring strategies to regional and demographic needs, public health practitioners can better prepare Canadians for the increasing frequency and intensity of heat events. Integrating IoT technologies, such as smart thermostats, with real-time alerts and community-based outreach could further enhance protective measures, particularly in vulnerable populations.

6.5.5 Outliers and research gaps

Notable outliers, such as the lack of weather information access among 16% of 18–24-year-olds and the regional disparity in awareness between Alberta (70%) and Newfoundland and Labrador (20%), highlight critical areas for targeted intervention. Additionally, the

prevalence of misinformation on social media platforms underscores a significant research gap in understanding its direct impact on public health behaviours during heat events.

Future research should explore the role of cultural and experiential factors in shaping public perceptions of heat risks. Expanding data collection to include rural and Indigenous communities, who may face unique vulnerabilities and communication barriers, will be essential for developing inclusive strategies. Furthermore, leveraging AI-driven sentiment analysis could provide deeper insights into public discourse, enabling real-time adjustments to health communication strategies during extreme weather events.

6.5.6 Strengths and limitations

This study has several strengths. First, while the Google Surveys platform was operational, it allowed for rapid and cost-effective data collection from a representative Canadian sample to see what Canadians thought about extreme heat. Unfortunately, this platform has since been decommissioned, but other alternatives exist.

The second strength of this study lies in its analysis of social media data, particularly X (formerly Twitter), within the Canadian context, which is the first study to do so to the best of our knowledge. Social media provided real-time data on public discourse, offering direct insights into public opinion on pressing issues such as climate change and public health. The study identified and categorized different themes by analysing social media content, highlighting potential emerging areas of focus for heat health communication. Using data from X enabled the tracking of public responses to heat waves, making the study highly relevant for understanding contemporary public health challenges, even getting ahead of misinformation and disinformation.

However, this study also faces several limitations. The most significant limitation is the discontinuation of the Google Opinion Rewards survey platform, which hinders the replication of the study in its original form. Future research must rely on alternative survey tools that can introduce variability in data quality, demographic reach, and integration capabilities. This loss represents a challenge for researchers seeking to collect large-scale real-time data cost-effectively.

Furthermore, the sale of X in 2022 and the subsequent termination of many staff members, including the trust and safety teams, have significantly changed the operational environment of the platform [Hern, 2024]. These changes may affect the integrity of data gathered from X, particularly regarding the moderation of misinformation and harmful content. With fewer safeguards in place, users are moving to other platforms as the prevalence of misinformation may be higher, potentially skewing public sentiment analysis

[Hern, 2024]. Researchers who attempt to conduct similar research should account for these changes and acknowledge that the current environment of the platform differs substantially from the period during which the original data was collected.

Finally, replicating the study presents several challenges, particularly due to the shifting landscape of social media platforms and the discontinuation of key research tools. Future studies will need to find alternative platforms and methods for data collection, which can affect the comparability of the results. In addition, the evolving nature of public health crises, such as the increasing frequency of extreme heat events and the dynamic misinformation landscape, may lead to different public reactions, making it difficult to compare directly with past data. Despite these limitations, the study offers valuable insights into public health communication and highlights the need for adaptive methodologies in changing technological environments.

6.6 Conclusion

The discourse surrounding extreme heat in Canada reveals a growing concern among Canadians about the impact of rising temperatures and heat waves on public health and well-being. As people turn to the Internet and social media for news and heat-related information, the risk of misinformation increases, especially since heat waves are closely tied to climate change and climate denial as a result. Emerging themes and topics illustrate areas where heat health messaging must be monitored and addressed, as certain narratives could affect public health efforts. The U-MAS pipeline illustrates how infodemic tools can be applied to extreme heat. However, more research is needed to explore how these sentiments evolve, especially in response to increasing climate impacts. Thus, understanding how public attitudes toward extreme heat shape policy support and behaviour changes will be crucial to developing effective public health strategies and climate resilience measures.

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Chapter 7

Enhancing heat resilience in community housing: Smart thermostats and early warning systems in British Columbia and Ontario

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7.1 Introduction

This study explored the use of a smart thermostat IoT to support existing HARS by providing real-time indoor temperature information. Indoor temperatures are hypothesised to be higher than outdoor temperatures, especially in dwellings with poor insulation and no air conditioning (AC). However, current HARS use outdoor data despite indoor conditions being different, and, in general, there have been few studies on indoor temperatures in Canada.

This project was carried out in partnership with BC Housing (BC Housing (BCH)) and Ottawa Community Housing (Ottawa Community Housing (OCH)) and was supported by Vancouver Coastal Health (Vancouver Coastal Health (VCH)), Fraser Health (Fraser Health (FH)), and Ottawa Public Health (Ottawa Public Health (OPH)) to better understand how heat and extreme heat affect the community, capture their experiences and challenges, and explore the use of the Internet of Things for real-time indoor temperature monitoring.

As the climate warms, once rare in Canada, heat waves have become more frequent, intense, and longer. A heat wave is usually when local temperatures are consistently above a certain threshold. The definition varies depending on geographical location and is determined by local public health departments and meteorological services [Gachon et al., 2016]. Environment and Climate Change Canada (ECCC) issues "Heat Warnings" based on region-specific criteria developed in collaboration with provincial and territorial health authorities [Environment and Climate Change Canada, 2010]. These criteria consider local temperature and humidity conditions to effectively alert the public to potential health risks. For example, in southern Ontario (ON), a Heat Warning is issued when daytime maximum temperatures are forecasted to reach or exceed 31°C and nighttime minimum temperatures are 20°C or higher or when humidex values are expected to be 40 or above for two consecutive days. In contrast, northern Ontario has slightly lower thresholds, with warnings issued at daytime highs of 29°C and nighttime lows of 18°C, or a humidex of 36, reflecting regional acclimatisation and vulnerability. For British Columbia (BC), including Southwest-Western Metro Vancouver (including the North Shore, City of Vancouver, and Richmond, Howe Sound, Whistler, Sunshine Coast, Vancouver Island (except northern sections), the heat warning is issued when 2 or more consecutive days of daytime maximum temperatures are expected to reach 29°C or warmer and nighttime minimum temperatures are expected to fall to 16°C or warmer. For British Columbia – Southwest inland - Eastern Metro Vancouver including Coquitlam and Surrey, and the Fraser Valley as far east as Hope, a warning would be issued when 2 or more consecutive days of daytime maximum temperatures are expected to reach 33°C or warmer and nighttime minimum temperatures are expected to fall to 17°C or warmer. These tailored criteria ensure that Heat Warnings are relevant to each area's specific climatic and health contexts, aiming to mitigate heat-related illnesses and fatalities.

Extreme heat can have many detrimental health effects, putting young children, older adults, those with pre-existing chronic illnesses, and those working outdoors or in hot environments at high risk for poor outcomes [Chigozie et al., 2022, Acharya et al., 2018, Ebi et al., 2021a]. The impacts of heat on the body range from heat exhaustion (characterised by sweating, headache, nausea, vomiting, anxiety, and dizziness) to heat stroke (characterized by the skin feeling hot and dry, to seizures, comas, severe headaches, al-

tered behaviour, irritability, aggression, and rapid and shallow breathing to death in severe cases [Kenny et al., 2018, Weinberger et al., 2021, Sorensen and Hess, 2022]. Developing robust localized heat health warning systems has been identified as a key tool by the IPCC (Intergovernmental Panel on Climate Change), Health Canada, and the BC Death Panel from 2022 to prevent heat-related illnesses, provide heat relief programmes, guide policy and municipal planning, and ultimately prevent deaths from extreme heat [BCCS Death Panel, 2022, Health Canada, 2012, IPCC, 2014].

Because heat impacts many systems in society (including infrastructure, agriculture, transportation, healthcare, etc.), our response efforts must include intersectoral collaboration between governmental agencies, private and community-based organizations, and academia [IPCC, 2014, IFRC et al., 2022, Singh et al., 2019, McGregor et al., 2015]. The focus of this study on better monitoring of indoor temperatures provides critical data that can directly support collaboration with community organizations working to protect vulnerable groups, including migrant workers. For example, by identifying areas with higher exposure to indoor heat, organizations can better target their efforts to distribute cooling resources, water, and heat-related education. In addition, the data collected can strengthen advocacy efforts to push for policy changes and programme offerings, such as improved housing conditions, workplace cooling regulations, and heat adaptation strategies tailored to the needs of these at-risk populations. This project demonstrates the functionality of a real-time indoor temperature monitoring system by involving stakeholders from government agencies, academia, and building managers to assess and act on indoor temperature conditions in unair-conditioned homes across Canada.

7.1.1 Indoor heat

As 92% of our time is spent indoors, the indoors pose a great risk to older adults, those with mobility challenges, those attending school, the incarcerated and those working in factories. As discussed in Chapter 2, there is a clear research gap surrounding our understanding of the indoor temperature people in Canada experience. Following the 2021 Heat Dome, the BC Coroner's report reported indoor temperature as subjective "hot" or "very hot" as there are no data available from indoors [BCCS Death Panel, 2022, Government of Canada, 2023b, Henderson et al., 2022].

Several studies have retrospectively studied indoor temperature using data loggers [Booten et al., 2017, Petrou et al., 2019, Dickson et al., 2023, Nguyen and Dockery, 2016]. In light of the absence of a national or provincial system for indoor temperature monitoring and the lack of indoor temperature data available for post-event analysis, such as after

the BC Heat Dome, we conducted an observational study in British Columbia, where air conditioning rates, a critical protective factor, are comparatively low [BC Hydro, 2021a]. By deploying ecobee thermostats, we sought to generate real-time indoor temperature alerts to mitigate heat-related illnesses and fatalities [Oetomo et al., 2022].

This commercially available technology could create a nationwide network of real-time indoor temperature alerts, supporting existing HARS [Oetomo et al., 2022]. Heat is invisible and silent, making it difficult to capture in images or videos, unlike other extreme weather events; this often leads to inaccurate portrayals in the media, obscuring its true dangers and complicating effective communication and messaging. [Tetzlaff et al., 2023c, O'Neill et al., 2023]. We also wanted to explore what Canadians were doing about indoor heat, as habits and behaviours can impact indoor temperatures [Vargas et al., 2023, Akompab et al., 2013, Kim et al., 2014].

7.1.2 Objectives

Following the 2021 Heat Dome, BC was identified as a potential study site given its geographical location, low air conditioning rates compared to other provinces in Canada, and the interest of local health and community partners. The report of the Death Review Panel stated that the indoor temperatures during the BC Heat Dome were "warm," "hot," or "extremely hot," but actual indoor temperature readings were not available [BCCS Death Panel, 2022]. The goal was to provide insights into the temperatures experienced in these homes.

This study aims to address the following research questions by leveraging real-time indoor temperature data and resident feedback.

- What are the highest indoor temperatures recorded during the 2022 summer heat events and how do these compare to safe thresholds?
- How did interventions such as window film treatments impact indoor temperatures?
- What behaviours and barriers were observed among residents in managing heat risks?

7.2 Methods

In this study, researchers from the University of Waterloo, Faculty of Health, School of Public Health Sciences, in collaboration with local partners, BC Housing, Vancouver Coastal

Health, and Fraser Health, deployed ecobee thermostats with Wi-Fi to collect data to understand better indoor heat in lower mainland British Columbia, Canada. During the project, the thermostats collected the indoor temperature and three short questionnaires would be administered at the beginning, midpoint, and end of the study (see Appendix F). Due to logistics, sensor installation and data collection began later than planned on 9 May-20th, 2022, and continued until 30 September, 2022. The automated alert system was launched on July 7, 2022 in BC.

7.2.1 Ethics and Recruitment

This study was reviewed and approved by the University of Waterloo Research Ethics Committee (ORE #43778). Furthermore, all documents were shared with the BC Housing Privacy Commission office and project team (including VCH and FH) before the start of the study for feedback and approval. The project plan can be found in the Appendix F. A term of reference agreement was created for the project team between the University of Waterloo and BC Housing and supporting stakeholders.

The recruitment process differed between Ontario and British Columbia, where BC Housing played an important role in identifying potential participants and calling ahead to inform them and ask if they would be interested. Recruitment poster were used to explain the study to potential participants, see Appendix F. If they pre-consented over the phone, a visit to install the thermostat was scheduled. In Ontario, recruitment involved walking the selected sites and knocking on doors to recruit Ottawa Community Housing tenants, making a 30-second research pitch, and obtaining consent before setting up the thermostats.

7.2.2 Sensors

The study equipment, as seen in 7.1, consisted of an ecobee thermostat (ecobee 3) attached to a bamboo tablet stand, one portable Wi-Fi router equipped with a SIM card and a local data plan, and a power cord [ecobee, 2019]. In addition, stand graphics containing important study information were displayed on the stand, making study information accessible at all times, see Appendix F.



Figure 7.1: Left: An ecobee thermostat on a wooden stand during the set-up visit in May. Right: Multiple ecobee thermostats in the UbiLab, University of Waterloo preparation phase.

The thermostat and router were powered via the power cord plugged into a wall outlet. Instructions on how to modify ecobee thermostats for data collection can be found in Appendix B. The thermostat was wirelessly connected to the router to enable real-time data collection and automated daily email alerts.

The placement of the thermostat within the unit varied and depended on proximity to an electrical outlet and the participant's preferences (i.e., a shelf nearby, an area not used or frequently accessed, etc.). During recruitment, BC participants were informed that they would need a place for the thermostat, preferably near an available electrical outlet. Most of the device(s) were placed in a spot in the home that enabled the participant to benefit from the temperature display during the study. The ecobee temperature sensor has a +/- 1.0º F accuracy and is programmed to provide readings every 15 seconds. It will use and average the previous two values into the current reading. The temperature is logged at 5-minute intervals in ecobee's database. Before deployment, the ecobee thermostats were tested in the lab for at least 24 hours to ensure they were within 1 degree of the Aranet4, and the readings were verified with an Aranet4 temperature sensor to ensure accuracy. Figure 7.2 shows two mockup examples of where thermostats might have been placed. Some thermostats were displayed in living rooms; others were tucked in unused corners of the

home, on shelves, or even placed out of the eye-level view high on a wall.

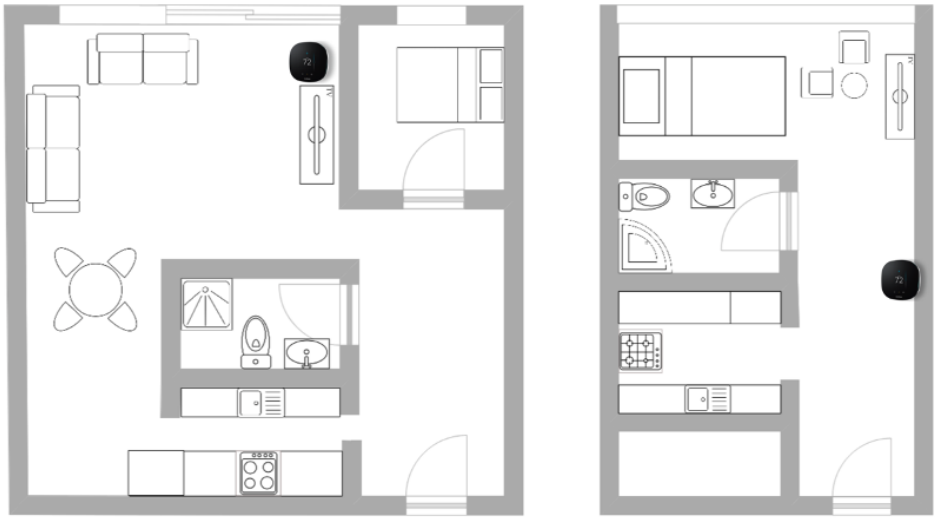


Figure 7.2: Examples of floor plans showing the placement of the ecobee thermostat in participants' homes. Locations were chosen based on outlet proximity, minimal obtrusiveness, and available space.

7.2.3 Data pipeline and real-time alerts

The temperature was measured in Fahrenheit using the thermostat's built-in sensor, recorded at 5-minute intervals, and stored on ecobee's servers. Data collection relied on a mobile router with a SIM card and an active data plan. The data were retrieved through an API developed by the UbiLab team and securely stored on the University of Waterloo's UbiLab research servers, utilising a Microsoft Azure NIST-compliant NoSQL database.

An automated script processed the data twice daily at 8:00 AM and 2:00 PM PST (UTC -8), sending alerts by email to a designated list of stakeholders. These alert times were carefully selected to allow the BCH team to address any concerns within their regular working hours (8:00 AM to 4:00 PM).

See Appendix F for an example of the email alert template, the threshold trigger examples for the alerts, and a sample email from June 28th, 2022. A screenshot of the Elastic dashboard is also provided, it displayed the status of the thermostats and was available to the stakeholders. The pipeline differed slightly in Ottawa, where only mobile

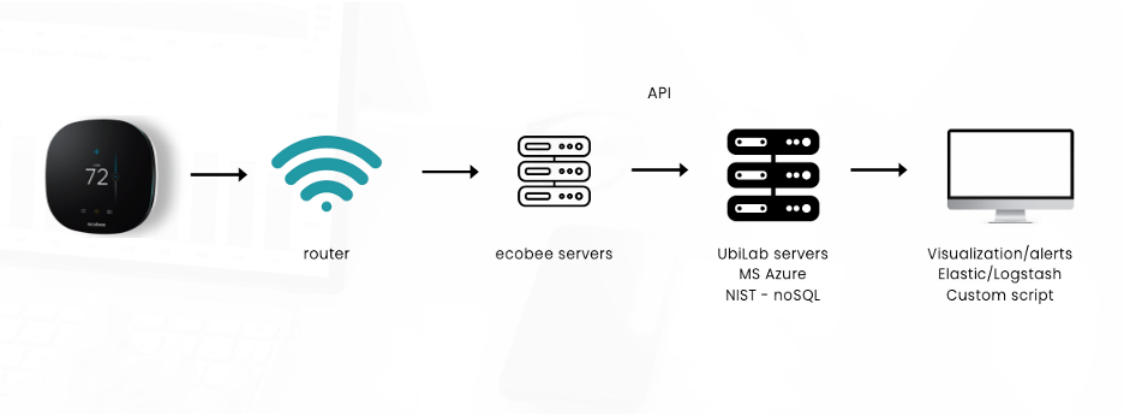


Figure 7.3: Data pipeline illustrating the real-time capture, transmission, processing, and utilization of data for email alerts and dashboard updates during the study.

routers were required, as ecobee thermostats had already been installed through a previous retrofit program. In addition, no real-time alerts were provided to the team in this region.

7.2.4 Study sites

The study was conducted in Ottawa, Ontario and the Greater Vancouver Area, British Columbia. Three sites, see 7.4, were selected by OCH to serve as study sites. The sites were in the West Ottawa area in Qualicum – Redwoodpark neighbourhoods and Whitehaven – Queensway Terrace North. Full site maps can be seen in Appendix G. All the homes were townhouses, multistory buildings that shared at least one wall with their neighbour, with gas furnaces and no central air conditioning. The goal was to recruit tenants without air conditioning (AC). However, almost all participants used portable air conditioners (both window units and standalone units). Tenants are permitted to have AC provided that they obtain approval from OCH.



Figure 7.4: Map of three study sites in Ottawa, Canada, indicated by the black stars and images of the three study sites. Map created and images taken by Arlene Oetomo

- Foster Farm, Ramsey (1973) The Foster Farms community was approved for public housing in 1970. The two-story townhomes contain mostly three-, four-, or five-bedroom configurations. Units have a large sliding door in the back and at least two openable windows on the main floor. The windows in the upper part depend on the room configuration. Most units share a wall with a neighbour and there were few trees to provide shade, many of which had recently been cut down, likely due to age-related safety concerns.
- Morrison Gardens (1972 and 1977) Morrison Gardens' units are mostly two- and three-bedroom configurations. Here, the units had, on average, three openings on

the main floor and at least two windows upstairs. Some properties had shade from surrounding trees, while others were very exposed.

- Michele Heights (the 1970s) In the Michele Heights community, most units are two-story townhomes with two, three, or four bedrooms. The population consists mainly of young people and children, forming 48%. Most units had at least two openable windows and a back door on the main floor. About half of the units received shade from trees or less sun exposure due to the orientation and sharing of the walls.

Across all sites, the hydro was the responsibility of the tenants.

Five sites in Metro Vancouver were selected, including Richmond, Burnaby, and New Westminster (American, Hall Towers, MacLean, Rosewood, and Ross Tower). See Appendix F for images from the study including the buildings described below. None of the sites had central air conditioning and all units had individual temperature controls for heating. Initially, three participants reported having a window or portable air conditioner. At the end of the study, five participants reported having air conditioning.

- American (˜1964): Located in Vancouver, this three-story low-rise building comprised two levels of Single-room Occupancy (SRO). The main materials used in the building were concrete with metal cladding, and information about insulation was not attainable. Windows were double-glazed with 20.5-inch openings, with units having two open windows, some with screens. This building had no balconies, and the north and south walls were shared with buildings next door. Two of the three thermostats were placed in unoccupied rooms used for storage.

- Hall Towers (1972 and 1977): Located in Burnaby, the two Hall apartment complexes stand 16 and 19 stories with 331 housing units. The buildings were built with pre-cast concrete structures with a brick exterior, rockwool, and fibreglass insulation. Windows are double-glazed, with the average openings about 6–8 inches. Some units have larger openings in windows (7.5–13 inches), and units with balcony doors have 4ft (1.22 m) openings. Units had between two and five operable windows, and seven of 12 reported having working screens. Two thermostats were placed here in unoccupied rooms, including one on the 19th-floor amenity room and an empty unit on the 7th-floor. Except for the 19th-floor amenity room (a communal recreational room for residents to host parties or events), the Hall Towers units received window film treatment to reduce the incoming heat and glare. Observation of the indoor temperature of a unit without window film treatment was requested by BC Housing, who installed the film as a solution to address high indoor temperatures [BC Housing, 2022]. According to

the manufacturer, the medium dual-layered solar film reduced heat and glare by 65%, light by 68%, and ultraviolet light by over 99%. In the winter, the film also reduces the outgoing heat by 19%.

- MacLean Park (1964–1978): This site is located in Vancouver, made of mixed housing types, including two high-rise towers with 9 and 12 floors, townhouses (units split over two floors), and walk-ups (2 levels, upper units have a third floor). The townhouse units have fibreglass insulation, and BCH believes the towers and walk-up buildings have insulation, but the specific types were unknown. The building materials were concrete, brick, and metal cladding with a layer of poly bead foam board with drywall attached. There is no insulation between suites, and the windows are double-pane. The floor space of the units ranged from 335 sq ft (31.12 m2) to 950 sq ft (ca. 88 m^2). Window openings were from 7.5 inches (19.05 cm) to 13 inches (33.02 cm) and between 20 — 40% of the wall space. The walk-ups had exterior walkways, and within the site, there were mature trees. Twelve thermostats were placed at MacLean.

- Rosewood (1977–1978): Two mid-rise 6-story buildings in Richmond. The buildings are made of brick and concrete, insulated with a layer of poly bead foam board, drywall, and insulation between the suits. And rockwool on the exterior. Each unit has a balcony and two to five operable windows. Trees near the buildings shaded some lower-level units.

- Ross Tower (1973): The Ross Tower in New Westminster is a 16-story building with 96 units. Three thermostats were placed here in units ranging from 365 sq ft (33.91 m^2) to 445 sq ft (41.34 m^2). Units had two to three windows (30-40% of the wall) that could be opened to about 6–8 inches (15-20 cm). From June 27 to Aug 2, 2022, the entire building's double pane windows receive the window film treatment during the study period. This was the same film used in the Hall Towers.

An assessment from HealthyPlan.City indicated that the MacLean Park and Ross sites are equity priority areas for land surface temperature [HealthyDesign.City, 2023]. Meanwhile, Ross is also an equity priority area for tree canopy cover for 65- and older and low-income individuals. Equity priority is defined as having higher than median proportions of vulnerable populations and lower than median levels of beneficial urban environments (such as green spaces or tree cover). MacLean Park's vulnerable populations include those living alone, minorities, those below low income, those aged 14 and under, and those aged 65+.

The American was indicated as an equity priority area for tree canopy coverage, with vulnerable populations including low-income people, those 65+ years old, minorities and

those living alone. Hall Towers was listed as an equity priority area for vulnerable populations of 65+ years of age, low-income, visible minorities, and individuals living alone. In measures of land surface temperature and tree canopy coverage, an increased risk of heat exposure was identified in adjacent dissemination blocks (areas bounded on all sides by roads and/or boundaries of Statistics Canada's standard geographic areas for dissemination) to the West and North, according to the HealthyPlan.City analysis. At Rosewood, the most at risk are those 65+ years old, those with low income, those who are visible minorities, and those living alone. Rosewood did not appear as an equity priority area for either land surface temperature or tree canopy coverage. However, it is important to note the proximity to Blundell Park, a green space that could reduce UHI and may have resulted in it not being categorized as an equity priority area.

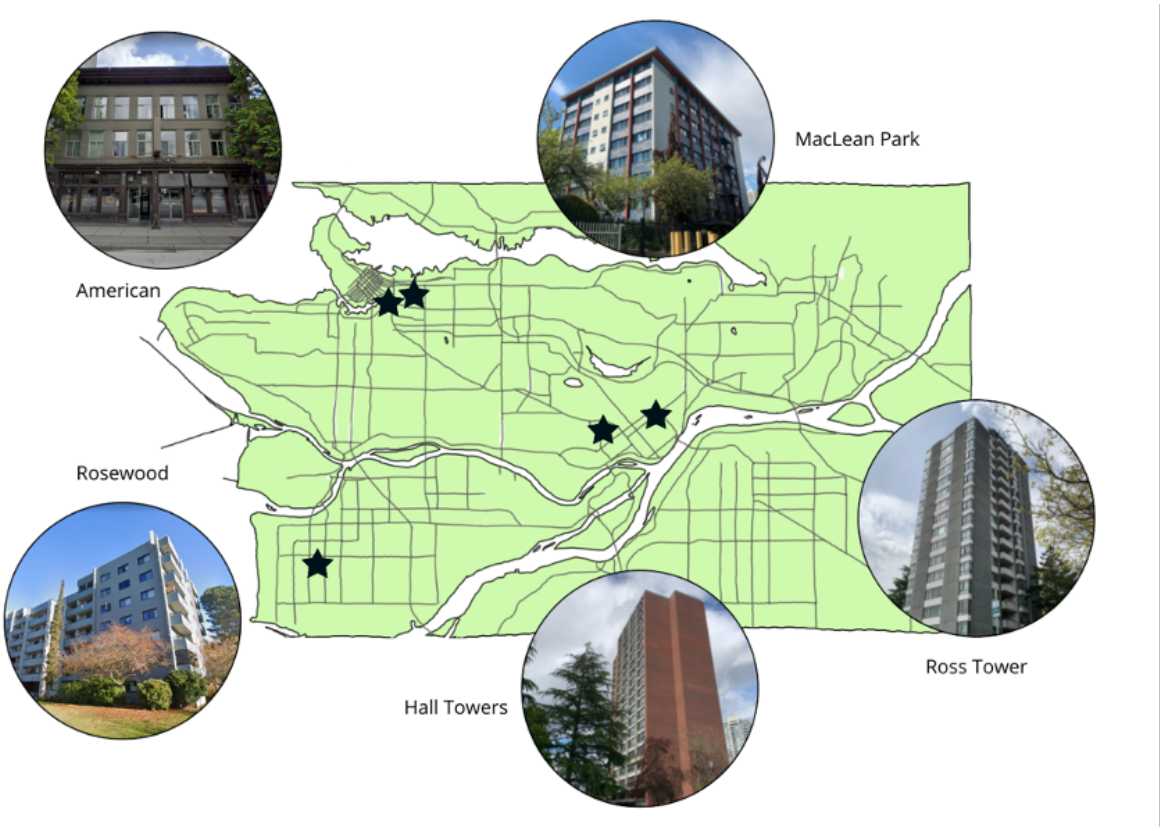


Figure 7.5: Map of five study sites in the lower mainland of British Columbia, Canada, indicated by the black stars and images of the five study sites. Map and images of MacLean Park, Ross Tower, and Hall Towers were created and taken by Arlene Oetomo. Images of Rosewood and American are from Google Maps

7.2.5 Participants

Participants in BC were recruited via recommendations from building managers and pre-called to discuss the study's requirements and their willingness to participate. Installation visits were scheduled in BC, but in Ontario, participants were recruited via door-to-door knocking by a researcher from the University of Waterloo and an OCH staff member. All thermostat installations were completed between May 9 - 12th in Ottawa and May 16 - 20th in BC. Efforts were made to recruit participants from higher levels within the identified sites, units with south exposure, and units with opposite orientations on the lower floors for comparison. Each participant had to be willing to have an ecobee thermostat and Wi-Fi router installed in their home for the duration of the study. At the end of the study, the team returned to collect the thermostats and remove them from the units. Participants were also informed that researchers could contact them to troubleshoot any sensor issues to ensure data collection.

7.2.6 Data collection

Each participant was assigned a unique identifier for anonymity and agreed to complete three surveys throughout the study. Three rounds of surveys were conducted: Visit 1 (Consent and Installation, Housing Characteristics), Visit 2 (Demographic Characteristics), and Visit 3 (Summer Characteristics). See Appendix F for the survey questions.

During Visit 1 between May 9 - 20th, 2022, written consent was obtained by the researcher, AO, in Ontario, and a BCH tenant support worker (Tenant Support Worker (TSW)) of the staff before AO entered the units in BC. The participant then completed the Housing Characteristics questionnaire with the assistance of AO or TSW, and the study equipment (Wi-Fi router and ecobee thermostat) was installed. This baseline included questions related to the characteristics of the home and the building, and the researcher or the community housing contact completed them. The participants received a CAD $25 grocery gift card for their time.

From July 8 – 16th, during Visit 2, BCH staff in BC and AO in Ottawa completed the Demographic Characteristic questionnaire; this included questions about age, thermal comfort in their homes and what actions they might take to stay cool. Visits were confirmed by telephone calls from the team approximately 1-2 weeks prior. Once again, the participants received a CAD $25 grocery gift card.

The final visit, Visit 3, occurred between September 27 – October 7, 2022, and the final survey on Summer Characteristics was administered. Visits were again confirmed by

telephone approximately 1-2 weeks earlier. The questionnaire asked questions related to the experiences of the 2022 season, the behaviours the participants engaged in, and how they received information about heat waves and staying safe during extreme heat events. The University of Waterloo also retrieved the study equipment. All participants were given a CAD $50 grocery gift card and entered into a random draw to win a $200 grocery gift card (1 prize for each province).

For context, participants were required for approximately two hours throughout the study, and the minimum wage in 2022 was $15.20 - $15.65 in BC and $15.50 in Ontario. This also accounted for the energy use to power the thermostat and the Wi-Fi router, which was less than CAD $1 for the duration of the study. The estimated cost of electricity to power the study devices was also considered to ensure that the participants were fairly compensated for the energy consumed and their time. See Appendix F for a detailed breakdown of the estimated energy cost to participants. Details on the project budget for BC can also be found in Appendix F and for ON see Appendix G.

Weather during the visits

During the survey periods in 2022, both Ontario and British Columbia experienced varying weather conditions.

Ottawa:

- May 9 - 12, 2022: Temperatures ranged from lows of approximately 3°C to highs around 30.5°C, indicating a warming trend these days.
- July 11 - 15, 2022: This period experienced typical summer warmth, with daily highs averaging between 25°C and 30°C.
- September 26 - 28, 2022: Early autumn brought milder conditions, fluctuating between 10°C and 20°C.

Greater Vancouver area:

- May 16 - 20, 2022: Spring in Vancouver saw cool temperatures, lows around 5°C and highs up to 17.7°C.
- July 8 - 16, 2022: Summer temperatures were moderate, with daily highs ranging from 20°C to 25°C, providing comfortable conditions.

- October 4 - 6, 2022: Early October experienced cooler autumn weather, with temperatures varying between 10°C and 15°C

These temperature variations during the survey periods are essential for interpreting participants' responses, as weather conditions can significantly influence individuals' experiences and perceptions.

ecobee thermostat data was recorded from May 9 until Sep 30, 2022 (approximately 137 days), depending on when the thermostats first went online and were disconnected. The base ecobee smart thermostat models collect temperature, humidity and motion data. The device collects temperature, motion, and humidity data according to the manufacturer's (ecobee) user agreements. Although motion data was collected, it was not used in this study. The completed consent forms and the paper surveys were stored securely at the University of Waterloo and a BC Housing Office. The survey results were digitised into a spreadsheet for analysis.

The ecobee thermostat data from the Donate Your Data program was collected and anonymised by ecobee for research purposes and provided to the University of Waterloo through a research agreement. The data were stored on a Google Cloud Platform server retrieved through a data pipeline and stored on secure on-premises server research at the University of Waterloo.

Through ecobee's DYD program, the authors also extracted a subset of DYD data from May to September 2022 for homes in Burnaby, New Westminster, Richmond, Vancouver, British Columbia, and Ottawa, Ontario, for comparison.

7.2.7 Analysis

Data from ecobee thermostats was accessed through an Application Programming Interface (API) provided by ecobee, allowing for the secure extraction of thermostat metrics directly from ecobee's servers. Once retrieved, these data were stored on the Google Cloud Platform (GCP), which provided a robust and scalable cloud-based server environment for data storage, then exported as .csv files for analysis.

Data analysis was performed using R, Python, and Data Wrapper. Within Python, the NumPy library facilitated efficient numerical operations on arrays and matrices, and the Pandas library was used for structured data manipulation and analysis. The temperatures were converted to Celsius from Fahrenheit and the missing values were removed. The analysis began with a descriptive statistical exploration of indoor and outdoor temperatures

and visualisations to explore patterns. A two-sample independent t-test comparing indoor and outdoor temperature, Cohen's d-effect test, and Mann-Whitney U test were conducted to see if the window film had an effect. The results were vizualized using the Matplotlib and Seaborn Python libraries and Data Wrapper (version 0.6.1). Additional direct queries were executed within the GCP to analyse ecobee's "Donate Your Data" (DYD) data matching the city location of the unair-conditioned homes from the 2022 season. This integrated approach ensured a thorough examination and insightful representation of the thermostat data. Two final project reports were also delivered to stakeholders in BC and Ottawa in 2022 and 2023.

7.3 Results

7.3.1 The summer of 2022

Here is a summary of summer conditions in British Columbia and Ontario in 2022, providing a context for interpreting and understanding the results.

British Columbia
The spring of 2022 was cold, wet and gloomy in British Columbia, caused by a La Niña weather pattern before much of the heat arrived in late June. Some participants were using indoor heating in May. The heat arrived in July, and numerous temperature records were broken in late July and early August. BC experienced the hottest August ever, where the average temperature was 20.3°C, and the September temperatures continued with an unusual late fall heat wave in the last week of the month.

In 2022, there were 16 heat warning days for Metro Vancouver (Central, including the City of Vancouver, Burnaby, and New Westminster, and the southwest, including Richmond).

- 2022-06-26 - 2022-06-28 = 3 days
- 2022-07-25 - 2022-08-02 = 9 days
- 2022-08-16 - 2022-08-19 = 4 days

The BC Coroners Service reported that at least 16 heat-related deaths occurred between July 21 and August 3 in British Columbia. During the study, high temperatures above the safety guidelines and considered unsafe for human health were recorded. Isolated individuals

likely experienced similar conditions during the 2021 Heat Dome, as daily maximum and minimum temperatures were in the low 30s during the day and low 20s at night.

Ontario
The spring of 2022 brought early heat to Ottawa, Ontario, as record highs were recorded. June and July saw higher temperatures, and temperature records were broken in September. In 2022, there were four heat warning days for the City of Ottawa.

- 2022-07-18 - 2022-07-21 = 2 days
- 2022-08-5 - 2022-08-8 = 2 days

The early and late season heat waves in September also broke temperature records in Ottawa. During the study, high temperatures above the safety guidelines and considered unsafe for human health were recorded. Although many participants had air conditioning, all homes reached indoor temperatures at or above 26° C and above, as daily maximum and minimum temperatures were in the low 30s during the day and the low 20s at night.

7.3.2 Descriptive statistics

The indoor temperature data for British Columbia and Ontario reveal some clear trends. During the study in BC, the average indoor temperature is 26.04°C (SD = 2.42°C), with temperatures ranging from 16.33°C to 38.17°C. The 95% confidence interval for the mean indoor temperature in BC is [26.04°C, 26.05°C], indicating stable indoor conditions. The interquartile range (IQR), which represents the middle 50% of the values, lies between 24.39°C and 27.56°C. In contrast, ON shows a slightly lower average indoor temperature of 24.48°C (SD = 2.35°C), with a range from 14.61°C to 36.22°C. The 95% confidence interval for the mean indoor temperature in ON is [24.48°C, 24.49°C]. The IQR for ON falls between 23.00°C and 26.00°C. These data suggest that BC maintains slightly warmer average indoor temperatures while both provinces exhibit similar temperature variability.

The outdoor temperature data also reveal notable differences between BC and Ontario. In BC, the average outdoor temperature is 17.24°C (SD = 4.35°C), with temperatures ranging from 1.33°C to 33.06°C. The IQR for BC's outdoor temperatures falls between 14.22°C and 20.17°C, indicating a relatively consistent and moderate climate. In contrast, ON experiences a higher average outdoor temperature of 18.94°C (SD = 5.11°C), with a broader range of temperatures from 3.78°C to 31.89°C. The IQR for ON outdoor temperatures is between 15.39°C and 22.56°C, suggesting greater variability and a wider distribution of moderate and warmer temperatures.

In general, ON tends to experience slightly warmer and more variable temperatures than BC indoors and outdoors. However, BC maintains slightly higher and more stable indoor temperatures, while ON exhibits greater variability in both environments.

The results of the two-sample t-tests for indoor and outdoor temperatures in BC and ON reveal statistically significant differences between the two environments. In BC, the t-test yielded a t-statistic of 1879.02 and a p-value of $p < 0.001$, indicating a highly significant difference between indoor and outdoor temperatures. Similarly, in ON, the t-statistic was 653.28 with a p-value of $p < 0.001$, suggesting a significant difference between indoor and outdoor temperatures. Given that both p-values are below the standard significance threshold of 0.05, we can conclude that the differences between indoor and outdoor temperatures in both provinces are statistically significant.

The effect size, measured by Cohen's d, reveals substantial differences between indoor and outdoor temperatures in both BC and ON. Cohen's d is 2.53 for BC, indicating a large effect size. This suggests that the difference between indoor and outdoor temperatures in BC is not only statistically significant, indicating a strong disparity in temperature regulation between the two environments. Similarly, Cohen's d is 1.26 for ON, representing a large effect size. Although the effect size in ON is smaller than in BC, it still indicates a significant difference between indoor and outdoor temperatures. These large effect sizes in both provinces highlight substantial differences between indoor and outdoor temperatures, likely influenced by factors such as building design, insulation, and the use of climate control systems to mitigate extreme outdoor conditions.

Pearson's correlation analysis shows a moderate positive correlation between indoor and outdoor temperatures in both BC ($r = 0.47$, $p < 0.001$) and ON ($r = 0.45$, $p < 0.001$), indicating that as outdoor temperatures increase, indoor temperatures also tend to increase in both provinces, with statistically significant results.

7.3.3 Visualizations of indoor temperature

Figure 7.6 illustrates the daily maximum indoor temperatures recorded by the thermostats throughout the study. Each data point represents the highest temperature recorded by each thermostat daily, vizualized against the date of occurrence. Horizontal dashed lines at 26°C and 31°C delineate significant temperature thresholds used during the study.

Indoor temperature patterns throughout the study

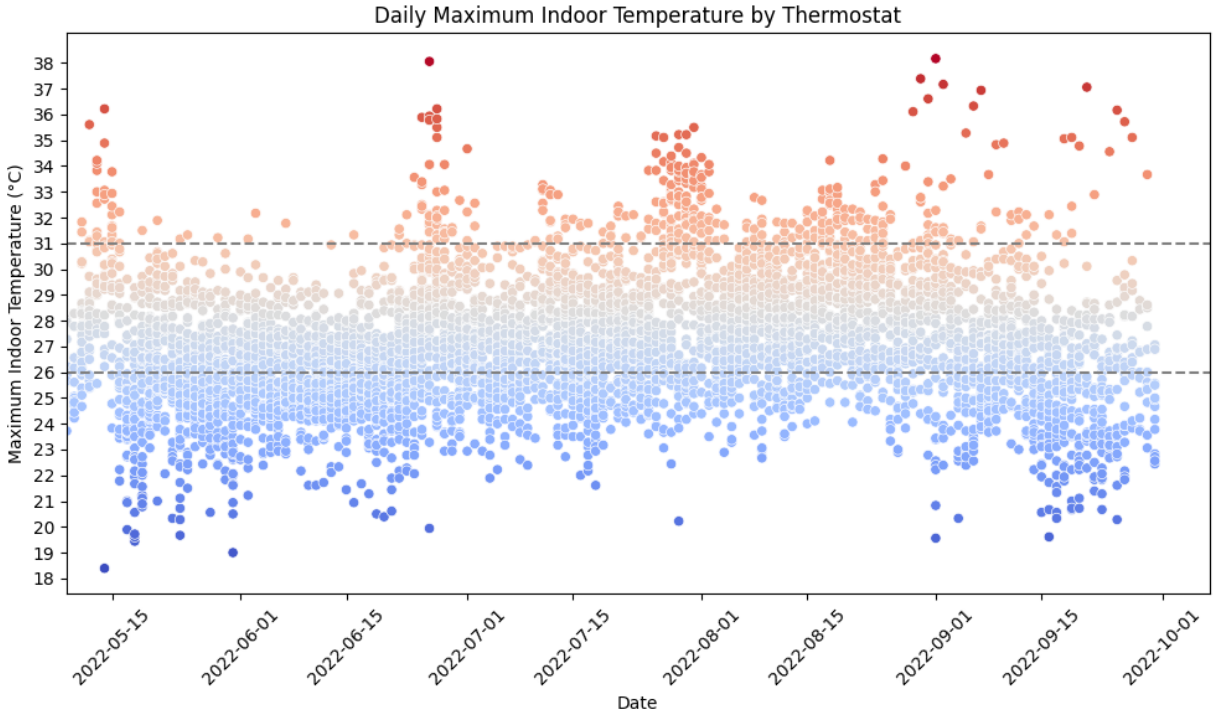


Figure 7.6: Daily Maximum Indoor Temperature

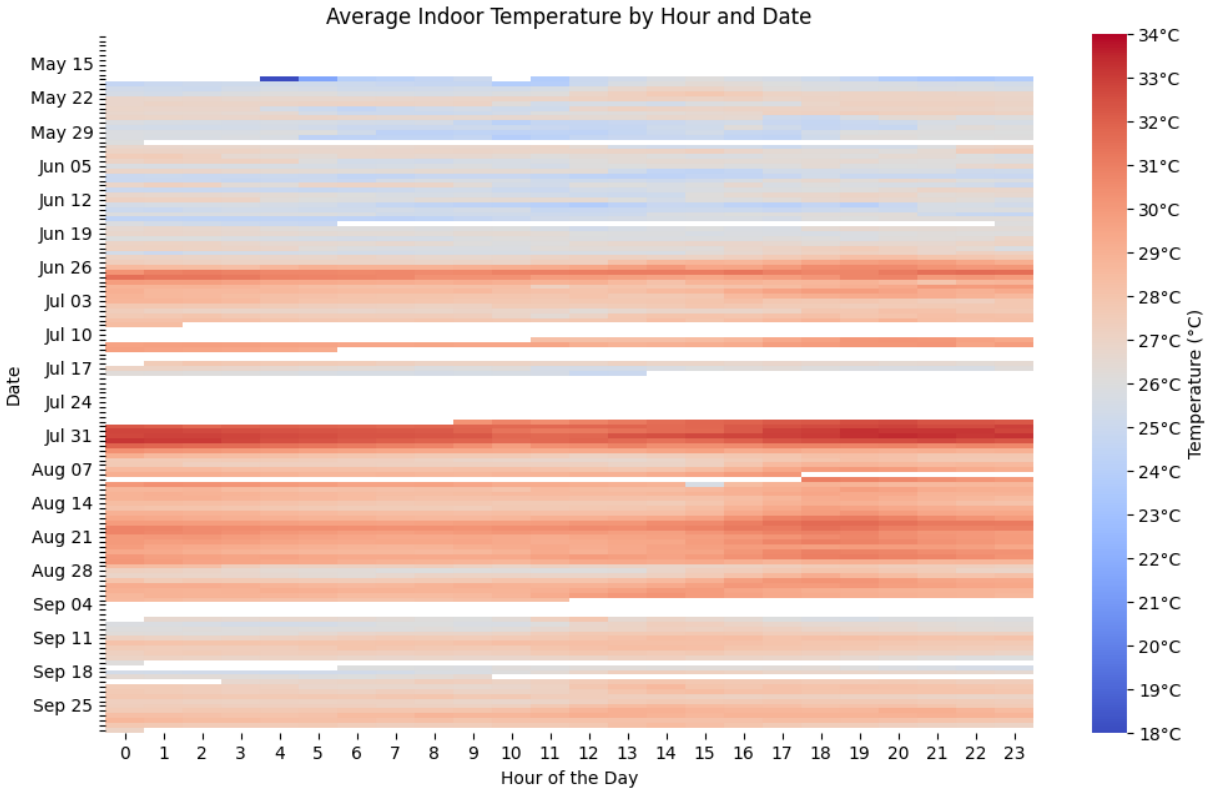


Figure 7.7: Heatmap of indoor temperatures for a thermostat on the 14th floor of an apartment building in Burnaby, BC

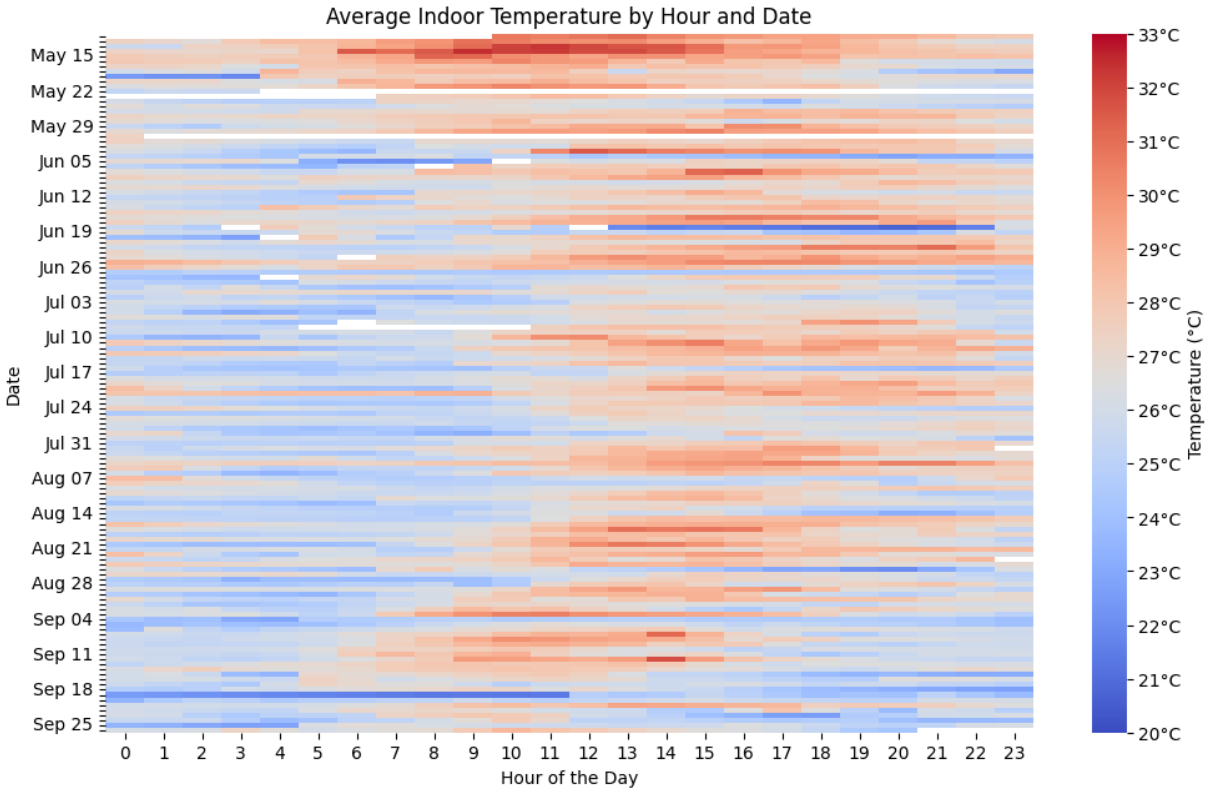


Figure 7.8: Heatmap of indoor temperatures for a thermostat in a two-storey townhouse in Ottawa, Ontario.

Average indoor temperature compared to outdoor temperature

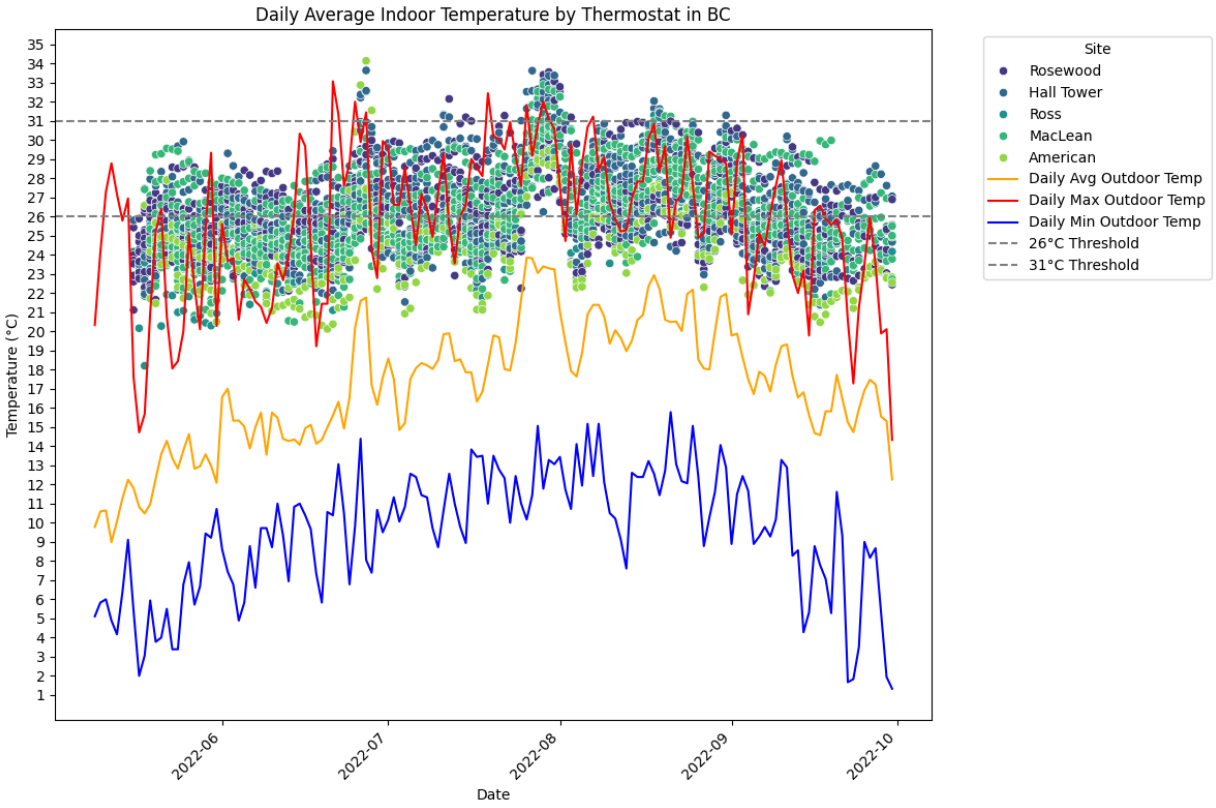


Figure 7.9: Daily average indoor temperatures from all thermostats in British Columbia

In Figure 7.9, the daily average temperatures of each thermostat in British Columbia were plotted and grouped by their respective sites, and the daily maximum, average, and indoor temperatures of the Vancouver area are shown.

Similarly, in Figure 7.10, the daily average temperatures of each thermostat in Ottawa, Ontario, were plotted and grouped by their respective sites, and the daily maximum, average, and indoor temperatures of Ottawa are shown.

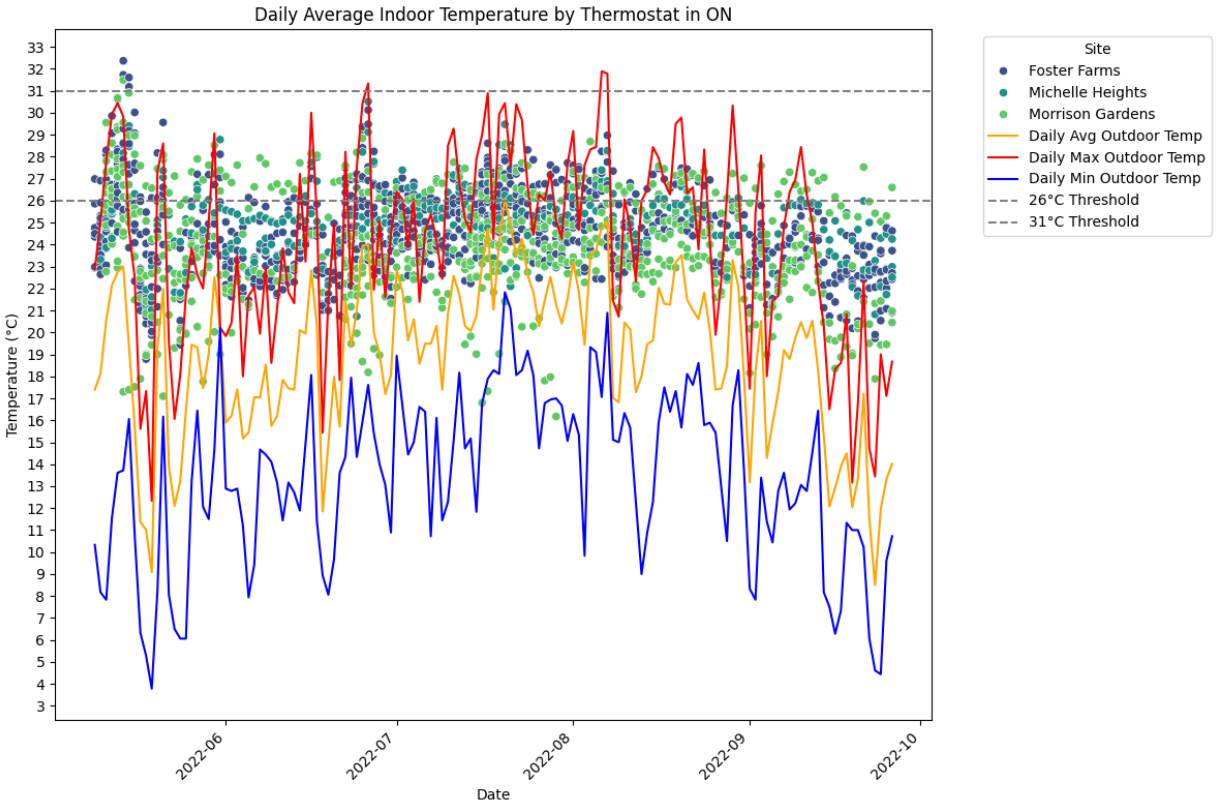


Figure 7.10: Daily average indoor temperatures from all thermostats in Ontario

Daily average, maximum, and minimum temperature

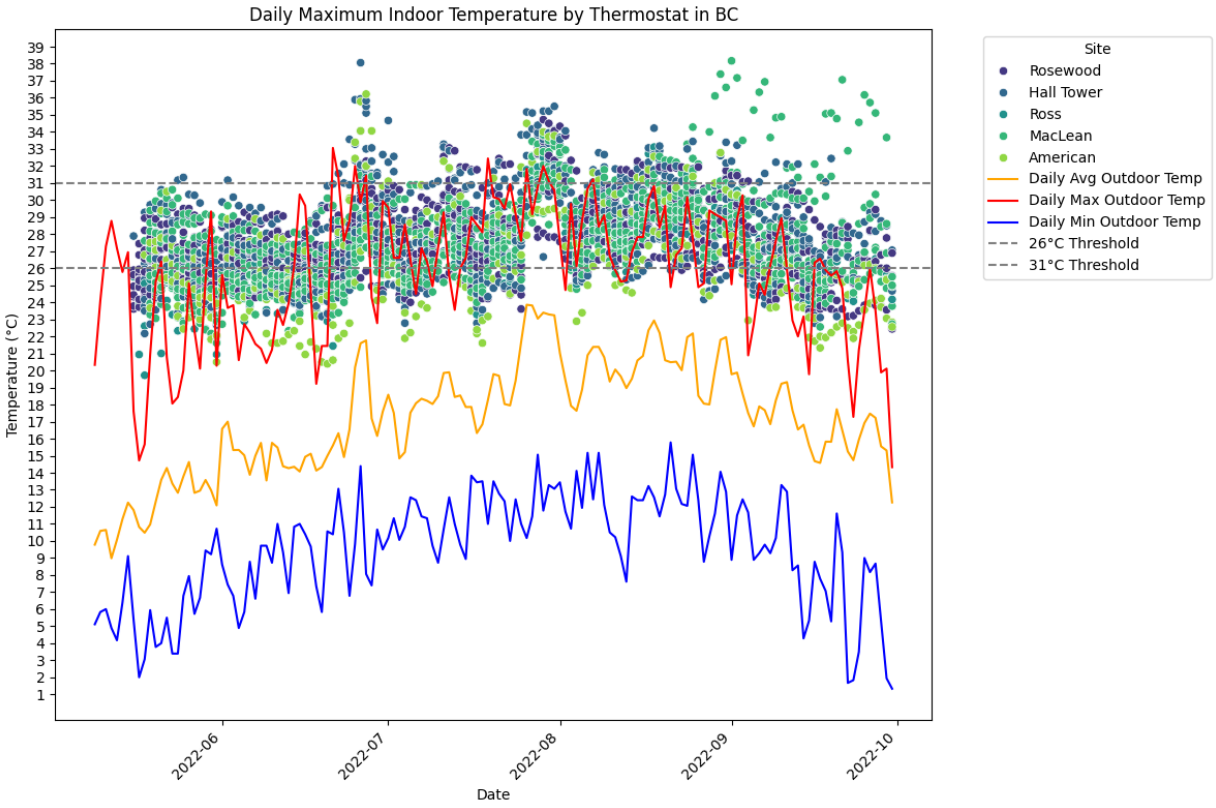


Figure 7.11: Daily maximum indoor temperatures from all thermostats in British Columbia

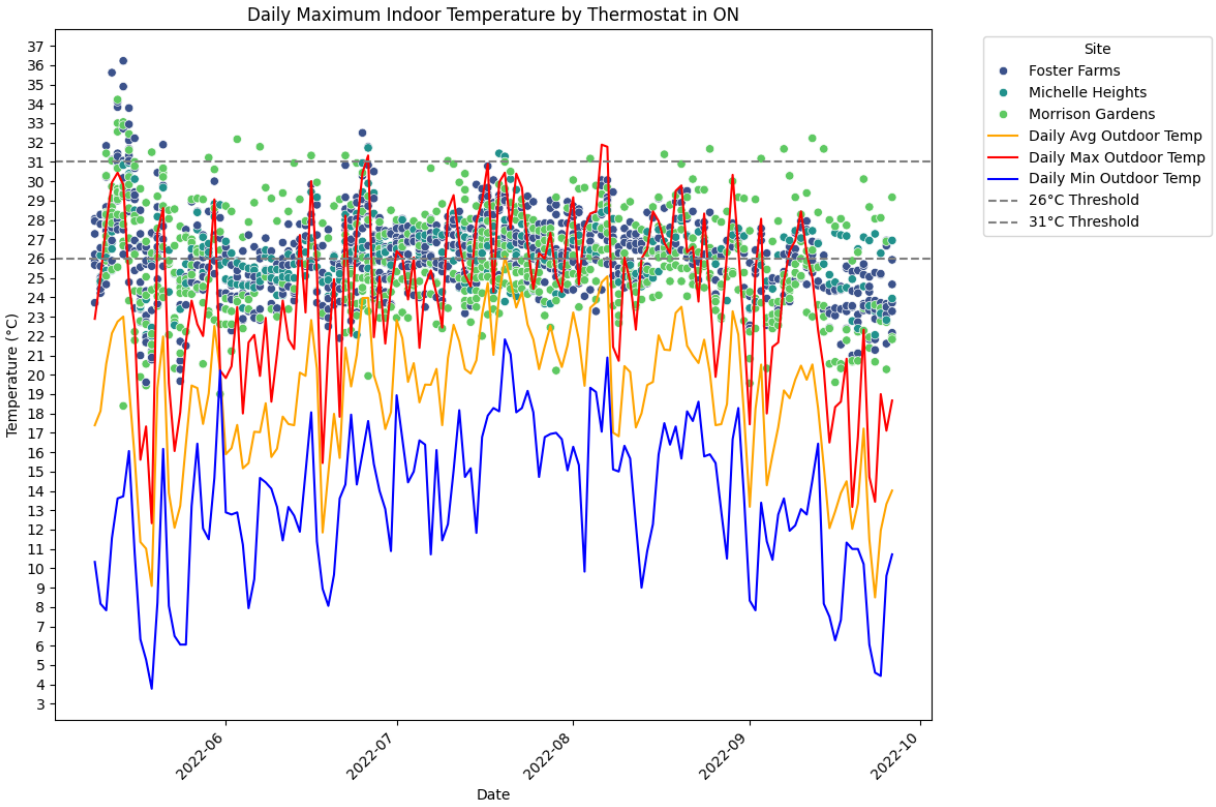


Figure 7.12: Daily maximum indoor temperatures from all thermostats in Ontario

Time at Level 1 and Level 2 threshold ranges

The total time was calculated for the homes that recorded temperatures within the two designated threshold zones for the project (Level 1 = 26°C up to 30.9°C and Level 2 = 31°C), then converted into days for easier interpretation.

Site	Floor Level	Days at Level 1	Days Level 2
American	3	5.33	1.67
Hall Tower	6	27.33	2.33
Hall Tower	9	64	6
Hall Tower	13	52.33	5
Hall Tower	14	78.33	3
Hall Tower	18	47.33	0.67
Hall Tower	19	14.33	0.67
MacLean	2	35.33	1.33
MacLean	8	48	2
MacLean	12	86.67	4
Rosewood	5	95.33	2.67
Rosewood	7	92	4.67
Rosewood	7	36	1.33
Ross	3	33	0.67
Foster Farms	1	25.33	0.33
Foster Farms	1	12.33	-
Foster Farms*	1	4	-
Foster Farms	1	0.66	-
Foster Farms*	1	4.33	-
Foster Farms	1	-	-
Foster Farms	1	4.66	-
Michelle Heights*	1	8.33	-
Michelle Heights	1	3	-
Morrison Gardens	1	1	-
Morrison Garden	1	27.33	-
Morrison Gardens	1	1.33	-

Table 7.1: Number of days thermostats that reached Level 1 (26°C up to 30.9°C) and Level 2 (31°C and above) spent in those temperature ranges. *Homes without air conditioning.

7.3.4 Survey results

Results from the first survey collected during the first visit in May 2022 are tabulated in 7.2 with responses from BC and Ontario.

Participants' characteristics		BC (n=36), n (%)	ON (n=29), n (%)
Number of adults	1	29 (81%)	9 (31%)
	2	7 (19%)	12 (39%)
	3 or more	-	11 (32%)
Number of children	0	*33 (92%)*	10 (35%)
	1	2 (6%)	5 (17%)
	2	1 (3%)	6 (21%)
	3 or more	-	8 (28%)
Number of bedrooms	0	16 (44%)	-
	1	17 (47%)	-
	2	2 (6%)	10 (35%)
	3	1 (3%)	16 (55%)
	4 or more		3 (10%)
Window use on hot days	Day (open), night (open)	28 (78%)	2 (7%)
	Day (closed), night (open)	3 (8%)	7 (24%)
	Day (closed), night (closed)	2 (6%)	9 (31%)
	Day (open), night (closed)	2 (6%)	6 (21%)
	Cannot open	1 (3%)	2 (7%)
	No data	-	3 (10%)
Use of window covers	Indoor window blinds, curtains or shades	33 (92%)	24 (83%)
	Indoor blackout curtains	4 (11%)	11 (38%)
	Outdoor window shades	0	2 (7%)
Use of air-cooling devices	Portable fan	31 (86%)	19 (66%)
	Air conditioner	5 (14%)	24 (83%)
	Windows fan	2 (6%)	10 (35%)
Type of air cooling device used	Window unit	-	13 (45%)
	Portable unit	-	5 (17%)
	Both types	-	2 (7%)

Table 7.2: Baseline characteristics of the study sample (n=36).

Results from the second survey, from Ontario and British Columbia, were collected in July 2022 in Table 7.3.

Participants characteristics		BC (n=36), n (%)	ON (n=29), n (%)
Age range	18-24	-	3 (10%)
	25-34	2 (6%)	7 (24%)
	35-44	2 (6%)	6 (21%)
	45-54	4 (11%)	5 (17%)
	55-64	12 (33%)	5 (17%)
	65-74	11 (31%)	3 (10%)
	75-84	5 (14%)	-
Gender	Man	19 (53%)	8 (28%)
	Woman	16 (44%)	21 (72%)
	Prefer not to declare	1 (3%)	-
Racial/Ethnic background	Indigenous	3 (8%)	3 (10%)
	South Asian	1 (3%)	-
	Black	1 (3%)	8 (28%)
	East/South East Asian	6 (17%)	2 (7%)
	Middle Eastern	5 (14%)	4 (14%)
	White	19 (53%)	12 (41%)
	Do not know	1 (3%)	-
Primary language	English/French	30 (83%)	30 (83%)
	Cantonese	2 (6%)	2 (6%)
	Farsi/Persian	2 (6%)	2 (6%)
	Punjabi	1 (3%)	1 (3%)
	Russian	1 (3%)	1 (3%)
Time living in BC/Ottawa	Less than one year	1 (3%)	1 (3%)
	More than a year	35 (97%)	35 (97%)
Living arrangement	Alone	28 (78%)	2 (7%)
	With roommates	-	1 (3%)
	With family	2 (6%)	9 (31%)
	With partner, no dependent(s)	5 (14%)	1 (3%)
	With partner, with dependent(s)	-	7 (24%)
	Single parent(s) with dependent(s)	1 (3%)	9 (31%)
Education level	Some school, no degree	9 (25%)	5 (17%)
	High school graduate	8 (22%)	8 (28%)
	Some post-secondary, no degree	7 (19%)	3 (10%)
	College diploma	8 (22%)	6 (21%)
	Bachelor's degree	3 (8%)	4 (14%)
	Special needs education	1 (3%)	2 (7%)
	Other	-	1 (3%)
Employment status	Full-time	-	7 (24%)
	Part-time	2 (6%)	6 (21%)
	Self-employment	1 (3%)	2 (7%)
	Unemployed and actively seeking work	3 (8%)	3 (10%)
	Unemployed and not seeking work	8 (22%)	4 (14%)
	Student	1 (3%)	1 (3%)
	Volunteer	6 (17%)	3 (10%)
	Retired	12 (33%)	2 (7%)
	Other	3 (8%)	1 (3%)
	No Answer	-	5 (17%)
Work night shifts	Yes	2 (6%)	23 (80%)
	No	34 (94%)	1 (3%)

Table 7.3: Demographic characteristics of the study sample.

Table 7.4: Questions on experience over the 2022 summer, activities and perceptions on preparedness.

Summer characteristics		**BC (n=36), n (%)**	**ON (n=29), n (%)**
Experienced symptoms	Yes	23 (64%)	12 (41%)
	No	13 (36%)	17 (59%)
Symptoms reported	Fatigue	16 (70%)	7 (24%)
	Dehydration	12 (33%)	7 (24%)
	Heat exhaustion	11 (52%)	2 (7%)
	Heat cramps	8 (35%)	2 (7%)
	Heat rash	6 (26%)	3 (10%)
	Heat stroke	3 (13%)	1 (3%)
	Other (Nausea, headache, etc.)	2 (9%)	1 (3%)
	No symptoms	-	8 (28%)
Comfort in home	Too hot	18 (50%)	14 (48%)
	Comfortable	13 (36%)	10 (35%)
	Do not know	4 (11%)	1 (3%)
	Too cold	1 (3%)	-
	Other	-	4 (14%)
Barriers to comfort	Building (windows, air pollution, heat in building, access to AC.)	15 (42%)	15 (42%)
	No barriers	10 (28%)	7 (24%)
	Personal (financial, health, etc.)	8 (22%)	6 (21%)
	External (climate change, too much sunshine)	2 (6%)	1 (3%)
	No answer	1 (3%)	5 (17%)
Barriers faced	Have financial barriers	13 (36.1%)	6 (21%)
	Other (purchase an extra fan, use the library, windows cannot open, etc.)	13 (36.1%)	9 (48%)
	Restrictions from landlord	3 (8.3%)	2 (7%)
	Prefer not to answer	2 (6%)	2 (7%)
	Information difficult to understand	-	2 (7%)
	Would prefer in a language I understand	1 (3%)	-
	Cool spaces far away or difficult to access	1 (3%)	1 (3%)
	Cool spaces not comfortable or not suitable for my needs	1 (3%)	1 (3%)
	No answer	-	1 (3%)
Use of public green spaces	¡5-min walk away	12 (34%)	5 (17%)
	Other (Mobility barriers, etc.)	9 (25%)	5 (17%)
	Do not know of any or there are none	4 (11%)	2 (7%)
	Do not like them	3 (8.3%)	3 (10%)
	Drive, take public transit or bike to green space	3 (8.3%)	2 (7%)
	5–10-minute walk away	3 (8.3%)	4 (14%)
	10–15-minute walk away	1 (3%)	5 (17%)
	15 min+ walk away	1 (3%)	2 (7%)
	Prefer not to answer	-	1 (3%)

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Table 7.4 – continued from previous page

Summer characteristics		BC (n=36), n (%)	ON (n=29), n (%)
Plan for a hot day	Do not know what they would do	18 (50%)	2 (7%)
	Do not have a place to go	12 (34%)	3 (10%)
	Cooler room, balcony / basement	4 (11%)	9 (31%)
	Outside	1 (3%)	-
	Family or friends	1 (3%)	5 (17%)
	Prefer not to answer	-	2 (7%)
Plan for a hot night	Family or friends	18 (50%)	4 (14%)
	Do not have a place to go	-	1 (3%)
	Do not know what they would do	9 (25%)	1 (3%)
	Cooler room, balcony / basement	4 (11%)	9 (31%)
	Outside	4 (11%)	-
	Prefer not to answer	1 (3%)	10 (34%)
Setting	Personal (body)	17 (47%)	9 (31%)
	Environmental	19 (53%)	10 (35%)
Activities undertaken	Stay hydrated	33 (92%)	21 (72%)
(italics = environment)	Watched for symptoms	24 (67%)	15 (52%)
	Wore appropriate clothing	27 (75%)	15 (52%)
	Wore a wet shirt or damp towels	19 (53%)	4 (14%)
	Stayed cool indoors	*20 (56%)*	*21 (72%)*
	Sought shade	*20 (56%)*	*13 (44%)*
	Cut down on exercise or strenuous activity	23 (64%)	8 (28%)
	Planned outdoor activities for AM	*16 (44%)*	*10 (35%)*
	Used hat, sunglasses, sunscreen	17 (47%)	9 (31%)
	Covered windows with drapes or shades	25 (70%)	10 (24%)
	Closed windows around 10 AM	*16 (44%)*	*11 (38%)*
	Used stove or oven less	*19 (53%)*	*12 (41%)*
	Used fan	*26 (72%)*	-
	Avoided direct airflow on the body	*16 (44%)*	*2 (7%)*
	Used cool room	*19 (53%)*	*4 (14%)*
	Considered getting AC	*5 (14%)*	*7 (24%)*
	Other (baths, sought medical attention)	*11 (31%)*	*2 (7%)*
Where heat waves were heard	TV (weather channel, news broadcast)	23 (64%)	13 (45%)
	Online weather information website (mobile app, weather website, etc.)	14 (39%)	14 (48%)
	Social media (Twitter, Facebook, etc.)	6 (17%)	6 (21%)
	Online health authority (health authority website, government website, etc.)	5 (14%)	1 (4%)
	Radio (AM or FM)	5 (14%)	6 (21%)
	Newspaper (printed)	4 (11%)	2 (7%)
	I did not hear about the heat wave	2 (6%)	6 (21%)
Where did they want to hear it from	TV (weather channel, news broadcast)	23 (64%)	8 (28%)
	Online weather information website (mobile app, weather website, etc.)	19 (53%)	11 (38%)

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Table 7.4 – continued from previous page

Summer characteristics		BC (n=36), n (%)	ON (n=29), n (%)
	Social media (Twitter, Facebook, etc.)	14 (39%)	3 (10%)
	Alert Ready	14 (39%)	14 (34%)
	Online health authority (health authority website, government website, etc.)	12 (34%)	9 (31%)
	Radio (AM or FM)	9 (25.2%)	4 (14%)
	Newspaper (printed)	5 (14%)	-
	Word of mouth (e.g., friends & family, neighbour, building manager)	-	5 (17%)
	Other (Family doctor, friends & family, home support worker, BCH, text messages / common sense, notice from OCH)	5 (14%)	2 (7%)

Table 7.5: Questions of perception and knowledge of heat waves

Questions about recent heat wave		BC (n=36), n (%)	ON (n=29), n (%)
Did you experience a heat wave between May 2022 and October 2022?	Yes	32 (89%)	13 (45%)
	No	1 (3%)	8 (28%)
	Not sure	3 (8%)	8 (28%)
Were you concerned about your health during this heat wave?	Very concerned	8 (22%)	3 (10%)
	Somewhat concerned	13 (36%)	6 (21%)
	Not concerned	15 (42%)	16 (55%)
	Not sure	-	4 (14%)
How did you hear about the heat wave(s)?	TV (weather channel, news broadcast)	23 (64%)	13 (45%)
	Radio (AM or FM)	5 (14%)	5 (14%)
	Newspaper (printed)	4 (11%)	2 (7%)
	Online weather information website (mobile app, weather website, etc.)	14 (39%)	13 (45%)
	Online health authority (health authority website, government website, etc.)	5 (14%)	-
	Social media (Twitter, Facebook, etc.)	6 (17%)	6 (21%)
	I did not hear about the heat wave	2 (6%)	6 (21%)
Did you hear about ways to protect yourself and stay safe during heat waves?	Yes	36 (100%)	22 (76%)
	No	-	4 (14%)
	Not sure	-	3 (10%)
I believe heat waves pose a risk to me personally	Strongly agree	13 (36%)	6 (21%)
	Agree	13 (36%)	9 (31%)
	Neither agree nor disagree	2 (6%)	8 (28%)
	Disagree	1 (3%)	6 (21%)
	Strongly disagree	-	-
How risky do you think heat waves are?	Extremely risky	16 (44%)	6 (21%)
	Very risky	7 (19%)	11 (38%)
	Somewhat risky	11 (31%)	11 (38%)
	Not so risky	-	-
	Not at all risky	2 (6%)	-
	No answer	-	1 (3%)
I am equipped to protect my health and those around me during the next heat wave	Strongly agree	9 (25%)	10 (35%)
	Agree	17 (47%)	14 (48%)
	Neither agree nor disagree	7 (19%)	3 (10%)
	Disagree	3 (8%)	-
	Strongly disagree	-	2 (7%)
Heat waves are dangerous to my community	Strongly agree	14 (39%)	6 (22%)
	Agree	18 (50%)	8 (28%)

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Table 7.5 – continued from previous page

Questions about recent heat wave		BC (n=36), n (%)	ON (n=29), n (%)
	Neither agree nor disagree	4 (11%)	10 (34%)
	Disagree	-	2 (7%)
	Strongly disagree	-	1 (3%)
Canada is prepared to handle more frequent, intense, and longer heat waves	Strongly agree	3 (8%)	5 (17%)
	Agree	13 (36%)	7 (24%)
	Neither agree nor disagree	13 (36%)	7 (24%)
	Disagree	4 (11%)	2 (7%)
	Strongly disagree	3 (8%)	-

Tables 7.4 and 7.5 display the survey responses collected at the end of September and the beginning of October during the final visit.

7.3.5 ecobee DYD from 2022

A subset of homes in Ottawa and Vancouver from 2022 was extracted from the ecobee DYD dataset that contains more than 230,000+ home thermostats (approximately 1.6 TB of data). The authors selected homes in the same cities as the deployment, specifically targeting those without air conditioning, to validate the recorded temperature ranges. These data were used to compare indoor temperatures across similar environmental conditions, ensuring the reliability of the findings and providing a basis for analysing the impact of indoor heat exposure on unair-conditioned households. For the analysis, the homes of the DYD data set were filtered to match the study cities, and those without air conditioning were selected. The average temperatures were calculated for the dates corresponding to the study period, converted to Celsius, and averaged to ensure consistency. In addition, the type of home was recorded to account for potential variations in temperature based on the characteristics of the house.

Figure 7.6 summarises the average indoor temperatures by month (May, June, July, August, September) by type of home (apartment vs detached homes) with air conditioning in 2022.

Type	Month	Burnaby	New Westminster	Richmond	Vancouver	Ottawa
Apartment	5	22.94	n/a	23.71	22.36	21.93
Apartment	6	23.50	n/a	23.26	23.12	22.00
Apartment	7	23.81	n/a	23.52	23.22	22.44
Apartment	8	23.82	n/a	23.87	23.27	22.35
Apartment	9	23.66	n/a	23.61	22.46	22.03
Detached Home	5	22.09	n/a	20.89	20.22	21.95
Detached Home	6	22.25	24.30	21.06	22.02	22.13
Detached Home	7	22.62	23.83	21.75	23.22	22.85
Detached Home	8	22.59	23.91	22.18	23.47	22.75
Detached Home	9	21.99	23.97	22.40	22.97	21.93

Table 7.6: The average indoor temperatures recorded during 2022.

7.4 Findings

7.4.1 Key Findings

The study revealed that:

- Indoor temperatures frequently exceeded safe thresholds (26°C and 31°C) across both provinces, with upper floors experiencing more prolonged heat exposure.
- Window film treatments were statistically significant in reducing indoor heat, but showed variability in effectiveness due to external factors such as shading and ventilation.
- Residents in British Columbia relied more on passive cooling strategies and adapting behaviours likely due to having more recent lived experiences and increased education on extreme heat, while Ontario participants preferred to use air conditioning and basements.

Notably, 16% of Ontario participants with air conditioning reported temperatures above 26°C, highlighting potential inefficiencies in cooling systems or usage patterns.

7.4.2 Challenges in data collection

From May to September 2022, temperature data was collected from thermostats in Ontario (May 9 - September 30) and British Columbia (May 16 - September 30), with over 1 million and 1.1 million data points, respectively. However, significant portions of the data were missing, with Ontario experiencing 47% missing data and British Columbia 26%. In Ontario, 30 thermostats were initially installed, but one participant withdrew before July, while all 40 thermostats in British Columbia participated throughout. Missing data was attributed to technical issues with routers requiring manual resets, faulty thermostats, occupants turning off furnace power (disabling thermostats), and a nationwide Internet outage with telecommunications company Rogers on July 8, 2022, lasting several days. Manual resets of the router required scheduling home visits during normal business hours, with efforts made to minimise disruption to participants. The Ontario site also faced additional challenges, with one thermostat being removed from the data after the participant's withdrawal. Both studies highlight the logistical complexities of ensuring consistent data collection in real-world settings.

7.4.3 Window film treatment at Hall Tower

Both Hall Towers in Burnaby had interior window film treatment installed in 2021, except for the amenity room on the 19th floor. Here, a thermostat was placed to compare the indoor temperature without window treatment and to compare the temperature to the units that received window treatment. Unfortunately, no measurements were available prior to window film installation to make a true comparison. The windows of this room face north and west and feature a large balcony along one side accessed through a large glass sliding door. During the study, the thermostat was removed from the room by unknown individuals. Upon its return, it was placed on a counter in the room instead of being reinstalled in its original location. The maximum indoor temperature recorded between May 16 - September 30, 2022, was 38.1°C on June 26, 2022, at 8:20 PM. This occurred during a 3-day heat warning period. Figure 8 shows how the indoor temperature on the 19th floor, in red, compares with two units, shown in brown and yellow, on the 18th floor that had interior window film installed from midnight June 25 to midnight June 28. At that time, the outdoor temperature was 24.6°C, shown in blue in Figure 7.13.

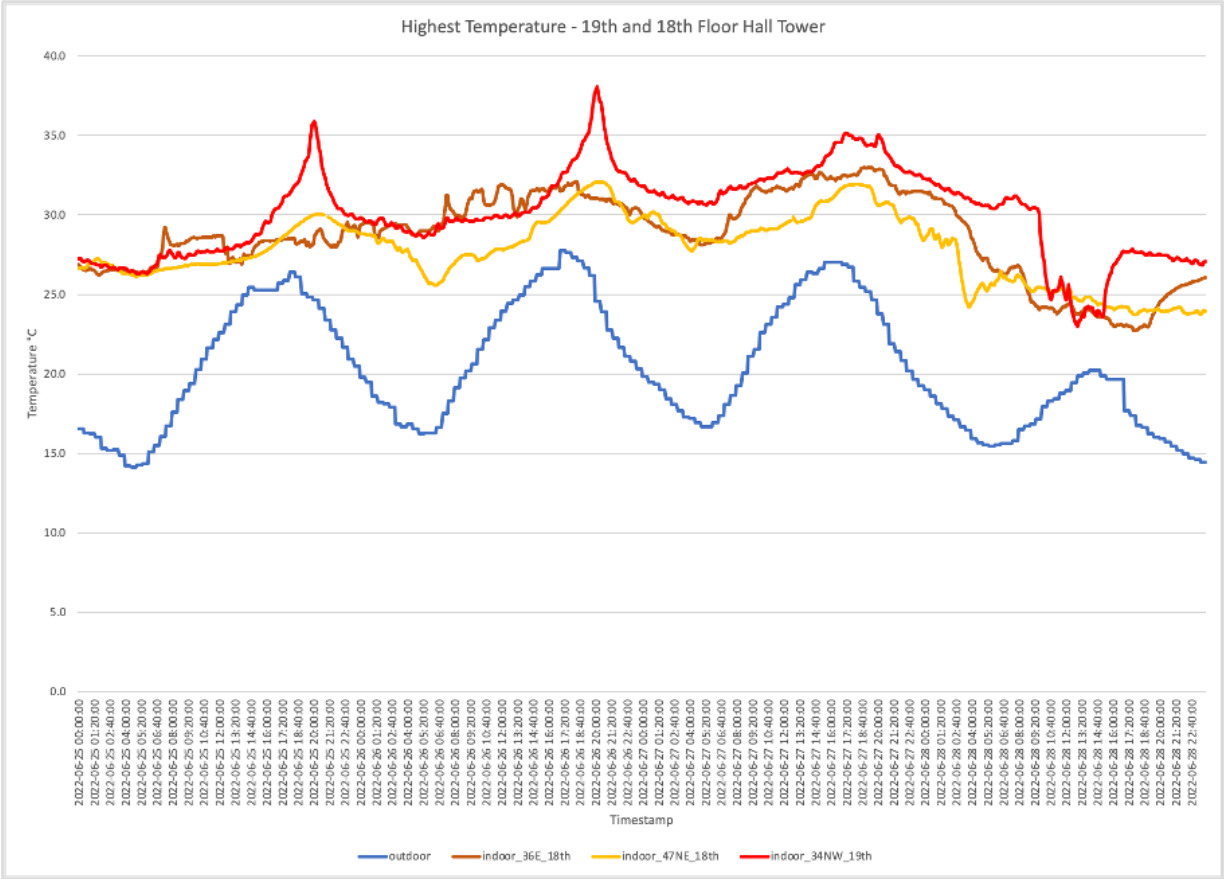


Figure 7.13: No-film versus film on the 19th (shown in red) and 18th floor (shown in brown and yellow) of Hall Tower. The outside temperature is shown in blue.

The 18th floor units follow a trend line similar to that on the 19th floor and, at first glance, appear to be protected by the film from spikes in higher temperatures. This appears to be the case for the first few days, but the effect is less pronounced on the third day. Also, it is important to note that the outdoor temperatures did not go above 30°C, yet the indoor temperatures were still above the outlined safe limits of 31°C for nearly three days. Additional factors that may have affected indoor temperatures include the following:

- The presence and proximity of generators and mechanical ventilation equipment on the roof
- Occupation of units

- Use of electronic devices (multimedia equipment, computer, etc.) or appliances (i.e., stovetop or oven, etc.)
- Use of doors and windows by occupants and placement of windows (cross-ventilation)
- Use of shading on windows to either block or reflect light from inside or outside.
- Use of mechanical ventilation such as fans
- The total amount of glazing and ratio to wall surface area
- Shade from buildings and trees (for lower levels)
- Reflected heat from surroundings (i.e., parking lots, streets)

The Mann-Whitney U test revealed a statistically significant difference in temperatures between the room without window film (thermostat 34) and the rooms with window film within the same building (thermostats 32, 36, 47, 60, and 67), U = 1,170,580,398.5, $p < 0.001$, indicating that the presence of window film has a significant impact on the regulation of temperature in the building.

Ross Towers received window film treatment between June 27 and August 2, 2022. Three thermostats were placed in the units at Ross. This film, a medium dual-layer solar film, reduced the incoming heat and glare by 63% and the light by 68% and was intended to reduce the incoming ultraviolet light by more than 99%. Furthermore, in winter, the film will reduce the outgoing heat by 19%. This is the same film that BC Housing had installed at Hall Towers before the start of the study.

If we examine the units individually, there is some variation in the temperature readings between the different units. The unit on the 7th floor experienced temperatures higher than those of the other two locations for most months. Furthermore, the data show a general trend of increasing temperatures from May to August, followed by a decrease in September.

7.4.4 Real-time automated alerts and thresholds

During the study period, thermostats across British Columbia and Ontario recorded critical indoor temperature patterns, offering insights into the frequency and duration of elevated indoor temperatures and their potential health risks. The 40 thermostats in British Columbia recorded temperatures within Level 1 ($\geq 26°C - 30.9°C$), and 14 thermostats reached Level 2 ($\geq 31°C$). Fourteen thermostats also recorded extended 8-hour periods

above 31°C (Level 2), which were adjusted to full days. On average, the thermostats recorded data for 135 ± 2 days.

Site	**Floor**	**Days at Level 1**	**Days Level 2**
American	3	5.3	1.7
Hall Tower	6	27.3	2.3
Hall Tower	9	64	6
Hall Tower	13	52.3	5
Hall Tower	14	78.3	3
Hall Tower	18	47.3	0.7
Hall Tower	19	14.3	0.7
MacLean	2	35.3	1.3
MacLean	8	48	2
MacLean	12	86.7	4
Rosewood	*5*	95.3	2.7
Rosewood	7	92	4.7
Rosewood	7	36	1.3
Ross	3	33	0.7

Table 7.7: Thermostats that reached Level 2 during the study and days spent at Level 2 and 1 in British Columbia.

Site	Thermostat	Days at Level 1	Days Level 2
Foster Farms	2	25.3	0.3
Foster Farms	3	12.3	0
Foster Farms*	8	4	0
Foster Farms	11	0.7	0
Foster Farms*	12	4.3	0
Foster Farms	14	-	0
Foster Farms	15	4.7	0
Michelle Heights*	4	8.3	0
Michelle Heights	7	3	0
Morrison Gardens	18	1	0
Morrison Garden	21	27.3	0
Morrison Gardens	22	1.3	0

Table 7.8: Thermostats that reached Level 2 during the study and days spent at Level 2 and 1 in Ottawa. *Homes without air conditioning.

Temperature thresholds in British Columbia

Table 7.7 highlights the days thermostats spent at Level 1 and Level 2 in British Columbia. For example, MacLean (Floor 12) and Rosewood (Floor 7) recorded some of the highest numbers of Level 2 days, indicating prolonged exposure to hazardous indoor temperatures. The data reveal that higher floor levels do not always result in higher indoor temperatures, challenging common assumptions. Insulation quality, building orientation, window and door placement, and construction materials likely influence temperature variation. For instance, buildings with increased solar exposure on higher floors may experience warmer temperatures, while those exposed to prevailing winds may remain cooler.

Temperature thresholds in Ontario Table 7.8 summarizes thresholds reached in Ottawa, where all thermostats recorded days within Level 1, but only a subset reached Level 2. In particular, homes with air conditioning (AC) were less likely to reach Level 2, although some homes equipped with AC still recorded extended periods at or above 26°C. Foster Farms, Michelle Heights, and Morrison Gardens show variations in exposure, with homes without AC (marked with an asterisk in the table) demonstrating a greater vulnerability to elevated temperatures. On average, thermostats in Ottawa recorded data for 141±2141±2 days.

Implications and further considerations Projections for 2050 indicate a significant increase in extreme heat events, with Vancouver predicted to experience five very hot days

($\geq 30°C$) annually, compared to one very hot day per year between 1976 and 2005. Similarly, Ottawa is expected to see an annual average of 50.1 very hot days ($\geq 30°C$) by 2050, up from 9.6 very hot days annually between 1976 and 2005. These increases suggest that unair-conditioned homes, which currently experience approximately 2.57 days of elevated indoor temperatures for every outdoor "very hot day," will face longer periods of dangerous indoor conditions as outdoor heat events increase.

The data show that indoor temperatures can exceed outdoor temperatures by as much as 10°C or more, influenced by factors such as insulation quality, glazing, building design, and orientation. Although higher floors are often assumed to be warmer, the study found that this is not universally true. The interplay of solar radiation, prevailing winds, construction materials, and home activities (e.g., cooking or appliance use) likely plays a significant role. Buildings with major glazing oriented towards the sun tend to experience greater heat accumulation, while those aligned with breezes may benefit from natural cooling [Kahsay et al., 2021].

The findings offer critical insights for building managers and public health officials. Understanding occupant behaviours during heat events and how building design influences indoor temperatures can guide the development of policies and interventions to ensure safe and comfortable living environments. Improved ventilation, insulation, and air filtration systems can mitigate the risks of extreme heat, wildfire smoke, and respiratory illnesses such as COVID-19 [Allen, 2023, Coker et al., 2024]. As awareness of indoor air quality increases, addressing these issues is crucial to enhance resilience to extreme weather and improving public health outcomes.

These results underscore the urgent need for targeted strategies to effectively manage indoor environments during heat events. By addressing the interplay of building-specific factors and external conditions, policymakers can develop comprehensive approaches to mitigate risks and support the most vulnerable by ensuring that they are not forgotten during extreme heat events.

7.4.5 Indoor temperature patterns

Apartments in British Columbia The heat map in Figure 7.7 illustrates the hourly average indoor temperatures of a thermostat on the 14th floor of a building in British Columbia. The colour scale ranges from cooler temperatures (blue, below 26°C) to warmer temperatures (red, above 26°C). The colour scale ranges from cooler temperatures (blue, below 26°C) to warmer temperatures (red, above 26°C). A clear pattern emerges, showing that the warmest indoor temperatures typically occurred in the afternoon and early evening,

from approximately 12:00 to 18:00, with some peaks reaching or exceeding 31°C in mid-June and mid-July. These periods coincide with the hottest times of the day, suggesting that the building may struggle to dissipate heat during the daytime, leading to a significant buildup of indoor heat.

In contrast, cooler temperatures (below 26°C) are most prevalent during the late night and early morning hours, particularly from 00:00 to 06:00, indicating that the apartment experiences some nighttime cooling. However, despite this cooling, the apartment remains warm throughout the day, particularly during the hottest summer months. Sustained high indoor temperatures during peak afternoon hours pose significant health risks, particularly to vulnerable populations such as older adults, individuals with pre-existing health conditions, and those without access to cooling resources. Research shows that indoor temperatures exceeding 26°C can increase the risk of heat-related illnesses, with prolonged exposure above 31°C being especially hazardous [Kenny, 2022].

The findings also raise concerns about the effectiveness of Heat Alert and Response Systems (HARS) in Canada, which are based on outdoor temperature thresholds, such as daytime highs of 29°C or more and nighttime lows above 16°C for two consecutive days in British Columbia [BC CDC, 2023]. This misalignment between outdoor-based alert systems and actual indoor temperatures could lead to inadequate responses during dangerous heat conditions. Addressing this gap is critical for protecting apartment residents during heat events.

Townhouses in Ontario The heat map in Figure 7.8 shows the average indoor temperatures per hour for a thermostat in a two-story townhouse in Ottawa, Ontario, from May to late September. Similarly to the apartment in British Columbia, a clear pattern emerges where cooler indoor temperatures (below 26°C) are prevalent during the late night and early morning hours (00:00 to 06:00), particularly in June and early July. However, as the day progresses, temperatures rise steadily, peaking between 13:00 and 19:00, frequently exceeding 26°C and occasionally surpassing 30°C. This pattern indicates that the home experiences significant heat accumulation during the day, particularly during the warmer months of July and August.

This pattern suggests significant heat accumulation during the day, indicating insufficient cooling mechanisms or insulation to regulate indoor temperatures during the hottest parts of the day. Although indoor temperatures cooled at night, persistent daytime heat could create uncomfortable living conditions and increase health risks, especially for vulnerable residents. The findings underscore the importance of improving thermal insulation and adopting effective cooling strategies to prevent prolonged exposure to indoor heat during the summer months.

7.4.6 Comparison of indoor and outdoor temperatures in Ontario and BC

Ontario In Ontario, data collection began on May 9, 2022, with some participants still used heating in late May and June due to cooler spring temperatures. August recorded the highest outdoor maximum and the highest average indoor and outdoor temperatures during the study period. The average indoor temperature at three sites, Foster Farms, Michelle Heights, and Morrison Gardens, ranged from 24° C to 24.93° C. The graph in Figure 7.10 illustrates the daily average indoor temperatures along with the maximum and minimum outdoor temperatures, with two critical thresholds (26°C and 31°C) highlighted.

Indoor temperatures frequently exceeded the 26°C threshold, and several readings surpassed the 31°C threshold, particularly from mid-June to mid-September. This pattern indicates prolonged exposure to elevated indoor temperatures, which poses substantial health risks to vulnerable populations. In particular, indoor temperatures remained consistently high, even when outdoor minimums often dropped below 20°C, suggesting that homes retained heat and did not effectively cool overnight.

On average, during the data collection period (May 9 - Sep 25, 2022), monthly indoor temperatures across Ottawa study sites were within 6.02°C - 7.65°C of the average outdoor temperatures. These findings highlight the challenge of managing indoor environments during heat waves, even when outdoor temperatures fluctuate, highlighting the need for effective cooling strategies to mitigate the risks associated with prolonged exposure to indoor heat.

British Columbia In British Columbia, data collection began on May 16, 2022, and similarly, some participants were still using heating in late May and June. July recorded the highest outdoor maximum temperature (38°C), while August recorded the highest average indoor and outdoor temperatures of 2022. The graph in Figure 7.9 presents the daily average indoor temperatures in five sites: Rosewood, Hall Tower, Ross, MacLean, and American, alongside outdoor maximum and minimum temperatures, with thresholds of 26°C and 31°C highlighted.

Indoor temperatures frequently exceeded the 26°C threshold from mid-June to early September, with several days exceeding 31°C, particularly at the Ross and American sites. These elevated temperatures pose significant health risks, especially for vulnerable populations, as prolonged exposure above 26°C increases heat-related health risks, with temperatures above 31°C being particularly hazardous [Meade et al., 2024a].

Despite relatively moderate daily minimum outdoor temperatures, indoor environments often remained consistently elevated. This disparity suggests poor ventilation, heat retention,

or insufficient cooling infrastructure, leading to hazardous indoor conditions even under less extreme outdoor temperatures. During the study period, the monthly indoor temperatures at the BC sites were within 7.5°C - 11.8°C of average outdoor temperatures.

7.5 BC thermostat data

During the 2022 heat season, all thermostats recorded indoor temperatures of 26°C or higher at some point, indicating widespread exposure to elevated indoor heat, see Figure 7.6. Furthermore, at least one thermostat consistently reached or exceeded the 26°C threshold every day of the study, highlighting a persistent and daily indoor heat risk throughout the season.

More than half (59%) of the thermostats in the study recorded 31°C during the 2022 heat season, and at least one thermostat recorded the indoor temperature threshold of 31°C on 100 days of the approximately 137-day study period. This is a reminder that Level 1 (26°C up to 30.9°C) and Level 2 (31°C and above) refer to the threshold ranges established for this study that trigger automated email alerts sent to BC Housing and public health officials. This study established two indoor temperature thresholds to trigger automated email alerts: Level 1 at 26°C to 30.9°C and Level 2 at 31°C and above. These thresholds are informed by health guidelines that indicate that indoor temperatures exceeding 26°C can increase the risk of heat-related illnesses, particularly among vulnerable populations [Kenny, 2022]. For example, Toronto Public Health advises that indoor temperatures should not exceed 26°C to reduce the risk of heat-related mortality [Medical Officer of Health, 2015]. By implementing these thresholds, the alert system aims to provide timely warnings to occupants and relevant authorities, enabling immediate actions to mitigate the adverse health effects of elevated indoor temperatures.

Key Observations and Implications Across both provinces, sustained elevation of indoor temperatures despite outdoor fluctuations highlights the significant challenge of managing indoor heat during the summer months. Factors such as poor ventilation, inadequate insulation, and inadequate cooling systems, particularly in residential spaces, contribute to this problem. The findings emaphazise the importance of improved insulation, ventilation systems, and affordable cooling infrastructure to mitigate health risks and ensure safe indoor environments during heat waves. Addressing these challenges will become increasingly critical as climate change increases the frequency and intensity of extreme heat events.

7.5.1 Daily averages, maximums, and minimums

British Columbia The graph in Figure 7.12 displays daily maximum indoor temperatures across all monitored thermostats in British Columbia. A significant portion of the data points exceeded the 26°C threshold, with a notable number exceeding 31°C, particularly from mid-June to early September. These findings highlight the challenges of maintaining comfortable indoor conditions, as insufficient cooling or ventilation can leave homes vulnerable to excessive heat.

The average indoor temperatures in BC sites ranged from 24.2°C to 26.3°C during the study period. The averages of the specific sites varied: America (23.9°C – 24.9°C), Hall Towers (24.6°C–28.3°C), MacLean Park (24.1°C – 29.2°C), Rosewood (24.39°C – 28.6°C), and Ross (approximately 25°C across all floors). Despite missing data, 73% (29 out of 40) of the thermostats recorded indoor temperatures at or above 31°C, with the 40 thermostats exceeding 26°C at some point. These data emaphazise the need for targeted cooling interventions, particularly in buildings where floor levels and orientation influence heat retention and distribution.

Ontario The graph in Figure 7.11 illustrates daily maximum indoor temperatures at three Ontario sites: Foster Farms, Michelle Heights, and Morrison Gardens. A substantial portion of the recorded temperatures exceeded the 26°C threshold, several exceeding 31°C, particularly from June through September. These elevated indoor maximum temperatures suggest inadequate cooling measures, highlighting the risks posed by sustained heat exposure, especially during prolonged heat waves.

On average, indoor temperatures at Foster Farms ranged from 22.8°C to 28°C, at Michelle Heights from 24.2°C to 26.3°C, and at Morrison Gardens from 19.9°C to 26.7°C. Despite incomplete data collection, all monitored units recorded temperatures above 26°C, and 12 of the 29 sites that continued throughout the summer recorded indoor temperatures exceeding 31°C. Significant differences between outdoor temperatures and indoor maximums indicate that heat retention within homes is critical to maintaining elevated indoor temperatures, further exacerbating health risks for residents during the warmest months.

Implications The sustained elevation of indoor temperatures across Ontario and British Columbia poses significant risks to public health, particularly for vulnerable populations such as older adults, individuals with pre-existing conditions, and those without access to adequate cooling resources. The consistent differences between indoor and outdoor temperatures, often by 10°C or more, underscore the critical role of heat retention, insulation, and ventilation in exacerbating indoor heat exposure.

7.5.2 Highest average and daily max

Highest and top temperatures in ON

In Ontario, a Foster Farms thermostat recorded the highest average indoor temperature during the study, reaching 28°C. Another thermostat at Morrison Gardens recorded an average of 26.86°C, followed closely by a thermostat at Morrison Gardens (Site 21) that recorded 26.7°C. The latter spent most of the summer above 26°C, with the most complete data capture for the study, indicating persistent heat retention within the home.

The highest indoor temperatures in Ontario were recorded between May and September 2022, even without an extreme heat warning in Ottawa at the time. In particular, the highest indoor temperatures occurred in mid-May, coinciding with an early heat wave on May 13 and 14, 2022. The unexpectedly high temperatures may have been exacerbated by closed windows and doors and the continued use of heating systems during the transitional season.

Highest and top temperatures in BC

In British Columbia, a thermostat on the 12th floor of MacLean Park recorded the highest average indoor temperature during the study, reaching 29.2°C. Indoor temperatures at this site remained consistently in the high 20s or exceeded 30°C throughout the study, reflecting significant heat accumulation and inadequate cooling.

The highest indoor temperature recorded during the study occurred on September 1, 2022, at MacLean's 6th-floor unit, reaching 38.2°C. This temperature was recorded despite the absence of an extreme heat warning in BC at the time. Factors contributing to this high temperature likely included closed windows and doors, heat-generating electronics, accumulated heat within the building, and a high outdoor temperature of 27°C that day.

Other notable events include unoccupied units in Hall Tower (19th floor) and American (3rd floor), which reached temperatures in the 30s during a Metro Vancouver heat wave on June 26 and 27, likely due to closed environments. Occupied units in Hall Tower (6th and 9th floors) also recorded temperatures of 30°C or higher during this period. MacLean's 6th floor unit peaked at 38.2°C for 10 minutes and remained at Level 2 for approximately three hours on September 1. This unit also reached 31°C on August 30, remaining in Level 2 until late evening. Similarly, the 9th floor of the Hall Tower was at Level 2 for more than 24 hours, with a peak of 35.8°C lasting more than 40 minutes. The 19th floor Amenity Room in the Hall Tower peaked for 10 minutes but remained at Level 2 for more than 10 hours.

Building heights in BC

The data revealed that the temperature ranges across the sites were varied. The floor level appears to have a noticeable impact on the temperature patterns of the buildings. In

the American building, the second floor has the narrowest range of temperatures, with a minimum of 18.0°C and a maximum of 34.5°C. The third floor in the same building has a wider range, with a minimum of 19.8°C and a maximum of 36.2°C.

In the Hall Tower building, the 13th floor has the narrowest temperature range, with a minimum of 23.3°C and a maximum of 28.8°C. The 19th floor in the same building has a wider range, with a minimum of 19.6°C and a maximum of 38.1°C. This indicates that the higher floors in this building may experience more extreme temperature fluctuations. Similarly, in the MacLean building, the 12th floor has a wider range of temperatures, with a minimum of 22.9°C and a maximum of 33.8°C, compared to the 7th floor, which has a narrower range of temperatures, with a minimum of 22.4°C and a maximum of 31.5°C. In the Rosewood building, the 7th floor has a wider range of temperatures, with a minimum of 17.2°C and a maximum of 33.8°C, compared to the 4th floor, which has a narrower range of temperatures, with a minimum of 19.8°C and a maximum of 28.9°C.

Implications

The findings from Ontario and British Columbia highlight critical challenges in managing indoor temperatures during heat events, even in the absence of extreme heat warnings. Persistent high indoor temperatures, often exceeding 26°C and sometimes exceeding 31°C, pose significant risks to health and comfort, particularly for vulnerable populations. Ongoing discussions about indoor temperature thresholds and maximum limits suggest they may be set too low, highlighting the need for further research.

7.5.3 Comparison with ecobee DYD

Homes and apartments without air conditioning in Ontario and British Columbia exhibited varying indoor temperatures, with notable differences between the two regions; see Table 7.6. In Ontario, apartments experienced their highest temperatures in July, with indoor maximums reaching 31.61°C, while detached homes peaked at 31.83°C in the same month. In British Columbia, temperatures peaked in August for detached homes, with Vancouver reaching 31.5 ° C and Burnaby reaching 31.28°C. Apartments generally showed slightly lower maximum temperatures than detached homes, but reached 31.39°C in Vancouver in July. These higher temperatures reflect the increased vulnerability of homes without air conditioning during heat waves, especially in urban areas. The data also suggest that detached homes in BC tended to be warmer than apartments, while in Ontario, both types saw similar peak temperatures.

Apartments in BC have slightly higher average indoor temperatures compared to detached homes across all months and locations. For example, in Burnaby, apartments in

July (23.81°C) are warmer than detached homes (22.62°C). This aligns with the patterns in the temperature graphs, where multi-story buildings (like apartments), particularly higher floors, tend to experience more sustained indoor heat than single-family homes. This suggests that apartments, likely due to their structural design, exposure, height, and materials, therefore retain more heat.

A clear increase in indoor temperatures occurs during July and August, the peak summer months. This is evident as the highest average temperatures occur in July and August, especially in apartments (e.g., Vancouver apartments reach 23.87°C). This aligns with the BC and Ottawa graphs, which show more frequent Level 1 threshold crossings (26°C–30.9°C) during these months, particularly in high-rise buildings in BC.

The graphs further emaphazises that higher floors in multistory buildings are more prone to sustained heat exposure, as seen in BC, where the upper floors of Hall Tower and MacLean experienced significantly more days at higher temperature thresholds than in Ottawa homes. The comparison highlights how structural design and floor level must be considered in mitigating or exacerbating indoor heat exposure during extreme heat events.

7.6 Survey findings

7.6.1 Housing characteristics

During the first visit of this study, when the thermostats were installed, participants in both Ontario and British Columbia completed Survey 1: Housing Characteristics, providing details about their living arrangements and strategies for managing indoor temperatures during hot days.

BC housing characteristics
A total of 36 questionnaires were completed in British Columbia. Most participants lived alone (n = 29, 81%) in either bachelor (n = 16, 44%) or single-bedroom units (n = 16, 47%). Participants were also asked about their window usage on hot days, most kept their windows open day and night (n = 28, 78%). Almost all participants used indoor window blinds, curtains or shades (n = 33, 92%), and 31 participants (86%) reported using a portable fan.

ON housing characteristics
A total of 29 occupied units were included in the Ontario study. Some participants lived alone (n = 9, 31%), 12 lived with one other adult (41%), and 11 lived in households with three or more adults (28%). Ten households had no children (34%), five had one (17%), six

had two (21%), and eight had three or more children (28%). The townhomes were mainly two-bedroom units (n = 10, 35%) or three-bedroom units (n = 16, 56%), with three homes having four or more bedrooms (n = 3, 10%).

Participants were asked about their window usage on hot days:

- Few kept windows open during the day and night (n = 2, 7%).
- Most either closed them during the day and opened them at night (n = 7, 24%) or kept them closed all the time due to air conditioning use (n = 9, 31%).
- Several opened windows during the day and closed them at night (n = 6, 21%).

Almost all participants used indoor window blinds, curtains or shades (n = 24, 83%), with 11 (38%) opting for blackout curtains. Many reported using portable fans (n = 19, 66%), and 24 homes (83%) used air conditioning. Among those with air conditioning, window units were the most common (n = 13, 45%), followed by portable air conditioners (n = 5, 17%), and two homes (7%) used both. Ten homes (35%) also reported using window fans.

Comparison
BC participants predominantly lived alone (81%) in smaller units such as bachelor or single-bedroom apartments, while Ontario participants lived in larger multi-bedroom townhouses, with 69% living with one or more other adults and/or children. Ontario participants were more likely to keep windows closed during the day and open them at night (24%) or to keep them closed entirely (31%) due to the use of air conditioning. In contrast, most of the BC participants (78%) kept their windows open day and night. Portable fans were widely used in both regions (Ontario: 65.5%; BC: 86%). Air conditioning was much more prevalent in Ontario (83%) compared to BC, where participants relied more heavily on natural ventilation.

7.6.2 Demographic characteristics

The demographic characteristics of the participants in Ontario and British Columbia reveal differences in age, household composition, language, and employment patterns, reflecting regional and housing variations.

BC demographics
A total of 36 participants from British Columbia completed the survey. Most of the

participants were between the ages of 55 and 74, and the gender distribution was more balanced, with 53% men and 44% women. Like Ontario, the majority were of European ancestry, and English or French was the primary language for 83% of participants. Additional primary languages included Cantonese, Punjabi, Russian, and Farsi.

Most of the participants lived alone, reflecting the prevalence of bachelor and single-bedroom units at BC sites. In terms of education, most had completed some post-secondary or high school education. More than a third of the participants were retired and only a small proportion reported working night shifts. Most of the participants had lived in the Vancouver area for more than a year.

Ontario demographics
A total of 29 participants from Ontario completed the survey. Most participants were between the ages of 25 and 34, and the majority were women (72%), with 28% identifying as men. Most participants were of European ancestry, with English or French as the primary language for 90% of respondents. Additional primary languages included Arabic, Russian, Somali, and Ukrainian.

The participants largely lived with others, including family (n = 9, 31%), partner and dependents (n = 7, 24%), or as single parents with dependents (n = 9, 31%). Regarding education, most participants had completed high school (n = 8, 28%) or college (n = 6, 21%). Most worked full-time or part-time, with 17% (n = 5) reporting they worked night shifts. Most of the participants had lived in Ottawa, Canada, for more than a year.

Comparison
Ontario participants were younger, with most between 25 and 34, and more likely to be employed, while BC participants were older (55–74) and more likely to be retired. Ontario participants were more likely to live with family or dependents, while BC participants predominantly lived alone. Both groups were predominantly English/French speakers, with Ontario participants reporting additional languages such as Arabic and Somali and BC participants mentioning Cantonese and Punjabi. Women comprised a larger proportion of participants in Ontario (72%), while BC had a nearly even distribution (53% men, 44% women).

7.6.3 Summer 2022 experience

The study results from Ontario and British Columbia reveal shared challenges and regional differences in participants' experiences during the summer of 2022, focusing on symptoms, comfort levels, and barriers to maintaining a comfortable indoor environment.

Heat-related symptoms

Ontario

Of 29 participants, 12 (41%) reported experiencing heat-related stress or illness symptoms, while 17 (59%) did not. The most frequently reported symptoms were fatigue (24%, n = 7) and dehydration (24%, n = 7), followed by heat exhaustion (14%, n = 4), and heat cramps and heat rash (7%, n = 2 each). Less common symptoms included heat stroke (3%, n = 1) and other issues such as nausea and headache (3%, n = 1).

British Columbia

Of 36 participants, 23 (64%) reported experiencing symptoms, while 13 (36%) did not. Fatigue was the most commonly reported symptom (70%, n = 16), followed by dehydration (33%), heat exhaustion (52%), and heat cramps (35%). Less common symptoms included heat rash (26%), heat stroke (13%), and other symptoms such as nausea and headache (9%).

Most Canadians can identify a symptom of heat illness and are more likely to mention dizziness (32%), excessive thirst (26%), nausea (21%, headache (21%), and fainting (21%)) [Health Canada, 2022].

Comfort in the home

Ontario

Half of the participants (50%, n = 14) reported feeling too hot, while 35% (n = 10) felt comfortable. One participant (3%) did not know, and four (14%) selected "Other."
British Columbia Similarly, half of the participants (50%, n = 18) reported feeling too hot, while 36% (n = 13) felt comfortable. Four participants (11%) did not know, and only one (3%) reported feeling too cold.

Barriers to comfort

Ontario

The barriers most commonly reported were building-related factors (21%, n = 6), including poor building insulation, lack of air conditioning, airflow limitations, and shared living preferences. Another 21% (n = 6) reported personal barriers such as financial or health issues, while one participant (3%) cited external factors like summertime. **British Columbia:** Building-related factors were also the most cited barriers (42%, n = 15), including issues like windows, air pollution, building heat, and limited access to air conditioning. Personal

barriers such as financial or health issues were reported by 22% (n = 8), and external factors such as climate change and excessive sunshine were mentioned by 6% (n = 2).

Comparison between ON and BC

Symptoms
Participants in British Columbia reported heat-related symptoms at a higher rate (64%) than those in Ontario (41%). Fatigue, dehydration, and heat exhaustion were the most common symptoms in both regions, although severe symptoms such as heat stroke were more frequently reported in BC (13%) than in Ontario (3%). **Comfort Levels**
Half of the participants in both regions reported feeling too hot in their homes, with building-related factors being the main barrier to comfort. **Barriers**
Building-related challenges, including poor insulation, limited airflow, and lack of cooling systems, were a common theme across both regions. Financial barriers were also significant, underscoring the inequities in accessing effective cooling solutions. 6% of Canadians reported installing or upgrading air conditioning in 2022 [Health Canada, 2022].

7.6.4 Access to cool spaces

Barriers to cool spaces

Participants in both Ontario and British Columbia faced various barriers to accessing cool spaces during the summer.

British Columbian experience
Of the 36 participants in British Columbia, 13 (36%) reported financial barriers to finding a cool space. Another 13 (36%) identified other barriers, such as the need to purchase an additional fan or using public places such as libraries and windows that could not be opened. Three participants (8%) cited landlord restrictions, while two participants (6%) preferred not to answer. One participant (3%) mentioned the need for information in a language they understood, while another (3%) noted the distance to cool spaces as a barrier. Similarly, one participant (3%) reported that the cool spaces were not suitable or uncomfortable for their needs.

Regarding public green spaces, 12 participants (33%) had a green space less than a 5-minute walk away, while nine participants (25%) cited mobility issues or other reasons for not using green spaces. Four participants (11%) did not know about green spaces or reported none in their area, and three participants (8%) said they did not like green spaces.

Another three participants (8%) reported using transportation to access green spaces. In contrast, three (8%) had a green space 5-10 minutes away, one participant (3%) had a green space 10-15 minutes away, and one (3%) had a green space more than 15 minutes away.

Ontarian experience
Of the 29 participants in Ontario, six (21%) reported financial barriers to keeping cool. Nine participants (48%) identified other barriers, such as needing one air conditioner per room or not being comfortable in large crowds. Two participants (7%) reported landlord restrictions, and two participants (7%) found the information about cooling spaces difficult to understand. One participant (3%) cited the distance to the cooling spaces as a barrier, and one (3%) found such spaces uncomfortable or unsuitable for their needs.

Regarding public green spaces, only 5 participants (17%) reported having a green space less than a 5-minute walk away. Five participants (17%) cited mobility barriers or other reasons for not using green spaces. Two participants (7%) did not know of any green spaces or reported none in their area, while three (10%) said they did not like green spaces. Two participants (7%) reported using transportation, such as driving, public transit, or biking, to reach green spaces. Four participants (14%) reported having a green space 5-10 minutes away, five participants (17%) had a green space 10-15 minutes away, and two participants (7%) had a green space more than 15 minutes away.

7.6.5 Staying cool in during heat waves

Strategies for hot days and nights

British Columbia
In British Columbia, 50% of the participants did not know what they would do on a hot day, and 33% did not have a place to go. Only 11% preferred cooler rooms or balconies, and 3% opted for outdoor spaces or visiting family and friends.

For hot nights, half of the participants (50%) preferred staying with family or friends, while 25% were unsure of what they would do. An additional 11% chose cooler rooms or balconies and 11% preferred outdoor spaces. Only 3% did not have a place to go.

Ontario
Participants in Ontario reported varying strategies to deal with hot days. Nine participants (31%) would use their basements as a cooling space, five (17%) would stay with family or friends, three (10%) did not have a place to go and two (7%) were unsure what they would do.

For hot nights, 31% preferred to stay in their basements, while 14% chose outdoor spaces or staying with friends and family. One participant (3%) did not have a place to go, and another (3%) was unsure of their options.

Comparison and Key Insights

Participants in both regions faced significant barriers to accessing cool spaces, with financial challenges and building-related limitations being the most frequently reported. Ontario participants relied more on air conditioning and basements, while British Columbia participants leaned on open windows and family or friends for relief during hot days and nights. Access to public green spaces was limited in both regions, with mobility issues and personal preferences playing a role. These findings highlight the need for equitable access to cooling resources, better infrastructure, and community planning to effectively address heat vulnerability.

Participants in Ontario and British Columbia used various strategies to stay cool during heat waves, reflecting differences in preferences, available resources, and environmental conditions. These strategies can be broadly categorized into activities that modify the environment and personal (body-focused) measures.

Activities to stay cool

British Columbia

In British Columbia, 53% of participants focused on environmental modifications, while 47% used personal measures. Staying hydrated (92%) and using fans (72.2%) were the most common strategies, followed by wearing appropriate clothing (75%) and watching for symptoms (67%). Participants also reported covering windows with drapes or shades (69%), using wet shirts or damp towels (53%), staying cool indoors (56%), and seeking shade (56%). Many participants reduced strenuous activity (64%) or planned outdoor activities for cooler morning hours (44%). Additional measures included closing windows around 10 AM (44%), using cool rooms (53%), avoiding direct airflow (44%), and cutting down on the use of the stove or oven use (53%). Fewer participants considered getting air conditioning (14%), while 31% reported participating in other activities, such as taking baths or seeking medical attention.

Regarding the types of activities undertaken in a hot weather setting, 34.5% were more likely to undertake activities that modified their environment, while 31% chose more personal (body) options. Activities undertaken by respondents during heat waves included staying hydrated (72%), watching for symptoms (52%), wearing appropriate clothing (52%), and using wet shirts or damp towels (14%). Respondents also stayed cool indoors (72%),

sought shade (45%), cut down on exercise or strenuous activity (28%), planned outdoor activities for the morning (35%), used hats, sunglasses and sunscreen (31%), covered windows with drapes or shades (24%), closed windows around 10 AM (38%), used the stove or oven less (38%), used fans (35%), avoided direct airflow on the body (7%), used cool rooms (14%), consider getting AC (24%), and undertook other activities (7%).

Ontario

Among Ontario participants, 34.5% prioritized activities that modified their environment, while 31% focused on personal measures. The most commonly reported activities included staying hydrated (72%), staying indoors (72%), wearing appropriate clothing (52%), and watching for heat-related symptoms (52%). Other measures included seeking shade (45%), planning outdoor activities in the morning (35%), and using fans (35%). Environmental modifications included covering windows with drapes or shades (24%), closing windows around 10 AM (38%), and using cool rooms (14%). Some participants reported using wet shirts or damp towels (14%), reducing stove or oven use (38%), and avoiding direct airflow on the body (7%). Additionally, 24% considered getting air conditioning, and 7% engaged in other activities like taking baths or seeking medical attention.

Comparison

Participants in both regions employed a mix of environmental and personal cooling strategies. BC participants were more likely to modify their environment (53% vs 34.5% in Ontario), while Ontario participants leaned slightly more toward personal measures (31% vs 47% in BC). Strategies like using fans, staying hydrated, and avoiding strenuous activity were common across both groups, but BC participants reported more frequently covering windows (69% vs. 24%) and using cool rooms (53% vs. 14%). Most Canadians said they would stay inside if it was too hot (53%) or would drink lots of liquids (52%), 33% would use air conditioning, and others stated that they would find outdoor shade (19%) [Health Canada, 2022].

In a 2022 survey on the actions taken by Canadians struggling to regulate indoor temperatures, 37% reported closing curtains and blinds, 29% opened all windows, and 27% used a fan to make their spaces more comfortable [Health Canada, 2022]. Additional actions taken included installing or using a thermostat (3%), not using the oven to bake (2%), and moving to the basement (2%) [Health Canada, 2022]. The proactive use of sunscreen by Canadians taking steps to protect themselves from the health impacts of climate change was reported as 3% in 2022 [Health Canada, 2022]. 3% of Canadians reported seeing medical attention due to extreme heat/ heat waves, and among those who rented their homes, it was (10%) and for those in good, fair or poor health (11%) [Health Canada, 2022]. The results of a 2023 survey showed that people bought fans (23%), installed air conditioners or AC units (19%), checked in on loved ones or neighbours (15%), planned locations to seek

refuge (10%), installed central air or heat pump (3%), temporarily moved out to a cooler place (2%) [Leger, 2023a].

7.6.6 Heat health information channels

Ontario
In Ontario, respondents primarily heard about heat waves through online weather information websites (45%) and TV (45%), with social media accounting for 21% of responses. Two participants mentioned newspapers, while 21% of respondents reported not hearing about the heat wave at all.

When asked about their preferred channels for receiving heat wave information:

- 38% preferred online weather information websites.
- Alert Ready and online health authorities were the next most preferred sources, each at 34%.
- TV and radio were selected by 27% and 14%, respectively.
- Social media was chosen by 10%, while none of the participants preferred printed newspapers.
- 7% noted other sources, such as notices from Ottawa Community Housing (OCH) staff or personal judgment.

British Columbia
In British Columbia, TV was the dominant channel for heat wave information, with 64% of respondents relying on this medium. Online weather information websites (39%) and social media (17%) were also common sources, while only 6% of respondents reported not hearing about the heat wave at all.

In terms of preferred channels for heat wave information:

- 64% preferred TV, followed by online weather information websites (53%).
- Social media, Alert Ready, and online health authorities were equally preferred at 34% each.

- Radio was chosen by 25% of respondents, while printed newspapers were preferred by only 14%.
- Another 14% cited alternative sources such as family doctors, friends and family, home support workers, BCH staff, and text messages.

Comparison
Primary Sources: TV was the most relied-upon source in BC (64%), whereas Ontario participants evenly divided their reliance between TV (45%) and online weather websites (45%). Social media played a smaller but notable role in both regions (Ontario: 21%, BC: 17%). Preferred Channels: BC participants strongly favoured TV (64%) compared to Ontario's wider distribution of preferences, which included online weather websites (38%) and Alert Ready (34%). Printed newspapers were among the least preferred sources in both regions. Barriers to Awareness: A notable 21% of Ontario respondents reported not hearing about the heat wave at all, compared to only 6% in BC, suggesting differences in outreach effectiveness or access to information.

The Internet (41%) was the main source of heat illness information for Canadians, followed by doctor (31%), Health Canada (8%), another government website (6%), or health clinic or public health unit (7%) [Health Canada, 2022]. The same survey showed that TV/radio was 3, social media was 2, and local weather forecasters/meteorologists were 2 [Health Canada, 2022]. Watch weather more closely was reported by 1% of Canadians in 2022 as a proactive step taken to protect from climate change health impacts [Health Canada, 2022].

These findings highlight the importance of tailoring communication strategies to regional preferences and ensuring comprehensive outreach through diverse channels, particularly for populations with limited access to digital resources or traditional media. Effective heat wave alerts require leveraging trusted sources like TV and online platforms while addressing gaps in awareness through community-based initiatives and alternative communication methods.

7.6.7 Heat health actions taken in 2022

The survey results highlight participants' experiences, concerns, and actions during heat waves between May and October 2022 and their perceived preparedness for future extreme heat events. Differences between Ontario and British Columbia emphasize varying levels of concern, access to information, and effectiveness of public health strategies.

Experiencing heat waves

British Columbia
In British Columbia, 89% of participants felt they had experienced a heat wave. Participants also commonly identified July and August as months during which heat waves occurred, with a few mentioning specific dates like August 20-30. A small number of participants (3%) did not feel they experienced a heat wave, and 8% were unsure. Concerns about health were more pronounced in BC, where 58% of respondents were very or somewhat concerned about their health during heat waves.

Ontario
In Ontario, 45% of the respondents felt that they had experienced a heat wave during the study period. Many could not recall specific dates or events, with July and August most commonly mentioned as months when heat waves occurred. A few participants identified specific dates, such as August 4-8 and September 29. Interestingly, 55% of respondents were not concerned about their health during heat waves, while 10% were very concerned and 21% somewhat concerned.

Access to heat health information

British Columbia In BC, 100% of participants reported hearing about ways to protect themselves during heat waves. Television was the most common source (64%), followed by online weather websites (39%) and social media (17%). Many participants credited BC Housing staff, tenant support workers (TSW), and materials such as cool kits and elevator notices as helpful sources of information. However, only 25% of the respondents agreed or strongly agreed they were equipped to handle the next heat wave, highlighting a perceived gap in preparedness despite exposure to public health strategies.

Ontario
Most Ontario participants (76%) confirmed they had heard about ways to protect themselves during heat waves. Heat wave information was most commonly accessed through TV (45%), online weather websites (45%), and social media (21%). However, only 35% strongly agreed, and 48% agreed they were equipped to handle future heat waves. Notably, only one participant mentioned learning about heat strategies from Ottawa Public Health.

Comparison
Participants in both regions struggled to recognize or recall specific heat wave events, with many reporting vague time frames or uncertainty about when heat waves occurred. BC participants noted that they often did not feel warm or hot in the later months of the study

despite recorded high temperatures. This observation aligns with research suggesting that the human body may acclimate to higher temperatures over time, with early heat waves potentially posing greater risks due to lower acclimatization.

Perceived risk and preparedness

British Columbia

In BC, 44% of the participants considered heat waves extremely risky, with 19% rating them very risky. Over 25% remained neutral, neither agreeing nor disagreeing on the risks posed by heat waves. This perception may contribute to a lower sense of urgency regarding personal heat protection. Many participants mentioned BC Housing's role in heat wave preparedness, underscoring the importance of community housing organizations in protecting vulnerable populations. This is slightly lower than the number reported from a survey conducted in 2022, where 51% of Canadians believe that extreme heat events pose a major risk to the health of Canadians and 26% reported extreme heat posed the greatest risk to health compared to other extreme weather events [Health Canada, 2022].

Ontario

In Ontario, most respondents believed heat waves posed a risk, with 21% rating them as extremely risky and 38% as very risky. Another 38% considered them somewhat risky. While 83% of the respondents felt equipped to handle future heat waves, access to mechanical cooling and effective environmental modifications was limited, leaving participants vulnerable despite their confidence. 24% of Canadians said that they were not prepared to handle the impacts of heat waves [Leger, 2023a]

Insights and challenges

While many participants felt equipped to handle future heat waves, reliance on passive measures and lack of mechanical cooling remain significant vulnerabilities. BC Housing's proactive engagement through cool kits, tenant support workers, and public notices emerged as a key factor in raising awareness and promoting preparedness. Ontario lacked a similarly visible community-based initiative. Many found the cool kits (usually a plastic shoebox containing a basic thermometer, a spray bottle for misting, and heat-health information) provided by BCH helpful. They wanted to be notified by the organization about heat waves in the future, indicating a level of trust. This is important as community housing authorities must consider their role in protecting their tenants in the future. Participants' perceptions of heat decreased over time, likely due to physiological adaptation. However, this does not negate the risks posed by early heat waves or prolonged exposure to high indoor temperatures.

These findings highlight the need for sustained efforts to improve access to cooling infrastructure, strengthen public health communication, and address systemic barriers to heat wave resilience, particularly among marginalized populations. Collaboration between public health authorities and community housing organizations could significantly enhance preparedness and mitigate risks during future extreme heat events.

7.6.8 Canada's heat preparedness

Ontario and British Columbia participants expressed varying perceptions of heat wave risks and Canada's preparedness to handle increasingly frequent and intense heat waves. While responses from both regions revealed concerns about access to cooling resources and protections for vulnerable groups, the level of risk and confidence in preparedness differed significantly.

Heat preparedness in BC
In contrast, BC participants showed a greater sense of urgency. Nearly 90% either strongly agreed (39%) or agreed (50%) that heat waves posed a danger. Only 11% neither agreed nor disagreed, and none expressed disagreement. This stronger consensus may be derived from BC's recent experiences with extreme heat events and limited access to air conditioning in residential settings.

In a 2023 survey, when participants were asked about their level of concern regarding the likelihood of increasingly hot summers and more frequent heat waves in the future where they lived, 35% reported being unconcerned, while 65% expressed concern[Leger, 2023a].

Heat preparedness in ON
Participants in both regions generally acknowledged the risks posed by heat waves, though BC residents were more likely to view heat waves as a serious threat to their communities. In Ontario, 22 of the participants strongly agreed and 28 agreed that heat waves were dangerous to their communities. However, 34% neither agreed nor disagreed, while 7% disagreed and 3% strongly disagreed. This distribution suggests some ambivalence about the immediate danger of heat waves, possibly reflecting Ontario's greater dependence on air conditioning and infrastructure than BC.

Perception of Canada's preparedness

British Columbia
BC participants were less confident. Only 8% strongly agreed, and 36% agreed that Canada

was prepared. A further 36% were neutral, while 11% disagreed and 8% strongly disagreed. These responses likely reflect recent experiences with extreme heat events, such as the 2021 heat dome, and the awareness of gaps in cooling resources and emergency response measures.

Ontario
In Ontario, 17% of participants strongly agreed and 24% agreed that Canada was prepared to handle worsening heat waves. Another 24% were neutral, while 7% disagreed. This optimism may reflect the broader availability of cooling infrastructure, such as air conditioning, and the perception of community resilience.

Comparison
Both regions expressed mixed confidence in Canada's ability to manage more frequent, intense, and prolonged heat waves, though BC participants were more sceptical. The results of a survey conducted in 2022 showed that 10% of Canadians believed that the Government of Canada was doing a good job protecting the health of Canadians from the impacts of climate change, while 58% said moderate and 26% said poor job [Health Canada, 2022].

Open-text responses from participants in both regions shed light on their concerns and priorities, revealing a shared desire for systemic improvements despite regional differences. Ontario participants emphasized the lack of access to air conditioning, insufficient outdoor cooling spaces, and limited shaded green areas. Several expressed concerns for vulnerable populations, such as older adults and families with young children, highlighting the need for additional resources to protect themselves and their communities. In BC, participants appreciated localized efforts by BC Housing, such as the fan distribution program. However, some did not receive or accept fans due to logistical challenges, energy cost concerns, or personal preferences for natural cooling methods such as open windows. Hygiene concerns were also cited as a reason for declining fan donations. In addition, participants expressed the need for more accessible cooling options and better infrastructure to address extreme heat risks.

7.6.9 Additional findings

Participants in both regions provided positive feedback on the ecobee thermostat provided for the study. The thermostat was praised for its ability to display indoor temperatures, helping participants monitor conditions and make informed decisions about their health. Many participants expressed disappointment when the thermostat was removed, noting its role in fostering awareness of heat risks and encouraging proactive health measures. In

both regions, the thermostat also served as a conversation starter, prompting discussions about heat and health among households.

Comparison
BC participants perceived heat waves as a greater danger than those in Ontario, likely due to regional differences in climate, cooling infrastructure, and recent heat wave experiences. Ontario residents were more likely to express ambivalence or neutrality about risks. Both regions expressed mixed confidence in Canada's preparedness, but BC participants were more sceptical. Higher confidence levels in Ontario may reflect the greater dependence of the region on air conditioning and other cooling infrastructure. BC participants highlighted the importance of localized efforts, such as BC Housing's fan distribution program, in building resilience. In contrast, Ontario participants noted the lack of similar community-focused initiatives. The ecobee thermostat received widespread praise in both regions, illustrating the value of tools that increase awareness and promote informed decision-making about heat health.

7.7 Discussion

7.7.1 Implications

The findings indicate that indoor temperatures in high-rise buildings often exceed safe levels during heat events, answering RQ1. Residents' reliance on passive cooling methods in British Columbia reflects barriers to access, addressing RQ2. These insights underscore the need for tailored interventions that consider building design, regional disparities, and behavioural trends.

This study highlights the importance of integrating indoor temperature thresholds into Heat Alert and Response Systems (HARS). Real-time monitoring can inform more precise interventions, such as prioritizing vulnerable populations in unair-conditioned homes and tailoring communication strategies to regional preferences.

Limitations such as Wi-Fi instability and geographic constraints impacted data completeness. Future research should explore larger sample sizes, more robust sensor networks, and integration with mobile health applications to enhance scalability and resilience.

7.7.2 Technology in the home

Balancing responses to extreme heat requires careful consideration of trade-offs that may affect other dimensions of health and well-being. For instance, while encouraging households to engage with indoor temperature data from thermostats can prompt behavioural adjustments, such as increased use of fans or air conditioning, this may inadvertently raise energy consumption and greenhouse gas emissions that can be mitigated by installing air-source heat pumps [Gard-Murray et al., 2023]. Public health programs could also leverage this data to tailor interventions based on household characteristics, such as pre-existing health conditions, to provide targeted support like cooling resources during the day. For example, some smart thermostats have programs that help strengthen the community's grid during high energy demands by adjusting the temperatures to reduce usage during peak demand [ecobee, 2024a]. In this case, certain thresholds would need to be set to ensure that a vulnerable person would not be exposed to unnecessary health risks from a higher set temperature being selected. However, such interventions could have unintended consequences, such as privacy concerns or inequitable access to assistance. The question of who should have access to indoor temperature data is critical, as well as who owns the data and could depend on who owns the property, the manufacturer, the device, who pays for the operating costs, and who lives in the home during the time the data is collected, etc. [Drenik, 2023]. For ecobee devices, the data belongs to the user and can be deleted upon request [ecobee, 2024c]. Stakeholders may include households, public health authorities, researchers, and policymakers. However, clear guidelines are needed to ensure that the data is used ethically and effectively in the case of indoor temperature monitoring systems. Transparent policies should prioritize protecting privacy while maximizing the data's utility in driving community-wide solutions and mitigating risks for vulnerable populations.

The widespread monitoring of indoor temperatures, particularly in homes without air conditioning, could have mental health implications as temperatures rise. Constant exposure to data highlighting unsafe or uncomfortable conditions may increase stress, anxiety, or feelings of helplessness, especially for individuals unable to take corrective actions due to financial or infrastructural limitations [Pappas, 2024]. However, temperature monitoring does not require high-tech solutions, nor does every household need a device to benefit from it. Community-based approaches or shared monitoring systems can provide actionable insights while reducing the psychological burden on individuals [NOAA, 2024]. Ensuring accessible, low-cost and inclusive monitoring systems and supportive public health interventions can help mitigate these mental health challenges while improving climate resilience.

7.7.3 Real-time alerts and dashboard

During the study, alerts were emailed twice daily to stakeholders (public health authorities, BC Housing), ensuring real-time data on indoor temperatures were continuously available. See Appendix F for the data pipeline and examples of the Elastic Dashboard. From July 7 to September 28, 156 emails were sent to stakeholders. During this period, Level 1 was reached on all 83 days (100%), triggered by at least two thermostats daily. Additionally, Level 2 was reached on 16 of the 83 days (19%), triggered by at least one thermostat. This proactive approach facilitated timely check-ins by BC. During the study period, 156 participants participated during periods of extreme heat, prioritizing their health and safety. During these periods, BCH staff called participants or performed door checks. During the heat wave in British Columbia, public health authorities shared indoor temperature data within 24 hours and brought it to BC Heat Committee meetings. Table 7.1 illustrates the number of days thermostats recorded indoor temperatures within Level 1 (26°C to 30.9°C) and Level 2 (31°C and above) thresholds across various sites and levels of the floor. Several notable patterns emerge from the analysis, highlighting the influence of building characteristics, floor height, and site-specific factors on indoor heat exposure.

In multistory buildings such as Hall Tower and MacLean, the upper floors experienced a significantly greater number of days in both Level 1 and Level 2 temperature ranges than lower floors. For instance, the 14th floor of Hall Tower recorded 78.33 days in Level 1, while the 6th floor experienced only 27.33 days. A similar trend is observed in MacLean, where the 12th floor recorded 86.67 days on Level 1, compared to 35.33 days on the 2nd floor. This pattern suggests that higher floors are more susceptible to heat accumulation, possibly due to increased solar radiation exposure and the tendency of heat to rise within buildings.

Rosewood consistently exhibited prolonged heat exposure. The site experienced many days at Level 1 across its monitored floors, with 95.33 days on the 5th and 92 days on the 7th floor. Interestingly, another unit on the 7th floor recorded only 36 days in Level 1, indicating variability due to differences in unit orientation, shading, or ventilation. The consistently high exposure to Level 1 temperatures at Rosewood suggests potential challenges with heat retention or insufficient cooling strategies.

Foster Farms and Michelle Heights exhibited minimal exposure to elevated temperatures. In contrast to Hall Tower and MacLean, the single-floor sites at Foster Farms and Michelle Heights recorded significantly fewer days at both Level 1 and Level 2 thresholds. The maximum number of days at Level 1 for Foster Farms was 25.33, while Michelle Heights recorded a maximum of 8.33 days. Moreover, several units at these sites did not experience any days at Level 2, indicating that these buildings may benefit from better insulation or more effective cooling systems.

Exposure to Level 2 temperatures was limited across most sites. While many units experienced prolonged periods of Level 1 heat, far fewer days were recorded at the Level 2 threshold (31°C and above). For instance, Hall Tower's 14th floor experienced 78.33 days at Level 1 but only three days at Level 2. Similarly, Rosewood's 5th floor recorded 95.33 days at Level 1 and only 2.67 days at Level 2.

To the best of our knowledge, this is the first study in Canada to implement real-time indoor temperature data delivery to inform public health interventions. The dashboard also enabled stakeholders to view the temperatures, which provided a way to monitor whether the thermostats were offline. It also enables a rapid comparison between the temperatures across sites. The system allowed immediate responses to hazardous indoor conditions critical for vulnerable populations, such as older adults or pre-existing health conditions. By delivering data in real-time, the study provided a novel method for addressing heat-related risks and allowed stakeholders to adjust strategies dynamically. These alerts can supplement and strengthen public health efforts by ensuring that resources and interventions—such as cooling centres, medical aid, or hydration supplies—are allocated efficiently and promptly. Furthermore, this system helps ensure that no one is left behind, as it enables targeted interventions for individuals at higher risk of heat-related illness, particularly those in under-resourced or isolated environments. This model could be expanded and integrated into broader public health strategies to manage heat waves and other environmental hazards, offering a scalable model for responsive, data-driven public health interventions.

7.7.4 Indoor heat interventions

Indoor heat interventions in Canada primarily target vulnerable populations, including older adults, individuals with chronic health conditions, and those living in socioeconomically disadvantaged circumstances. For instance, during the 2021 heat dome in British Columbia, a significant number of heat-related deaths occurred among older adults with chronic conditions and residents in areas of higher material and social deprivation [Public Health Ontario, 2023c].

Residents of community housing are particularly susceptible to extreme heat due to factors such as inadequate building infrastructure and limited access to cooling resources. Reports indicate that these residents face increased risks of heat-related morbidity and mortality, underscoring the need for targeted interventions [Action Canada, 2022].

When comparing the demographics of those receiving indoor heat interventions to the general population, it is evident that interventions are concentrated among groups with higher vulnerability. This focus is essential, as studies have shown that heat-related illnesses

and deaths disproportionately affect individuals from lower socioeconomic backgrounds, those who live alone and those who live in areas with higher crime rates or substandard housing [Eady et al., 2020].

The populations studied in this work received more indoor heat interventions in BC than in ON. The income thresholds for community housing through BC Housing and Ottawa Community Housing (OCH) would generally qualify as low-income in Canada. However, the definition of low income depends on the context and the measures used. While the thresholds for BC Housing and OCH may not fall strictly under Canada's low-income definitions, they reflect the realities of housing affordability in regions where even moderate incomes may struggle to secure housing [BCH, 2022, City of Ottawa, 2023]. These thresholds prioritize individuals and families who, while not the lowest-income earners, still experience significant financial strain due to high housing costs. In summary, indoor heat interventions in Canada are appropriately directed towards the most vulnerable segments of the population, who are at a greater risk of adverse health outcomes during extreme heat events than the general populace.

7.7.5 Commercial determinants of health

As socioeconomic status greatly determines health outcomes, the commercial determinants of health are a useful framework for understanding how people can adapt their personal spaces to extreme heat [Gilmore et al., 2023, Friel et al., 2023]. As housing is often determined by income, poorer neighbourhoods often lack green space and vegetation compared with wealthier neighbourhoods due to red-lining policies, gentrification, and allocation of public funds [Maantay, 2001, Hoffman et al., 2020, Manware et al., 2022, Plumer et al., 2020, Cuisick and E&E News, 2021].

Air conditioning has a high upfront cost and, if not already installed, may not even be permitted by landlords or building owners. Operating costs (electricity) are another factor that may deter individuals from using cooling equipment. Suggested adaptations may incur various costs, both financially and by requiring permission from the landlord, and their benefits may not be easily realized or quantifiable. Tsoulou et al. also found that heat stress could be reduced through cost-effective strategies focused on individual behaviours and outdoor amenities [Tsoulou et al., 2020]. The Intact Centre for Climate Change at the University of Waterloo developed a list of heat-protective adaptations for apartments, condos, and houses that cost between $0 and $500 and can provide reprieve and reduce indoor heat [Eyquem and Feltmate, 2022].

However, the suggestions listed at $0 still require external costs, maintenance costs

(e.g., water and plant food) and time investment, such as having a mobile phone with a data plan or a device able to access the Internet to receive weather alerts via the WeatherCan app, purchasing energy-efficient appliances and lights, and transportation and parking costs associated with a cooled space [Eyquem and Feltmate, 2022, Environment and Climate Change Canada, 2020]. At a time when wages remain stagnant, the cost of living has increased, and record breaking company profits drive inflation, these adaptations may be out of reach as 8.7 million Canadians face food insecurity or inadequate access to food of sufficient quantity/quality [PROOF, 2023, Food Banks Canada, 2023].

The "digital rainbow" or digital determinants health framework by Jahnel et al. provides examples of how digital technologies, when integrated into society, can exacerbate health inequities [Jahnel et al., 2022]. A recent poll by Leger reported that half of Canadians live pay cheque to paycheque [Leger, 2023b]. Rising household debt, particularly among Canada's low- and middle-income earners [Statistics Canada, 2024a], makes individual household solutions to address extreme heat and implement climate mitigation and adaptation measures increasingly unattainable without support.

A less commonly discussed method for building community resilience is human bonds of social connection. Factors such as high social isolation, changing societal norms, and increased media use as entertainment have increased the time spent indoors [Klinenberg, 2001, National Academies of Sciences, Engineering, and Medicine, 2020]. However, strong social bonds are protective and have added mental health and cognitive benefits, especially among older adults. Examples include family, friends, and neighbours checking in with each other regularly, especially if they know someone is alone, has prior health challenges, or is without air conditioning. Building social capital takes time, but a solution requiring no technology is more likely to withstand the stresses of climate extremes [Kawachi et al., 1997, Wolf et al., 2010]. Environmental racism also contributes to the increased risk that Indigenous communities and communities of colour experience, from less tress to poor air quality; IoT sensors could provide communities with the tools they need to demand change for their communities [Cuisick and E&E News, 2021, Waldron, 2020].

7.7.6 Framework for IoT-based indoor systems

The authors propose a framework for understanding how an IoT-based sensor might integrate into the current public health HARS (see Figure 7.14). This framework illustrates a comprehensive approach to addressing the challenges of extreme heat, combining adaptation and mitigation strategies across varying time frames. The concentric rings represent different time frames, with immediate interventions (hourly/daily) situated at the centre and long-term solutions (yearly/decades) located outward.

At the core of the framework are real-time insights and short-term interventions, such as leveraging social capital, empowering individuals, and utilizing data-driven insights. These focus on community preparedness, individual-level actions (e.g., staying hydrated, using cooling devices), and real-time data collection to mitigate immediate heat effects.

Moving outward, mid-term interventions, such as cooling centres, early warning systems, and social safety nets are crucial for heat wave responses. Retrofits to improve heat resilience are positioned in the weekly/monthly time frame, representing structural adaptations that require planning and implementation [McIlroy et al., 2024, Tozer et al., 2024].

The outermost ring represents long-term strategies, including data-informed policies, integrated technology systems, and climate-resilient infrastructure development. These systemic changes, along with nature-based solutions, emission reductions, and low-carbon alternatives, are necessary to address the broader issue of climate change, ensuring long-term resilience to heat events and reducing greenhouse gas emissions.

The framework visualizes heat adaptation and mitigation interventions, categorizing them by time frames (hourly, daily, yearly, etc.) and scope, from individual actions to broader systemic changes. It incorporates real-time insights, early-warning systems, social capital, and nature-based solutions to build climate-resilient communities. Although this framework is expansive, its connection to Heat Alert and Response Systems (HARS) lies in its ability to enhance the specificity and effectiveness of real-time interventions, using data such as indoor temperature monitoring as a critical input.

This study on measuring indoor temperatures provides actionable insights to significantly improve HARS. For example, integrating real-time indoor temperature data allows for more precise targeting of at-risk populations, especially in unair-conditioned homes, where heat exposure is most dangerous. Current HARS thresholds are based on outdoor temperature and forecasts, which often do not align with indoor conditions. By incorporating indoor temperature data, HARS can issue more tailored alerts, prioritize resources for vulnerable communities, and refine public health recommendations to mitigate heat-related illnesses.

Furthermore, including real-time monitoring aligns with the framework's emphasis on dynamic, data-driven decision-making. For example, real-time alerts generated through IoT technologies can inform individual actions (e.g., using fans or closing blinds) while guiding systemic responses, such as activating cooling centres or deploying emergency services. These capabilities demonstrate how the framework, while broad, can directly incorporate findings from indoor temperature monitoring to strengthen heat resilience strategies and improve public health outcomes.

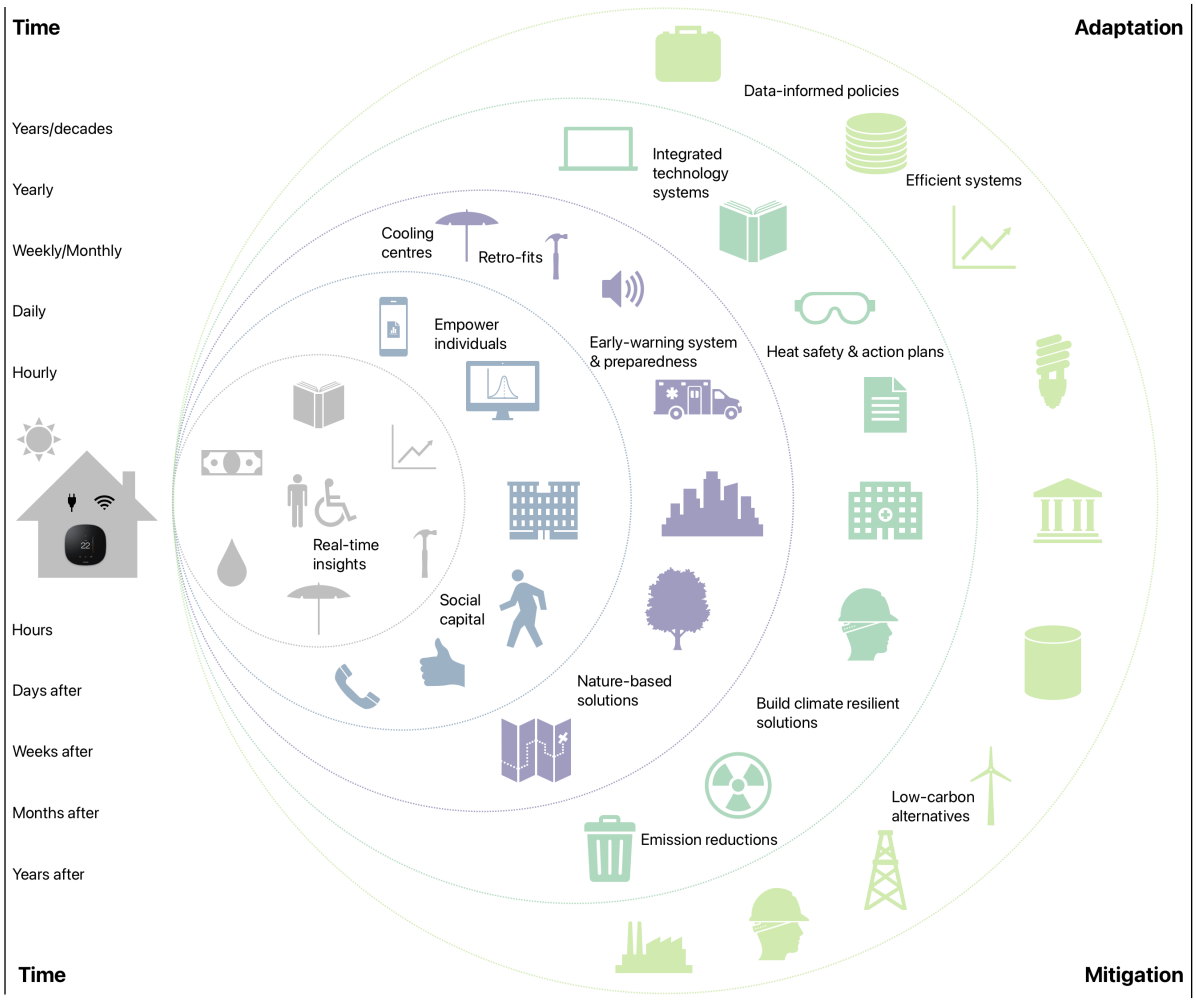


Figure 7.14: Integrated Framework for Heat Adaptation and Mitigation Strategies Over Time: The framework visualizes various heat adaptation and mitigation interventions, categorized by their time frames (hourly, daily, yearly, etc.) and their scope from individual action to broader systemic change. It integrates real-time insights, early-warning systems, social capital, and nature-based solutions to create climate-resilient communities.

This framework is informed by the socio-ecological model, emphasizing the interconnectedness of individual, community, and societal factors in addressing extreme heat. The concentric rings represent different levels of stakeholders, from individuals at the centre to communities, organizations, and governments in the outer rings.

The innermost circle focuses on immediate individual-level actions, such as using real-time insights to guide behaviour. As the rings expand outward, they capture community-level responses (e.g., social capital, early-warning systems) and local infrastructure roles (e.g., cooling centres, retrofits). Human chains offer greater resilience during climate extremes, particularly when power and phone lines are down. Communities can communicate through phone call chains or in-person visits, ensuring connection during extreme heat events. Phone call chains are a communication method in which a message is relayed through a sequence of phone calls, with each recipient calling the next person on the list to quickly disseminate information. Designating "heat muster points" similar to fire muster points can serve as gathering spots during heat waves, where individuals can check in daily or twice a day, enhancing community safety and response.

Further out, the rings encompass organizational and institutional stakeholders responsible for data-informed policies, heat safety action plans, and the integration of technology systems to address larger-scale challenges. Involves collaboration across sectors to borrow and leverage technologies, such as smart thermostats.

In the outermost ring, governments, policymakers, and international organizations are tasked with promoting emission reductions, low-carbon alternatives, and nature-based solutions to mitigate the future impacts of climate change. This level requires other sectors to consider the downstream impacts, including emissions and altering landscapes.

These levels are interconnected and interdependent, illustrating the multi-layered nature of heat adaptation and mitigation. For example, real-time insights at the individual level can significantly improve HARS at the community level, which drives higher-level policy-making. This emphasizes the need for collaboration and coordination across all stakeholder levels to ensure effective, scalable, and sustainable solutions for short-term heat management and long-term climate resilience.

Indoor temperature should be an integral component of Heat Alert and Response (HARS) systems, as it directly impacts the health and safety of individuals, particularly during extreme heat events. Similar to how social determinants of health shape overall health outcomes, indoor environmental conditions play a critical role in determining vulnerability to heat-related illnesses. Extreme heat is one of many interconnected challenges facing our population, often exacerbated by underlying inequities such as inadequate housing, energy poverty, and limited access to cooling resources. Incorporating indoor temperature data into HARS would allow for more precise targeting of at-risk populations, improved public health recommendations, and tailored interventions that address these broader systemic issues. This approach enhances the effectiveness of heat mitigation strategies and acknowledges the complex interplay between environmental factors and social determinants of health.

7.7.7 Strengths and limitations

Given the prevalence of ecobees across North America (over 230,000 Donate Your Data users alone), this project demonstrates how it can be used for indoor temperature warming systems. We can utilize this technology to create a robust, real-time indoor temperature monitoring platform to support early warnings of extreme heat and responses during extreme events. As mentioned previously, many technologies introduced for environmental monitoring are not as easily introduced to the home. However, the ecobee received compliments from participants for its attractiveness and the built-in screen, which served as a source of information that was empowering and a conversation starter when having guests over. Given that there is a web-based platform, mobile app, and screen on the thermostat, the development of notifications and warnings is extremely feasible. In addition, the Web-based connection enables real-time or near-real-time analysis and insights that can be useful for public health response and even for families to check in on loved ones, offering peace of mind. This also aligns with recommendations from Action Canada and WMO to create early warnings and real-time syndromic surveillance capacity [Action Canada, 2022, World Meteorological Organization, 2023a]

The ecobee thermostat provides a way to "monitor" the environment and check in on the health of the occupant(s) within a home by movement. The thermostat and remote room sensors can also observe movement patterns through 915MHz radio waves, measured at five-minute intervals. This method has been used to monitor sleep patterns and could be leveraged to check for signs of or absence of movement during extreme heat [Sahu et al., 2020a, Jalali et al., 2022]. Other monitoring devices for older adults often require participants to remember to wear the device or charge the battery. In contrast, the ecobee monitors the environment rather than the individual. Movement (motion data) is also considered less invasive than audio or visual monitoring and would likely have a lower acceptance barrier to being used.

One major challenge was providing reliable Wi-Fi for real-time data collection, as many homes lacked internet access, despite 92% of Canadian households using the internet by 2022 [Statistics Canada, 2023a]. Portable Wi-Fi routers with SIM cards were used. Still, these were unstable, requiring manual resets after power outages, service disruptions, or thermostat malfunctions, leading to data gaps and in-person troubleshooting. Environmental signal interference further disrupted data collection, resulting in 26% missing data in BC and 47% in Ottawa.

Recruitment challenges included selection bias in BC and random sampling issues in Ottawa, where households without air conditioning were hard to recruit. Confounding factors like heat from cooking and electronic devices, recall bias, and language barriers may

also have impacted the study.

Geographic distance between the research team and study sites compounded issues, and the reliability of technology such as Wi-Fi routers, which performed well in testing, became a significant limitation during deployment. Future studies should increase sample sizes and sensor deployment for better statistical power. Real-time data access, facilitated by the UbiLab partnership with ecobee, was a key asset, although improving network reliability will be crucial in future projects.

7.8 Lessons learnt and recommendations

7.8.1 Study implementation and insights

To improve future studies, it is recommended that data collection begin before May 1st and continue until at least the end of September. Warmer weather starts earlier and extends later, and early-season heat waves pose significant risks to populations accustomed to cooler temperatures. This aligns with the literature suggesting that early-season heat waves can be particularly hazardous.

Study materials were initially provided in English and French, but after the first visit, all participants were comfortable completing the surveys in English. However, offering materials in additional languages could improve inclusion in future studies. A Terms of Reference was developed for the project, and regular team meetings facilitated task updates, issue resolution, and real-time data analysis, ensuring the project remained on track.

7.8.2 Recruitment challenges and solutions

Recruitment in Ottawa proved challenging. Initially, participants without air conditioning were targeted, but the approach was broadened to include those with air conditioning due to the limited response to cold-door knocking. In contrast, pre-recruitment and screening in British Columbia allowed a larger sample of participants without air conditioning. During initial visits in May, Ottawa Public Health "Beat the Heat" information sheets were handed out in French and English, see Appendix G. However, these were not fully utilized early in the season; distributing additional heat-health materials later in the summer might better prepare participants for heat waves. Participants in BC also received "Cool Kits" during the summer from BCH and this likely increased their awareness and preparation of heat illness.

7.8.3 Operational considerations

Equipment loss to pests, such as bedbugs or cockroaches, highlighted the need for thorough sanitation plans or the ability to write off affected equipment. Compensation was provided via President's Choice gift cards. Although some participants raised concerns about accessibility to retailers, all participating retailers were within a 20-minute walk or public transit ride. The participants appreciated the support, particularly in light of rising inflation. Future projects could improve impact by supporting local businesses and participants' preferred retailers.

Technical limitations, such as unstable Wi-Fi, affected data collection quality. Budget constraints prevented investment in more advanced equipment (see Appendix \ref{Appendix F} for details). Additionally, unplanned visits were necessary to address technical issues caused by power outages. Fieldwork with a BCH tenant support worker was essential to build participant trust, arrange visits, troubleshoot devices, and assist with surveys. A two-person team improved efficiency and minimized participant inconvenience, although participants often expressed enjoyment of visits.

7.8.4 Recommendations for future studies

1. **Timing and Planning:**
    - Begin data collection before May 1 to capture the increasingly warmer shoulder months.
    - Ensure that dashboards and automated alerts are functional at the start of the study.
2. **Participant Support:**
    - Include participants and community partners in future studies from the beginning if possible.
3. **Interventions:**
    - Explore direct delivery of alerts to participants/home dwellers through the thermostat screen or through a connected mobile app or website.
    - Participants indicated support for alerts sent via the Amber Alerts platform.
4. **Operational Improvements:**

- Invest in stable Wi-Fi solutions for data quality.
- Anticipate and mitigate equipment losses due to pests with sanitation or write-off plans.
- Prepare equipment and paperwork thoroughly before entering homes and maintain a two-person team for efficient visits.

5. **Enhanced Incentives:**
    - Adjust compensation to support local businesses and participants' preferred retailers when feasible.
6. **Technology and Design:**
    - Use participant-friendly technologies such as the ecobee thermostat, which participants found both functional and aesthetically pleasing.

These recommendations are essential to support vulnerable communities adapt to increasingly hot summers. They emaphazise both immediate benefits for the participants and long-term resilience planning.

7.8.5 Future work

We need further studies on indoor temperatures in a wider range of buildings and types of homes. Future studies must overcome the challenges of Wi-Fi to ensure continuous data flow with minimal interruptions to participants. Alerts should also be shared with individuals, possibly via the ecobee thermostat, ecobee mobile app, or web portal to give participants agency over their health. Rather than raw temperature data only, how they behave and act with this information could be assessed.

Using machine learning prediction models developed using the DYD dataset, we can also address data loss and fill in missing data in the event of a network or power outage. Creating indoor temperature predictions using data from DYD would also enable more targeted interventions, health checks, or assistance for those who need financial support or aid to adapt their behaviours or homes to extreme heat.

Participants cited additional barriers to adapting behaviours to heat, which could be investigated with qualitative interviews. Some reasons mentioned by participants include pests, noise from neighbours, pets, traffic (living close to highways), safety concerns for themselves and their children (ground-level access through windows and doors), broken

windows, and lack of screens as reasons for not opening windows and doors. Other tenants mentioned that older trees on the property were removed for safety issues; however, no new trees had been planted to replace the ones that once provided shade.

Another important consideration is the indoor air quality in the units. Several participants complained about how "stuffy" the air was or that they did not leave their homes because it was "suffocating." in the hallways and elevators. Smoke from cigarettes and vapes, pests (e.g., bed bugs, fleas, cockroaches) and garbage smells in common areas also prevented people from using natural ventilation.

7.9 Conclusion

In conclusion, this study highlights that, despite relatively lower summer temperatures in 2022, there were 16 heat warning days in Metro Vancouver (Central, including the City of Vancouver, Burnaby, New Westminster, and the Southwest, including Richmond) and four in Ontario. Extreme indoor temperatures at or above 26°C were still recorded in homes across British Columbia and Ontario, including in air-conditioned and traditionally unair-conditioned spaces. Although some occupants may have acclimatized and did not experience serious impacts, Canada must take proactive steps by educating the public, providing accessible cooling options during heat waves, monitoring indoor temperatures, and promptly communicating associated risks.

Real-time alerts were utilized during the study to ensure participants' safety and, as the first Canadian study of its kind, to demonstrate how smart thermostats can enhance existing Heat Alert and Response Systems (HARS), particularly in low-income settings. While air conditioning may be necessary to mitigate extreme indoor temperatures in some cases, the associated greenhouse gas emissions cannot be ignored. To address the risks of extreme heat sustainably, stakeholders must explore additional solutions, such as natural ventilation, external shading, reflective materials, and greening of surroundings. This project has provided valuable insights into implementing a real-time indoor temperature system and the challenges posed by indoor heat in community housing settings, while underscoring the importance of continued research and interdisciplinary action in this area.

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Data availability: Due to the nature of the data, they cannot be made openly available.

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Chapter 8

Discussion and future work

The only recognizable feature of hope is action.
Grace Paley

8.1 Future of early heat warning systems

The work described illustrates how many individuals and groups are necessary to solve indoor heat problems. This includes the public, meteorologists, public health officials, building managers, city and environmental planners, architects, builders, engineers, policymakers, etc.

As discussed previously, indoor temperatures are currently not included in heat warnings. Indoor temperature data can clarify and establish safe and appropriate indoor temperature limits. It may be possible to create co-benefits with the indoor air quality community to advance indoor heat safety. Indoor air quality awareness has increased following the research conducted in the wake of COVID-19 and concerns about indoor air pollution from volatile compounds and pollution that makes its way into homes, such as fine particulates and gases from wildfires [Morawska et al., 2024, Morawska et al., 2021, Laguerre and Gall, 2024]. This exemplifies how interdisciplinary cooperation can simultaneously address two health concerns.

Since starting this thesis in 2019, public awareness and knowledge about extreme heat have only increased. This positive change is only made more serious by the growing risk of climate extremes and the lack of action to drastically reduce greenhouse gas emissions. As the climate and health community works to create a better and safer world, the biggest

polluters show no sign of reducing their share of emissions, putting the health of the entire planet at risk [Romanello et al., 2022]. As a researcher at the downstream end of the cascading impacts caused by a warming climate, the ability to create change further upstream requires the stepping out of academia and the political sphere [Biabani, 2023, Narayan, 2023, van Eck et al., 2024, Thomas-Walters et al., 2024]. This is especially true when politicians lack the training and knowledge of subject matter experts.

The COVID-19 pandemic demonstrated how well-positioned voices of science communicators can provide evidence-based information, ensure a way forward to protect health, and how social networks have ushered in a new era of science communication [Pollett and Rivers, 2020, Wiles et al., 2023]. However, this may come with personal costs and individual risks, such as personal attacks [Nogrady, 2021].

8.2 Improvements and extensions

As global temperatures rise, more data and early warning systems are needed. The work in this thesis has laid the foundation within the UbiLab and beyond to continue developing low-cost hyperlocal early warning systems, including predictions, within Canada and beyond via the Internet of Things. Such systems can contribute to a more secure and healthier future in the face of the climate crisis and even save lives.

8.2.1 Scaling solutions

IoT devices have the potential to collect data to inform policy change and develop robust early warning predictions to protect people from the dangers of indoor heat. The work described in Chapter 7 was carried out in a limited number of homes to test how a real-time indoor temperature alert system would function using smart thermostats. With over 10,000 registered ecobee DYD donors in Canada and over 200,000 more in the United States, the opportunity to create hyperlocal mesh networks with real-time insights into homes and indoor conditions is immense. Given the availability of connected thermostat devices, future studies should collect and leverage long-term data. In 2021, Statistics Canada reported that 92% of Canadian homes have a thermostat, and 53% have a not-programmed or non-programmable thermostat, indicating that many homes could benefit from education on optimising usage (e.g., around time-of-use rates) or deep energy retrofits including switching to a more efficient and climate-positive technology for heating and cooling, like a heat pump [Statistics Canada, 2017]. Ontario's rate of programmed or non-programmable

thermostats was 40%, lower than BC's 60%, indicating room for education and broader adoption.

To ensure these devices, such as the ecobee, are climate disaster resilient, they can benefit from on-board data storage in the short term and a backup battery to ensure home dwellers can still know the temperature in the home in case of a network or power outage. The integrated web dashboard provides an overview of the entire ecosystem and allows messages to be sent through direct devices, mobile apps, and web portals. For example, high temperatures can be sent to home dwellers and caregivers. With the integration of smart home assistants, the hubs could also disseminate alerts or information promptly, increasing accessibility for individuals who need a higher level of assistance or live with a disability. Previous work at the UbiLab demonstrated its potential to support healthy aging [Sahu, 2022]. This real-time data stream can support care teams, benefiting caregivers, families, emergency response services, hospitals, organizations, and governments that prepare and provide aid during crises.

Together, thermostat data across North America can train prediction models to protect home dwellers' well-being by identifying vulnerable homes and expected indoor conditions. This would also benefit those who may not have access to smart thermostat technology through policy and legislation. Artificial intelligence (AI) development has created opportunities to leverage this data for social benefit. However, ensuring that the benefits do not come at detrimental costs to the planet is vital. While it might provide additional value, the emissions generated must be quantified and accounted for to be correctly implemented. As researchers, we are responsible for ensuring our technological advancements do not further exacerbate the inequalities experienced by communities and contribute to the "Jim Code," a modern-day version of Jim Crow replicating and reproducing systemic inequities, as Dr. Ruha Benjamin writes in *Viral Justice* [Benjamin, 2022].

It is important to understand where Canadians get their information when delivering information and educating them about best practices for staying safe. Further research ought to be conducted to investigate preferred delivery channels at a provincial level. Given the variation in Canadian voter beliefs about the causes of climate change and outright denial of climate change, this could present significant barriers to public health communications and requires local knowledge [Hatch et al., 2024]. The social media landscape has also shifted significantly in recent years, and decision-makers and public health communicators must address the rampant misinformation spread across these various platforms [Ittefaq, 2024]. In this case, inter-governmental agencies would greatly benefit from sharing access to platform data for research purposes and collaborating with social media platforms to speed up the research process. Unfortunately, accessing data may prove challenging as public health and science are also under attack in the public sphere [Guyon and Perreault, 2016, Hotez, 2023]

8.2.2 Within the UbiLab

The work undertaken at the UbiLab has largely been Canada-focused, exploring applications for ecobee's DYD. At the time of writing, the team at the UbiLab has continued to leverage the ecobee DYD, building on the work started by Dr. Kirti Sundar Sahu and myself.

Today, ecobee, owned by Generac, has been expanding its sensor lineup to include indoor air pollution monitoring, creating an opportunity to expand the area of inquiry with additional variables and areas of study such as indoor air pollution (wildfire smoke, pollen allergies, asthma, VOCs (Volatile organic compounds), noise pollution, and health communication. Efforts are also being made to position its technologies to feature in climate-resilient homes during emergencies and for sustainability (i.e., off-grid or resilience during power outages). The UbiLab has had a long-standing research partnership with ecobee and is well-positioned to continue to build upon the research conducted since 2017.

Related projects surrounding extreme heat and ecobee data, some ongoing at the time of this writing, include:

- Julia de Lazari, a visiting student from the University of Campinas, Brazil, explored Calgary's indoor temperatures and the temperature in unair-conditioned homes. This project found that indoor temperatures were consistently higher than outdoor temperatures, with some homes spending 20% of the time above the ASHRAE recommended indoor thresholds.

- Dr. Jasleen Kaur has been exploring the political impacts of policies during COVID-19, sleep quality impacts from restrictions, and Canadian hospital data during heat waves and sleep quality during heat waves. The ecobee has already been used by the UbiLab to study the quality of sleep.

- Aline De Souza, a visiting MSc student from the University of Campinas, Brazil, has been leading a scoping review of prediction models used to forecast indoor temperatures to support the development of indoor temperature prediction models. They have also supported the preparation of heat wave date data for all of Canada, segmented by provincial regions.

- Navneet Kaur has been developing models to predict indoor temperatures based on the ecobee indoor data to create indicators to assess risk in real-time and identify homes for retrofitting. Adaptation would be the most beneficial given the vulnerability score of a home; more details will be provided in the next section.

- Irfhana Zakir Hussain is continuing the development of the environmental surveillance platform, working to develop prediction algorithms and deploy ecobees in resource-poor communities in Canada and an LMIC (Low or Middle Income Country).

See Appendix H for additional contributions and features of the work conducted during this thesis.

8.2.3 Identifying and predicting vulnerable homes

The team is developing models to forecast indoor temperature using the ecobee data. This is based on historical data but would benefit from live data streaming to enable early warning system capacity. Using machine learning algorithms (like XGBoost), the model's accuracy was enhanced via lag features incorporating five years of historical temperature data from the ecobee thermostats in homes without air conditioning (AC). The findings have been visualized with Matplotlib and Seaborn and will be featured within the planned UbiLab Environmental Monitoring dashboards that will be shared with stakeholders.

The aim is to understand local heat wave patterns, identify homes vulnerable to extreme temperatures, and inform policy and programs at all levels. The next steps include adding additional variables (building characteristics and features) and datasets (e.g., greenness scores, proximity to bodies of water, and vulnerability index) to increase the accuracy and timeliness of indoor heat conditions predictions. By identifying homes before extreme heat periods or pre-determined thresholds, we can ensure that individuals receive resources and support, such as wellness checks. They may also be used for resource planning, ensuring enough hospital staff and ambulances are available. They could also identify homes that require interventions to encourage natural ventilation or nature-based solutions, such as small-scale or micro-grants to install curtains, external awnings, landscaping, or greenery to cool surrounding areas.

While this work has focused on urban environments, Canada's many rural communities also experience extreme heat, and this demographic setting has largely been unstudied. Rural communities are often less prepared for extreme heat shocks and may experience compounding climate events such as droughts and wildfires. Agricultural areas may also experience localized weather phenomena, such as corn sweats or transpiration, or elevated levels of ground-level ozone that can increase heat-related illness symptoms [Jones, 2024, Copernicus, 2022]. Lessons learned here can also be applied to these settings, especially when creating climate-resilient solutions. Overall, this work on indoor heat risk and adaptation to make Canadian communities more resilient to heat waves is essential and will continue.

8.3 Ethical and privacy considerations

With any technological innovation, it is important to consider the ethical and privacy implications carefully. There is valid concern for ethical implications and privacy concerns related to IoT devices and the introduction of AI into the monitoring of indoor environments. It is critical that the data being collected is used for its stated purpose, that users are aware of and able to understand the Terms of Service, and that they can opt out of invasive or excess data collection at any point with the opportunity to have all their associated data deleted [Sen et al., 2023] Many IoT devices include more invasive forms of data collection that can be tied to home users via voice, video, or image capture [Guhr et al., 2020]. Unfortunately, the rules and regulations often lag behind technological developments, making it harder for users to access innovations without giving up their rights to their data and privacy. Thus, there is a further need to study and develop legislation to address the potential pitfalls for users and how they might protect themselves from instances when their data is leaked or used for training AI models without their consent.

With the proposed solutions in this thesis, the ecobee thermostat is unique because it provides a built-in level of anonymity for the user since the data (temperature and humidity) pertains to the space. The advantage is that the data is tied to a household and is not necessarily identifiable at the individual level unless it is a household of one. Similarly, the ecobee system can be installed without microphones (for voice assistants) and cameras because its core function is indoor temperature control and measurement. This separates it from other home assistive technologies, with surveillance or monitoring as their core function. Another advantage of the ecobee thermostat is its well-established research program, Donate Your Data. It ensures user privacy by scrubbing location data and room locations before data is shared with researchers. Together, these features make it a technology that simultaneously solves several issues.

8.3.1 Protection of participants

Not losing sight of humanity is vital when creating technology-based solutions. Rapid technological progress often excludes voices that should be included [Christoforaki and Beyan, 2022, Zowghi and Bano, 2024]. Progress should not happen at the mistreatment or detriment of others. It should neither create new nor exacerbate existing inequities (i.e., the Tuskegee Syphilis experiment and testing of baby formula on Indigenous children) [Brandt, 1978, MacDonald et al., 2014]. Governments must also ensure that the human rights of dignity, privacy, and security are protected and not merely handed

over to companies in the name of progress [Sen et al., 2023, Mooney and Pejaver, 2018]. Additionally, any study to protect the health of individuals living without air conditioning should ensure that all participants remain safe before, during, and after a study for as much as possible. For example, it is important to ensure that there is a plan to notify participants and check in on them during the study, especially if unsafe temperatures are measured in their homes.

The work described in Chapter 7, such as viewing the temperature data in real-time via the ecobee thermostat, enabled the participants to take action to protect their health. Empowering individuals to be agents of their health ensures that they are not just used for the research process and do not experience any benefits.

8.3.2 Environmental cost of technology

When recommending technology-related solutions, it is crucial not to ignore the environmental impacts from the entire life cycle of these devices [Redvers et al., 2022]. Both software and hardware rely on natural resources, often at the expense of Indigenous communities and ecosystems [Department of Economic and Social Affairs, 2021]. Additionally, operating these technologies, particularly fossil fuel-powered ones, can further exacerbate environmental damage. AI, for example, is extremely energy-intensive and dependent on computer chips built with precious metals from the mining industry, an industry with significant environmental and human rights concerns [Allan-Blitz et al., 2022].

As an advocate for climate health, it is essential to prioritize sustainability when developing technological solutions [van Eck et al., 2024]. This means ensuring sustainability is considered from the ground up, including using renewable and sustainable materials for hardware, optimizing software for energy efficiency, and powering databases with renewable energy. Solutions should be designed to reduce energy consumption, with systems able to power down when not in use. In doing this work, I have recognized the important need to step outside academia and into the health advocate role, for how we use research data on machines cannot be isolated from the climate crisis. Supporting initiatives like the Fossil Fuel Non-Proliferation Treaty Initiative and RAISE - Responsible AI for the Environment, and also learning from experts in other areas is inherently a component of our work as public health practitioners [Fossil Fuel Non-Proliferation Treaty Initiative, 2023, Responsible AI Working Group, 2023].

The field of digital health must also adopt these sustainability principles in practice, not just in theory. Neglecting to assess technology's environmental and social impacts in healthcare critically would be irresponsible. For instance, healthcare emissions present an

opportunity to contribute to net-negative emissions, which can help mitigate climate change for the populations digital health seeks to protect.

Organizations such as the Canadian Association of Physicians for the Environment (CAPE) are actively working to reduce healthcare-related emissions, such as healthcare facilities and waste practices [CAPE, 2024]. Another notable example is a move made by pharmacists to prescribe greenhouse gas-emitting inhalers with propellant-free alternatives for asthma patients [CASCADES, 2023]. However, as AI becomes more integrated into healthcare and other sectors, the energy demands of data centres have increased drastically, offsetting gains from renewable energy sources [Heikkila, 2023]. The ongoing debate over the utility of AI versus its environmental and societal costs is crucial to ensure that AI enhances our lives without contributing to issues like misinformation or job displacement.

In public health, AI's role in predicting heat waves and assessing indoor heat exposure risks exemplifies how it can serve society, but this must be done responsibly. Developers must write efficient code, and data centres should shut down unnecessary programs and servers [Verdecchia et al., 2023]. AI and machine learning can potentially improve heat wave and thermal resilience predictions and vulnerability mapping [Siu et al., 2023, Gustin et al., 2018, Ogata et al., 2021, Yu et al., 2020]. Integrating AI with IoT systems can create more advanced real-time monitoring and early warning systems that respond to environmental risks.

8.3.3 Low-cost and non-technical solutions

We use science to understand the best strategies for staying safe during extreme heat. Educating the public on practical solutions, such as properly using fans depending on the ambient temperature and humidity and optimizing natural ventilation by opening and closing windows at the right times, is equally important. Simple, renter-friendly solutions—like blocking sunlight—can also be effective [Malik et al., 2022, Eyquem and Feltmate, 2022]. For example, using temporary barriers instead of installing curtains or blinds (which can be costly and may require landlord approval for drilling holes in the wall) offers a more accessible option.

Automated tools, such as mobile apps or text scripts, can further help by alerting individuals when to open or close their windows to maximize natural cooling. However, implementing these low-cost solutions requires addressing barriers and providing practical insights. For example, while opening curtains or windows at night can improve airflow, it may also introduce noise, light, or safety concerns, potentially disrupting overall sleep quality. For those worried about security, bars on lower-level windows can offer

protection, though addressing noise pollution may require coordination with municipal departments—highlighting the complexity of managing heat risks.

Moreover, it's important to move beyond individual solutions to avoid placing undue blame on individuals for climate change, as has been done in the past by industries like fossil fuel companies that promoted personal responsibility (e.g., recycling and reducing air travel) to deflect attention from systemic issues. Focusing solely on individual actions risks falling into greenwashing traps, diverting attention from larger, necessary systemic changes needed to combat the climate crisis.

Community and social connections are vital tools for building climate resilience and addressing extreme heat, requiring collaboration among diverse partners to ensure success [Kafeety et al., 2020]. For example, the Tsleil-Waututh Nation analyzed Elders in their community during the 2021 Heat Dome and implemented enhanced wellness checks. This effort revealed that support often needed to be extended to companions and caregivers before Elders would agree to relocate to temporary cooler space [Yumagulova et al., 2023]. Community-based organizations are crucial in bridging gaps between residents and experts on heat health, fostering trust and facilitating effective communication and outreach efforts [Guardaro et al., 2020]. These examples highlight the importance of community-driven approaches to heat resilience, ensuring that interventions are inclusive, culturally appropriate, and tailored to the needs of vulnerable populations.

8.3.4 Heat as a gendered issue

While this work did not investigate the gendered experiences of participants, gender is an important risk factor that requires more research. In Canada, both men and women face risks from extreme heat, but their vulnerabilities differ due to physiological, occupational, and social factors, as well as regional and demographic variations. Men are often at higher risk due to occupational exposure, as they are overrepresented in outdoor and physically demanding jobs such as construction, farming, and mining. These occupations increase heat exposure and the likelihood of heat-related illnesses, particularly during heat waves. For instance, in Ontario, agricultural and construction workers, predominantly men, are especially vulnerable during extreme heat events [Pierre and Wilson, 2023]. Studies have also indicated that men tend to experience heat illness significantly more than women, largely due to prolonged occupational exposure and greater metabolic heat production during physical activity [Gifford et al., 2019].

Women, on the other hand, face unique vulnerabilities influenced by socioeconomic and caregiving factors [UN Women, 2023]. Older women, in particular, are at higher risk

during heat waves due to a greater prevalence of chronic health conditions, lower average incomes, and a higher likelihood of living alone, especially among seniors [Khanam, 2023]. Additionally, caregiving responsibilities often place women in roles and responsibilities where their own needs, such as hydration and access to cooling, may be deprioritized during heat waves [Rajvanshi, 2023]. These risks are amplified for women in low-income or marginalized communities, where access to cooling resources and healthcare may be limited.

Geographic and community contexts also play a role in shaping vulnerabilities. In urban centres like Toronto and Vancouver, gendered vulnerabilities intersect with socioeconomic factors. Women are more likely to live in subsidized or community housing, where inadequate cooling systems can exacerbate heat exposure [Khanam, 2023]. Meanwhile, in rural areas, men working in outdoor labour face the highest risks due to prolonged exposure to extreme heat and limited access to cooling facilities or healthcare infrastructure [El Khayat et al., 2022].

Despite these differences, limited gender-specific research on heat-related risks in Canada exists. To address this gap, it is essential to collect gender-disaggregated data on heat-related illnesses and deaths to understand physiological and occupational differences in vulnerability better. Additionally, more research is needed to explore intersectional vulnerabilities, particularly among Indigenous populations, where unique socio-environmental challenges may exacerbate heat-related risks for both men and women. Addressing these gaps will ensure more equitable and effective responses to extreme heat in Canada.

8.4 Implications for public health policy and research

Heat waves are a complex challenge, and solutions require multidisciplinary inputs from public health, urban planning, policymaking, and technology development in environmental monitoring, including indoor monitoring. Dying from extreme heat is mostly preventable, and no one should have to suffer indoors due to poverty or mobility issues.

8.4.1 Short-term recommendations for policy and practice

Early warning systems are essential to protecting health and ensuring people can provide the information they need to stay safe during extreme heat. Policies to protect health and well-being during extreme heat should include preparedness plans, such as wellness checks, and strategies for heat-proofing buildings through natural greening, nature-based solutions, and using materials that reflect or minimize heat absorption. However, more research is needed,

as recent research has shown that the painting of rooftops can have unintended consequences, making nearby areas hotter [Cheng and McColl, 2024]. Low-cost sensors can provide benefits in low-resource settings, and any use of available resources and solutions should also limit GHGs emissions should be the focus. Educating Canadians on the dangers of climate change requires nuance. As lessons learned from infodemics research highlight, there are several areas where decision-makers may get ahead of damaging narratives that inhibit the ability to protect the health of Canadians. Legislation that demonetizes misinformation on websites and social media platforms could deter bad-faith actors and mitigate the broader spread of harmful narratives. Given that most Canadians receive information via social media platforms or internet websites, paywalls and legislation that impede the flow of information from reputable sources make it harder for Canadians to receive high-quality information from trusted sources. Further censorship and paid platform badges make it harder for individuals to identify trustworthy individuals and organizations. In the short term, smaller-scale home improvements, such as those from the Intact Centre for Climate Change [Eyquem and Feltmate, 2022, Intact Centre on Climate Adaptation, 2023], could be socially prescribed by doctors or pharmacists, such as how park passes are prescribed for mental health can increase access [Saragosa et al., 2024, BC Parks Foundation, 2024].

8.4.2 Long-term recommendations for policy and practice

The work can be expanded to include more sites and longer study periods, and the process of sharing data insights with the spectrum of stakeholders must also be explored (i.e., during an extreme heat event). The data on indoor temperature can also be used for indoor temperature modelling to inform legislation and policy development. New and existing homes must be built with a climate lens to withstand extreme weather. Homes should minimize total greenhouse gas emissions by installing energy-efficient appliances, utilizing heat pumps, and being off-grid or powered by renewables. Additionally, urban planning and landscaping must be considered, as the surrounding environments are important in reducing the surrounding temperatures and the urban heat island effect. This can be achieved by governments providing support (such as the Canada Greener Homes program or similar incentives) for those at the most risk to adapt and be more climate resilient and able to withstand extreme heat [Natural Resources Canada, 2021]. These home improvements may also have co-benefits for the greater environment, indoor air quality, and overall health and well-being of the household. Due to the high cost of living, such household improvements fall outside of priorities for most families, especially the low and middle-income dwellers and renters. Finally, governments must implement legislation on maximum temperatures in indoor spaces and for outdoor workers to increase access for equity-deserving groups

[Canadian Centre for Occupational Health and Safety Government of Canada, 2023a, Geenen, 2024].

These efforts align with research and recommendations calling for integrated, evidence-based solutions to mitigate the impacts of extreme heat and enhance community resilience.

8.5 Interdisciplinary solutions

8.5.1 Interventions

Beyond Air Conditioning: Sustainable Cooling Solutions While air conditioning is the most common solution to prevent heat-related deaths, it is not sustainable globally, as the widespread installation of air conditioners would significantly contribute to global warming [Quick and Tjepkema, 2023, De Munck et al., 2013]. The solution must be multifaceted, balancing immediate human needs with long-term environmental sustainability. Innovative solutions are emerging that go beyond cooling spaces, such as taking lessons from nature and other fields like architecture [Sarswat and Kamal, 2015, Ozarisoy, 2022, United Nations Environment Programme, 2021]. Additionally, shifting from air conditioners to heat pump technologies will require education and myth debunking [Gard-Murray et al., 2023, Carbon Brief Staff, 2024]. Combating climate denial and addressing misinformation about extreme heat risks is crucial to protecting public safety, but without addressing these challenges, efforts to reduce heat-related deaths could be undermined.

Leveraging New Technologies for Healthier Homes The home should be a safe environment, but rising temperatures challenge the building codes we have utilized in our society over the past hundred years. As the earth enters a poly-crises phase, with co-occurring climate events such as wildfires and extreme heat, it may be possible to leverage technologies to create healthier and more climate-resilient homes. For example, the ecobee, with its thermostat and indoor air sensors, could help balance indoor conditions during heat waves and poor air quality events (wildfires) by managing ventilation and filtering the air entering the home. A system could also provide residents with information about the air quality and automate the opening and closing of window shades during the day to reduce heat indoors.

Technologies such as induction stoves, heat pumps, and heat recovery ventilators (HRVs) can improve indoor air quality and energy efficiency, making homes safer and more sustainable [McIlroy et al., 2024]. However, the high upfront costs of these technologies

mean that policies like the Canada Greener Homes Grant, which provides financial support, are necessary to make them accessible [Natural Resources Canada, 2021]. Policymakers must remain vigilant against fossil fuel interests that resist the transition to cleaner technologies. Additionally, with wildfire seasons growing longer, homes must be equipped to handle smoke exposure, a growing air quality threat, alongside heat.

8.5.2 Initiatives

Social Prescribing and Resilience Building Social prescribing is an emerging practice that can help individuals access low-cost cooling adaptations. By prescribing practical cooling solutions, such as window film or fans, healthcare professionals can help vulnerable populations stay safe during extreme heat [Saragosa et al., 2024]. Research shows that social connections and high social capital are protective factors during extreme weather events [Wolf et al., 2010, Klinenberg, 2016]. Providing financial support to purchase fans is a feasible solution. However, this should also be accompanied by the latest guidance on appropriate temperatures for fan usage, as at extreme temperatures (above 31°C), fans are dangerous [Meade et al., 2024b]. Encouraging social prescribing can help build resilient communities that can withstand extreme heat and other natural disasters.

Upstream Harm Reduction The conversation around heat waves is increasingly shifting toward upstream harm reduction, focusing on proactive measures to mitigate climate impacts [The Lancet, 2021, Jay et al., 2021]. Funding mechanisms to prevent harm, like releasing monetary resources before extreme weather events, are vital [UNDRR, 2024a, UNDRR, 2024b]. This approach spans climate mitigation and adaptation, reducing the effects of heat waves and helping individuals protect themselves. For example, Canada is projected to face billions of dollars in costs from heat waves over the next century, underscoring the need for creative and effective solutions [Canadian Institute for Climate Choices, 2021].

Global Lessons and Local Solutions In Gujarat, India, the Extreme Heat Income Insurance program offers financial protection to women whose livelihoods are threatened by extreme heat, illustrating the importance of gender-sensitive approaches to climate resilience [Desai, 2023]. Women, often more vulnerable due to their roles in outdoor markets and household responsibilities, are disproportionately affected by rising temperatures. Meanwhile, centuries-old architectural designs from warm climates, such as central courtyards and wind towers, offer passive cooling techniques that could be revived and adapted to modern contexts [McCabe and Roaf, 2013].

Combining Traditional Knowledge and Modern Innovation Modern examples,

like Bangladesh's Friendship Hospital, use passive cooling systems that eliminate air conditioning or move to more efficient systems like heat pumps [Wainwright, 2022]. Singapore's district cooling system, which pipes cool air underground to buildings, is another innovative solution [SPgroup, 2023]. When combined with advanced materials and technologies, these designs can significantly lower ambient temperatures and reduce energy demand.

8.5.3 Policy level actions

The Role of Policy Policy is the government's most powerful tool to protect Canadians from extreme heat. Much like the principles of public health that focus on upstream prevention, the risks of heat waves are predictable and can be mitigated with proper foresight. Updating building codes to reduce the urban heat island effect, incorporating nature into urban planning, and regulating IoT and AI technologies are all crucial strategies [Purcell, 2022, Abdeen et al., 2020, UNDRR, 2024a, AI4PH, 2024]. These measures can form the backbone of robust public health methods to shield communities from the escalating threat of heat waves.

Preparing for the Worst Governments must prepare for the worst by investing in early warning systems, creating green spaces, and reducing the urban heat island effect through sustainable urban planning [Wong et al., 2013, Health Canada, 2009]. They should also finance deep energy retrofits and create training programs for the workforce to integrate renewables, AI, and IoT technologies that support these efforts [Sacred Earth Solar et al., 2023, Menotti, 2024]. By preparing communities in advance, we can mitigate the harmful impacts of extreme heat on vulnerable populations.

Integrating social and behavioural research with building science, engineering, and architecture is critical to addressing the challenges of extreme heat. Successful examples, such as the innovative building designs in Singapore and the award-winning hospital in India, demonstrate how interdisciplinary approaches can lead to climate-resilient structures that cool naturally, reducing reliance on air conditioning.

Breaking Silos to Tackle Extreme Heat Addressing the complex issue of extreme heat requires breaking down traditional silos between disciplines. Collaboration across fields is essential to develop holistic solutions that mitigate heat and address human, social, and behavioural aspects [Jandaghian et al., 2022, Anderson et al., 2022]. Future research should focus on understanding human behaviour in response to heat wave warnings and how IoT-based monitoring systems can influence these behaviours. Improving public awareness and education on heat wave preparedness through interdisciplinary efforts will also be key to safeguarding public health.

8.6 Additional experiences of extreme heat

While many solutions focus on populations with low access to resources, displaced populations in refugee camps and migrant workers face unique challenges [Zimmer and Van Den Hoek, 2024, Balasundaram, 2023, Fleischer et al., 2013]. These groups often experience extreme indoor heat in temporary shelters, where traditional heat mitigation advice, such as staying indoors or using air conditioning, is impractical or unattainable. Inadequate infrastructure, unreliable electricity, and overcrowded living conditions exacerbate their vulnerability to heat-related illnesses. For example, temporary shelters like tents can become dangerously hot, and camps lack climate-resilient infrastructure to weather extreme weather conditions [Moran et al., 2021, Fransen et al., 2024] More research is needed to develop targeted strategies that address indoor and outdoor heat exposure in these settings, ensuring that interventions are tailored to protect these highly vulnerable populations.

8.7 Reflections

The world is increasingly experiencing extreme heat, and the significant events of the past decade have revealed vulnerabilities in our systems that leave many individuals exposed to its dangers. Addressing these challenges requires place-based solutions in addition to agency-based approaches, which ensure sustainability and empower individuals and communities to adapt effectively to their local conditions. Mitigation and adaptation are critical, and sharing best practices globally is essential for fostering resilience across diverse contexts.

This work demonstrates how technology, often considered a luxury and inaccessible to lower-income populations, can be repurposed to redistribute access to essential services and data. By illustrating how IoT sensors like ecobee devices can collect actionable indoor temperature data, this research highlights opportunities for governments and organizations to implement data-driven strategies to mitigate heat risks. Moreover, there is significant potential for community organizations and individuals to leverage this technology to address gaps in institutional support. Equipping community organizations with the tools and knowledge to monitor indoor temperatures empowers them to protect vulnerable populations, even without formal government interventions.

Data can be a transformative tool for driving change. For individuals, simply knowing the indoor temperature of their homes can inform timely actions to safeguard their health

during extreme heat events. This democratization of information shifts power dynamics, enabling proactive measures to mitigate heat risks. Appendix B provides detailed guidance on retrofitting an ecobee device, ensuring that this technology can be deployed in diverse settings to enhance climate resilience and health outcomes.

The goal is not to install such devices in every home but to envision a hyper local network that empowers individuals to protect themselves while i forming and driving policy change. However, it is crucial to recognize that the vulnerable communities discussed here have often faced systemic harm and institutional failures, fostering mistrust toward proposed solutions. These concerns are valid and must be addressed with transparency, community engagement, and culturally sensitive approaches to ensure equitable solutions are trusted.

The collaboration with a device company that upheld ethical standards ensured the research process maintained integrity. Navigating the balance between conducting meaningful work, serving the public, and securing funding often presents significant ethical challenges for researchers. It is essential to carefully evaluate a technology company's values, ethics, leadership, manufacturing practices, product pipeline, and policies. These considerations are critical, as they directly impact the integrity of the research and its broader societal implications. Addressing these tensions is vital for ensuring responsible and equitable outcomes.

When thoughtfully implemented, technology can provide value rather than create further disparities by working collaboratively to consider potential pitfalls. Environmental justice is tackling the issues and dismantling the systems that create the oppression. As privileged individuals living in the Global North, we also have a duty of care to reduce the inequities perpetuating the harm to the planet felt most by those living in the Global South [Oxfam, 2023].

Technology is merely a tool; the most enduring and resilient response to climate change lies in the strength of the community. While this work highlighted the use of such technology, the take away message should be that technology can support our efforts. The power of caring for one another during times of need has been vividly demonstrated by communities coming together in the aftermath of heat waves, power outages, hurricanes, floods, and wildfires. These moments of solidarity underscore the importance of collective action and mutual support. However, the hope is that such care and collaboration do not remain reactive, emerging only after disaster strikes. Building a culture of proactive compassion and preparedness is essential for fostering resilience and ensuring that no one is left behind in the face of climate challenges.

Chapter 9

Conclusion

Do the best you can until you know better. Then, when you know better, do better.
Maya Angelou

Dr. Robert Bullard once stated, "The people most responsible for climate change historically — globally, as well as domestically — are not the same people who are feeling the pain first, worst and longest." [Chow, 2020].

The work described here is part of a broader interdisciplinary effort to mitigate and adapt to the impacts of the climate crisis. By leveraging our resources and knowledge while safeguarding those most vulnerable to extreme heat, we can create a more resilient world. Urgent action is needed to ensure that extreme heat events, increasing frequency and intensity, do not endanger populations worldwide further [Romanello et al., 2021]. With 2023 and, highly likely, 2024's record-breaking temperatures affecting large parts of the globe, the risk of heat-related illness and mortality is higher than ever [Copernicus, 2024]. In Canada, indoor temperatures in homes and buildings are reaching dangerous levels, even during 'milder' summertime conditions and on non-heat wave days. This underscores the pressing need for effective climate adaptation strategies. Compounding these challenges, the spread of misinformation and disinformation is undermining climate resilience efforts, programs, and education on the risks of heat waves and best practices for staying safe. The widespread use of smart thermostats presents a promising solution for studying indoor temperature trends over time. It enables a large-scale monitoring system for a long-term approach to addressing heat vulnerabilities nationwide.

9.1 Contributions of this dissertation

Chapter 5 laid the groundwork for this study by demonstrating how IoT devices, specifically smart thermostats, can monitor indoor heat exposure and inform public health strategies for heat wave resilience. It also highlights the dual benefits of smart home technologies in enhancing personal well-being and safety while improving home comfort by optimizing heating and cooling systems.

Chapter 6 delved into IoT devices, particularly in home environments, and reviewed the literature on their applications for monitoring indoor conditions, focusing on extreme heat and maintaining safe living spaces. It found a wide range of technologies being used, but none were devices which normally exist in the home, except for one. The IoT space is ready for innovation and is well suited to support efforts to develop early warning systems.

In Chapter 7, the authors analyzed relevant keywords and language used on social media to discuss extreme heat events and related developments. This includes data from a Google survey that captures how Canadians feel about extreme heat and sentiments, and topics Canadians discuss on Twitter. Canadians are aware of heat waves, but more education is needed, and the shifting social media landscape presents challenges for heat health messaging initiatives.

Chapter 8 presented a deployment of smart home thermostats in homes without (central) air conditioning. This marks the first Canadian study to provide real-time temperature alerts to building managers and public health officials, offering actionable insights. The chapter underscores the importance of effective communication methods and delivery channels for heat-related information. Additionally, it introduces a framework exploring how early warning systems integrated with IoT devices can enhance heat wave resilience across all levels of society.

This work supports the fight against the serious threat of high indoor temperatures, a reality for many Canadians living in older, non-air-conditioned buildings nationwide. The data collected and research presented here add to the growing body of literature on extreme heat and the development of policies to create safer indoor spaces. This is the first indoor temperature study to use IoT and deliver real-time alerts to stakeholders in Canada. Given the rapid integration of off-the-shelf, commercially available IoT devices into homes worldwide, a nationwide hyper-local network able to collect indoor temperature and humidity data is highly feasible. The implications of real-time data collection mean that the critical time delay is eliminated, increasing safety indoors and enabling evidence-informed resource allocation of emergency services during an extreme heat event.

Additionally, the results from the social media analyses and surveys will help educate

and disseminate information surrounding extreme heat. Heat waves are still vastly underdiscussed in the media and the public discourse; see Figure 9.1, where searches for other natural disasters like floods, wildfires, hurricanes, and tornadoes on Google within the past five years overshadow heat waves.

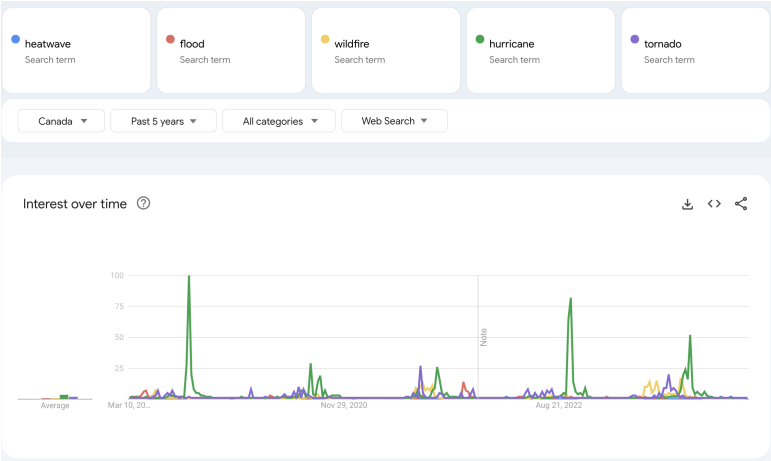


Figure 9.1: Search results for Canada's most common natural disasters in the past five years. Source: Google Trends

The importance of this work is also echoed at various levels of international and national governmental organizations working towards climate adaptation for extreme heat and protecting individuals from extreme heat impacts. Here are some of the initiatives this work aligns with:

- The international community has called for more research and development that aligns with the Sustainable Development Goals (SDGs): 3 - Good Health and Well-being, 11 - Sustainable cities and communities, and 13 - Climate Action [Cool Coalition, 2024],
- The GHHIN and WMO call for early warning systems and enhanced preparedness [World Meteorological Organization, 2023a],
- The WMO launched the Early Warnings for All initiative to ensure everyone is protected from extreme weather by the end of 2027 [World Meteorological Organization, 2023b],
- The experts have called on governments from the federal to the municipal level to strengthen preparedness for future extreme weather events, such as extreme heat [Lao, 2021, Eyquem and Feltmate, 2022, Jay et al., 2023, Action Canada, 2022],

- The Government of Canada plans to eliminate deaths caused by extreme heat by 2040. This work contributes to understanding the indoor conditions experienced by individuals living in Canada [Environment and Climate Change Canada, 2022].

By integrating interdisciplinary approaches that combine behavioural research, innovative technology, policy reform, and traditional architectural wisdom, we can build resilient communities and create a future where the impacts of extreme heat are mitigated, and all people are better protected. Extreme heat affects everyone, but it is essential to recognize that it does not occur in isolation. It intersects with and exacerbates existing health conditions, such as mental health disorders and disabilities, intensifying its impact. Addressing and mitigating the dangers of extreme heat exposure is a critical responsibility of our government. There is an urgent need to evaluate and update current guidelines, programs, and legislation to foster safer and more resilient environments for all. Tackling these challenges requires interdisciplinary collaboration, especially as we confront unknown risks and potential equity issues that may arise. Through ongoing research, we can develop innovative solutions that improve public health, enhance urban living, and accelerate climate adaptation. Our work today will set the foundation for a healthier, more sustainable future where communities are better prepared to face the increasing threat of extreme heat.

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APPENDICES

Appendix A

Impact of heat waves

A.1 Global major heat wave events

List of notable global heat waves and attributed excess mortality counts (actual death counts may not be exact due to records variation among sources or no records being available).

1901 Eastern United States Heat Wave: 9,500 deaths.
1936 North American Heat Wave: 5,000 deaths.
1980 United States Heat Wave: 10,000 deaths.
1987 European Heat Wave: causing hundreds of deaths.
1995 Chicago Heat Wave: 739 deaths.
2003 European Heat Wave: 70,000 deaths.
2006 European Heat Wave: 3,000 deaths.
2010 Russian Heat Wave: 56,000 deaths.
2015 Indian Heat Wave: 2,500 deaths.
2019 European Heat Wave: 62,862 deaths.
2020 Siberian Heat Wave: Environmental impact great, death toll not well-documented.
2021 Western North American Heat Dome: 1,400+ deaths.
2022 European Heat Wave: 60,000 deaths.
2023 European Heat Wave: 47,000 deaths.
2024 India Heat Wave: 700 deaths.

A.2 Heat-related illnesses and symptoms

Being able to recognize these symptoms early and take appropriate action can be life-saving. Heat-related illnesses can progress rapidly and require immediate action, especially among the elderly, children, and individuals with chronic health conditions.

Heat cramps
Symptoms: Muscle pains or spasms occurring in the abdomen, arms, or legs.
Notes: Typically occur during intense physical activity in hot environments due to dehydration and electrolyte imbalance.

Heat exhaustion
Symptoms: Heavy sweating, general weakness, cold, pale and clammy skin, fast and weak pulse, nausea or vomiting, and fainting.
Notes: Develops after multi-day exposure to high temperatures and insufficient fluid replacement.

Heat stroke
Symptoms: Marked by high body temperature (over 39.4°C or 103°F), hot, red, dry, or moist skin, rapid and strong pulse, and unconsciousness.
Notes: This is a medical emergency; seek immediate medical attention, as it may lead to death if not treated promptly.

Heat edema
Symptoms: Indicated by swelling in lower legs and feet.
Notes: Often occurs in individuals not acclimatized to hot environments.

Heat rash/prickly heat
Symptoms: Appears as red clusters of small pimple-like blisters on the skin, usually in the neck, chest, groin and inside elbow areas.
Notes: Symptom of sweat duct becoming blocked and inflamed.

Sunburn
Symptoms: When skin feels hot, it displays redness, pain, swelling, blisters, fever, and headaches.
Notes: It is not a heat illness, but it is caused by heat exposure and can exacerbate other heat-related illnesses.

Dehydration
Symptoms: Characterized by extreme thirst, less frequent urination, dark-coloured urine, fatigue, dizziness, and confusion.

Notes: Also not a heat illness, it is a critical factor that can warn individuals they may be starting down the path of heat-related illnesses.

A.3 How to prevent and treat heat-related illness

Strategies are recommended during extreme heat events to protect yourself and your loved ones. This is not a comprehensive list, so please seek professional medical assistance if you are experiencing symptoms.

Stay hydrated
Drink plenty of fluids, even if you do not feel thirsty. Water is preferred. Avoid alcoholic or caffeinated beverages as they may lead to dehydration.

Wearing appropriate clothing
Wear loose-fitting, lightweight, and light-coloured articles of clothing. Darker colours absorb sun rays and become hotter, while tight clothing can restrict circulation.

Use sunscreen
Use a broad-spectrum sunscreen with a higher SPF value; the higher, the better. Use and reapply regularly, especially after swimming and activities that induce sweating.

Seek shade and cooler environments
Stay under trees, awnings, or overhangs to shield yourself from the sun's rays. Seek air-conditioned spaces, if possible, including public spaces such as malls, libraries or cooling centres.

Avoid strenuous activities
Reduce or avoid physical exertion, especially during the hottest periods (10:00–16:00 or 10 AM to 4 PM). If this is not possible, then take frequent breaks and stay hydrated.

Take regular breaks
If outside or in a non-air-conditioned environment, take frequent rest breaks in shaded areas.

Acclimate the heat
The body can adjust gradually to high temperatures, so give it time if you are not used to high temperatures.

Eat light
Eat smaller and more frequent meals. Avoid high-protein foods that increase metabolic heat and raise the body temperature.

Stay informed
Pay attention to local heat advisories and weather forecasts. Knowing this can help you prepare for high temperatures and humidity.

Protect the vulnerable
Stay vigilant, especially for those most at risk, including infants, young children, people aged 65 or older, those who are physically ill (e.g. cardiovascular disease or high blood pressure), mental health issues (e.g. schizophrenia). Check-in frequently with isolated or individuals living alone.

Keep environment cool
Use fans, take cool showers or baths, keep living space cool by covering windows to block out the sun and close the windows during the hottest period of the day (10:00–16:00 or 10 AM to 4 PM).

Keep environment cool
Use fans, take cool showers or baths, keep living space cool by covering windows to block out the sun and close the windows during the hottest period of the day (10:00–16:00 or 10 AM to 4 PM).

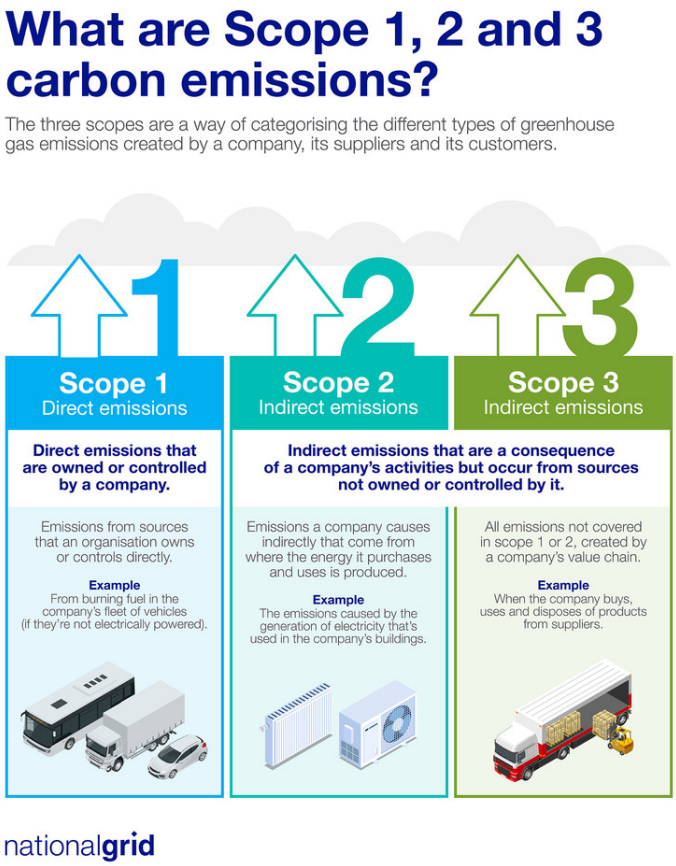
Know the symptoms
Know the signs and symptoms of heat-related illness to ensure early detection and treatment.

A.4 Greenhouse gas emissions

The path to Net Zero is often discussed regarding Scope 1, Scope 2, and Scope 3 emissions reductions [National Grid Group, 2023].

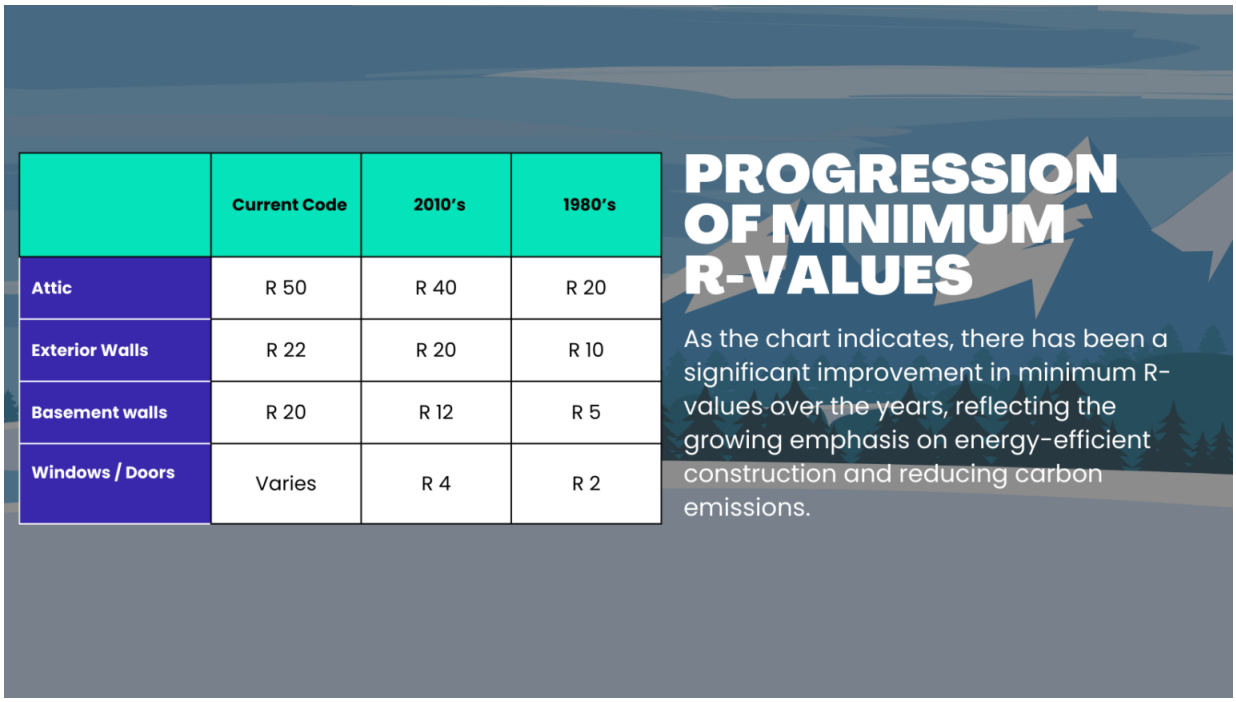
The main greenhouse gases in earth's atmosphere are carbon dioxide, methane, nitrous oxide and water vapour. These are naturally occurring, however human activity has also contributed additional gases that trap heat, hydrofluorocarbons (HFC), perfluorocarbons (PFC) and sulphur hexafluoride (SF_6).

Each entity (organization or company) has a responsibility to assess its emissions and take action to reduce them as much as possible.



A.5 Insulation R Value progress

R values for home insulation have increased over the years [The Shannon Household, 2023].



	Current Code	2010's	1980's
Attic	R 50	R 40	R 20
Exterior Walls	R 22	R 20	R 10
Basement walls	R 20	R 12	R 5
Windows / Doors	Varies	R 4	R 2

Appendix B

ecobee thermostat

B.1 How to modify ecobee thermostats for data collection

To facilitate easy setup of ecobee's thermostats for the purposes of data collection, the thermostats have been modified to plug into a wall outlet. This method does not interfere with a building/home/dwelling/unit's existing heat or cooling systems, as only power and Wi-Fi are needed for data collection. Overall bandwidth use (¡20MB per year) and power draw is minimal.

Items you'll need:

- ecobee thermostat
- 24V AC wall adaptor
- Wire stripper/cutter

Overview of steps

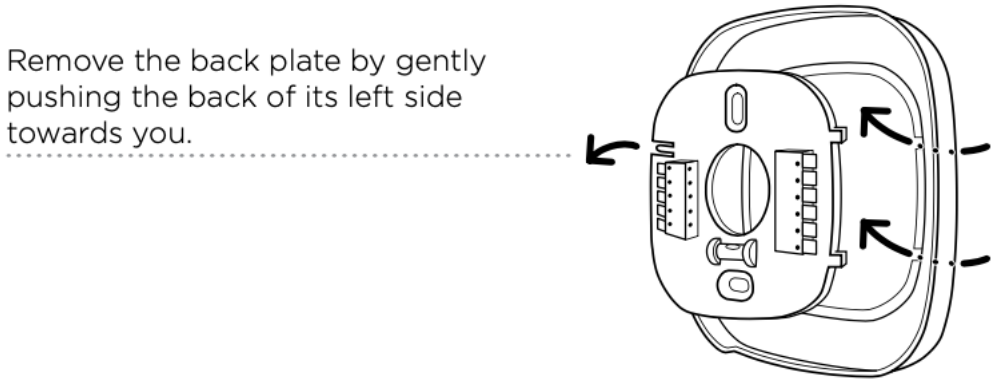
STEP 1 Prepare wall adaptor wires
STEP 2 Connect wall adaptor to ecobee backplate

STEP 1 Prepare the wires of the AC adaptor

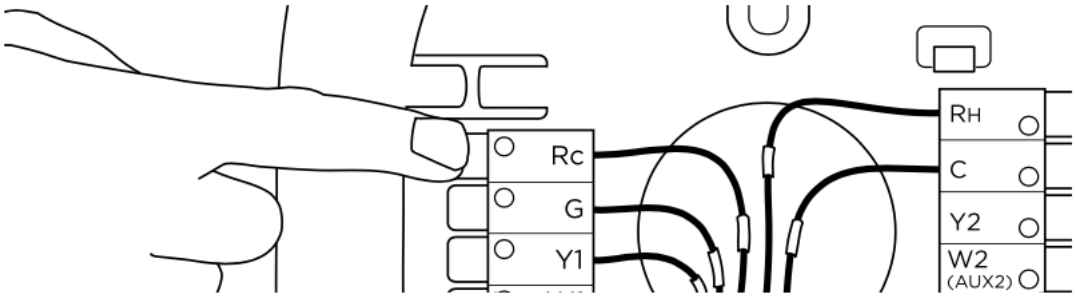
1. With the wire cutters, cut the far end of the 24V AC wall adaptor.
2. Separate and strip the two wires to expose approx. 1/2 inch or 1.5 cm in length.
3. Fold the two lengths in half to create the end that will connect to the terminals.

STEP 2 Connect wall adaptor to thermostat.

1. Remove the backplate from the ecobee thermostat.

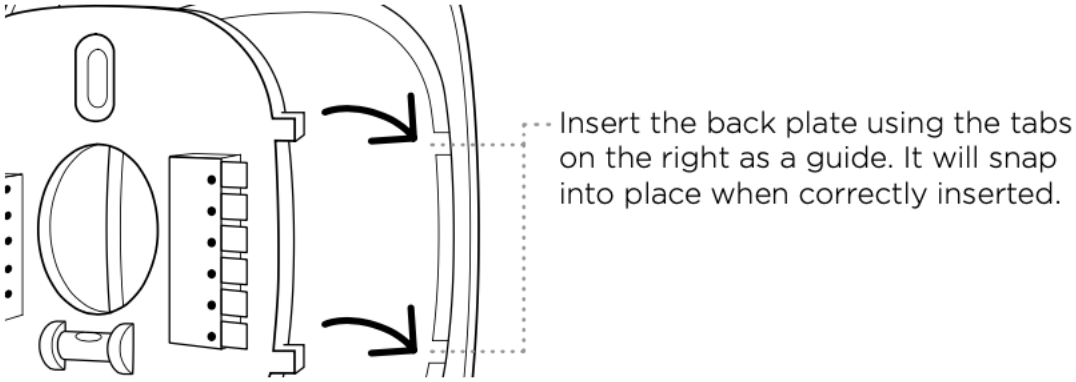


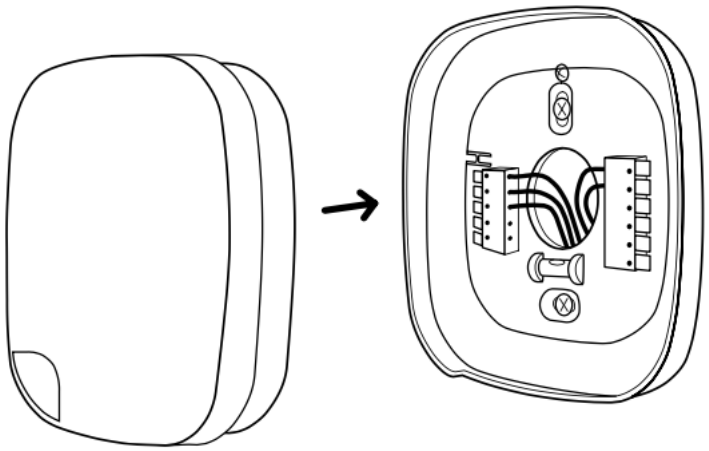
2. Identify the Rc and C terminals.



3. While pressing down on the lever, insert one folded wire end into the Rc terminal and the other in the C terminal.

4. When installed correctly, the release lever of the terminal black will lower to indicate engagement. Gently tug on the wires to ensure they are engaged in the terminal.
5. Connect the ecobee thermostat to the backplate, making sure to run the wires through the back.





Congratulations! Plug the wall adapter in a wall outlet, and you are now ready to start data collection.

Adapted from ecobee's installation guides.

B.2 Assembly and installation of thermostat stand

Adapting the ecobee thermostat to collect data in a location with no Wi-Fi and no thermostat installed. Assembly requires a power drill.

Materials

- 1 Ikea VIVALLA tablet stand
- 1 modified ecobee thermostat and backplate (see above)
- 2 1/8 sized nuts and bolts (backplate)
- 1 mobile router (KuWfi or Alcatel)
- 1 adhesive Velcro strips (to attach router)
- 2 power supply/ adapters (for ecobee (24V) and router (5V))
- 6 ft extension cord (with min. two outlets)
- 2 zip-ties (to secure adapters and cables)

Instructions

1. Drill 1 hole on the front of the stand, located at the centre of the backplate for the wires, that is 8 cm from the left of the edge stand and 9 cm down from the top of the stand.
2. Drill 2 holes, above and below the first hole, to secure the ecobee thermostat backplate.
3. Secure the backplate with the nuts and bolts. Be sure to feed the wires through, and the electronics are hidden behind the front and back of the stand.
4. Drill 2 holes on the back of the stand. Located 11.5 cm in from the right edge (when the back is facing you), 5 cm and 9 cm down from the top of the stand.
5. Plug in the two adapters from the thermostat and the router into the extension cable and place them within the stand, ensuring nothing is visible from the sides and the stand can sit flush on a flat surface.
6. Use the zip ties to secure the electronics (power adapters and extension cords.

7. Place the router inside the back of the stand with the adhesive Velcro strips.
8. Place on the wall with multiple removable poster strips.

Appendix C

Supplementary to "Indoor temperatures in the 2018 heat wave in Quebec, Canada: exploratory study using Ecobee smart ther- mostats"

C.1 Weather station and number of associated ecobee households in Quebec 2018

Weather Station	No of Households
BEAUPORT	23
GRANBY	8
ILES DE LA MADELEINE A	2
JONQUIERE	5
L'ACADIE	2
L'ASSOMPTION	41
LAC BENOIT	208
LAC MEMPHREMAGOG	6
LENNOXVILLE	3
MANIWAKI AIRPORT	1
MANIWAKI UA	1
MCTAVISH	149
MONTREAL INTL A	70
MONTREAL MIRABEL INTL A	26
MONTREAL/ST-HUBERT	80
OTTAWA GATINEAU A	59
SAINT-GERMAIN-DE-GRANTHAM	3
SHAWINIGAN	1
ST-ANICET 1	2
ST-JOVITE	1
STE-ANNE-DE-BELLEVUE 1	31
STE-CLOTHILDE	1
THETFORD MINES RCS	2
VALCARTIER A	3

Table C.1: Weather station and number of ecobee households in each location

C.2 Quebec Health Regions that declared heat waves in the summer of 2018

Health region	Start date of heat wave	Length (days)	Average temperature	
			Maximum (°C)	Minimum (°C)
02 Saguenay-Lac-St-Jean	July 3rd	3	32.6	18.1
04 Mauricie et Centre-du-Québec	July 1st	5	32.1	18.9
05 Estrie	June 30th	5	31.9	19.0
06 Montréal	June 30th	6	33.7	22.1
07 Outaouais	June 29th	5	34.1	19.6
07 Outaouais	August 4th	4	30.8	18.9
13 Laval	June 30th	6	33.7	22.1
14 Lanaudière	June 30th	4	33.3	20.5
15 Laurentides	June 30th	4	33.3	21.0
16 Montérégie	June 30th	4	33.4	21.3

Figure C.1: Source: www.climatedata.ca/case-study/extreme-heat-waves-in-quebec/

Appendix D

Scoping review

D.1 Search strategy

Table D.1: Search strings (last search on Jan 4, 2024)

Database	**Search String**
Pubmed	(”indoor comfort” OR ”thermal comfort”) OR (”temperature” OR ”heat stress”) AND (”sensor” OR ”technology*” OR ”early warning system” OR ”realtime”) AND (”extreme heat event” OR ”heatwave”)
Scopus	(TITLE-ABS-KEY ((indoor AND comfort OR thermal AND comfort) OR (temperature OR heat AND stress) AND (sensor* OR technology* OR early AND warning AND system* OR realtime) AND (extreme AND heat AND event OR heatwave*)))
Medline/OVID	(”indoor comfort” OR ”thermal comfort”) OR (”temperature” OR ”heat stress”) AND (”sensor” OR ”technology*” OR ”early warning system” OR ”realtime”) AND (”extreme heat event” OR ”heatwave”)
Web of Science	TS=(”indoor comfort” OR ”thermal comfort”) AND TS=(”ambient temperature” OR heat OR ”heat stress”) AND TS=(sensor OR technolog* OR ”temperature monitoring devices” OR ”early warning system” OR ”temperature alert system”) AND TS=(”extreme heat event” OR heatwave)
IEEE Xplore	(”indoor comfort” OR ”thermal comfort”) OR (”temperature” OR ”heat stress”) AND (”sensor” OR ”technology*” OR ”early warning system” OR ”realtime”) AND (”extreme heat event” OR ”heatwave”)
CINAHL	(”indoor comfort” OR ”thermal comfort”) OR (”temperature” OR ”heat stress”) AND (”sensor” OR ”technology*” OR ”early warning system” OR ”realtime”) AND (”extreme heat event” OR ”heatwave”)
Google Scholar (first 200)	(”indoor comfort” OR ”thermal comfort”) OR (”temperature” OR ”heat stress”) AND (”sensor” OR ”technology*” OR ”early warning system” OR ”realtime”) AND (”extreme heat event” OR ”heatwave”)

Continued on the next page

Table D.1: Search strings (continued)

Database	**Search String**
Google Search Engine (first 10 pages)	"indoor comfort" OR "thermal comfort" OR ("ambient temperature" OR "heat" OR "heat stress") AND (sensor OR technology OR "temperature monitoring devices" OR "early warning system" OR "temperature alert system") AND ("extreme heat event" OR "heatwave")

Appendix E

Google Survey Questions

E.1 Survey questions

1. Have you heard about a heat wave (extreme heat event) happening in Canada in the last 5 years (between 2016 and 2021)?

   - Yes
   - No
   - I'm not sure

2. How often do you currently access weather information?

   1. 5 or more times per day
   2. 2-4 times per day
   3. 1 time per day
   4. Weekly
   5. Monthly
   6. Rarely

3. How do you access weather information? (Check all that apply)

1. TV (weather channel, news)
2. Radio (AM/FM)
3. Newspaper (printed)
4. Online weather information website, etc.)
5. Social media (Twitter, Facebook, etc.)
6. I do not access weather information

4. Have you experienced a heat wave in the last 5 years (between 2016 and 2021)?

- Yes
- No
- I'm not sure

5. How did you hear about the heat wave?

- TV (weather channel, news)
- Radio (AM/FM)
- Newspaper (printed)
- Online weather information website, etc.)
- Social media (Twitter, Facebook, etc.)
- I did not hear about the heat wave

6. Is hearing about heat waves important to you or your dependants? Scale from 1 to 7 (1 being not at all important to very important at 7)

7. How would you like information about heat waves to be shared with you? Please select up to 3 choices

- TV (weather channel, news broadcast)

- Radio (AM or FM)
- Newspaper (printed or online)
- Online weather information website (The Weather Network)
- Weather app on mobile device (The Weather Network, Apple Weather, etc.)
- Alert Ready (like the Amber Alerts)
- Other (please specify)

8. Why do you think heat waves pose a risk to your health?

- Open text box

9. Is Canada prepared for a future of more frequent, intense, and longer heat waves? Scale from 1 to 7 (1 being not at all prepared to very prepared at 7).

10. Please indicate your total household income.

- Less than $20,000
- $20,000 - $39,999
- $40,000 - $59,999
- $60,000 - $79,999
- $80,000 - $99,999
- $100,000 - $119,999
- $120,000+
- Prefer not to disclose

Thank you for participating in this survey! You will receive $2.00 CAD for your time via the Google Surveys App.

Note: As of November 2022, the Google Surveys app was shut down. Age was already pre-collected by Google, and respondents were representative of Canada based on geographic location.

E.2 Keywords used to collect relevant tweets from X (Twitter)

Keywords/ Concepts	Screened related Concepts/Regular Expressions for inclusion as Twitter or Google Trends terms
Level 1 - related to environmental situation and health outcomes due to extreme heat	
Heat	Heat wave, heatwave, extreme heat, extreme heat event, heat dome, heat warning
Hot	Hot weather, too hot, very hot, humid*
Temperature	High temperature, hot temperature
Heat stroke	Heat stroke, sun stroke
Dehydration	dehydrat*, thirst*, rehyr*
Heat exhaustion	Excessive heat, over heat*
Hyperthermia	Hyperthermia
Heat cramp	Heat cramp, muscle cramp, muscle spasm
Fatigue	Fatigue, weak, tired, weariness
Level 1 - French	
Syncope	Syncope, faint*, pass* out
Chaleur	Chaleur, Vague de chaleur
Level 1.5 - related to staying safe during extreme heat event	
Air conditioning	Air conditioning, A/C, AC, cooling
Humidity	Humid*, humidex
Hydration	Drink lots of water
Stay	Stay indoors, stay inside, stay cool, stay hydrated
Seek	Seek shade, seek cool space*, seek cool place*, cooling centre/center
Protect	Protect vulnerable, protect from sun
Avoid	Avoid strenuous activities, avoid going out during middle of the day, avoid when sun is at its peak
Cover	Cover windows, cover up
Level 2 - related keywords	
Alert	Heat alert*, heat warning, special weather statement
Illness	Heat-related illness*
Urban heat island	Urban heat island, urban heat island effect
Silentkiller	silent killer
Beattheheat	beat the heat

Appendix F

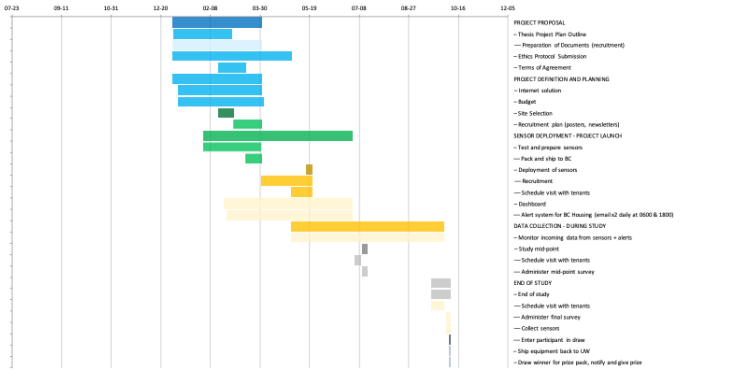
Study Documents for British Columbia Sites

F.1 Project plan

PROJECT TITLE	START DATE	PROJECT DURATION in days
UW indoor temp study	01-02	
PROJECT MANAGER	END DATE	
Arlene Delomo	10-07	279

WBS NO.	TASK NAME	STATUS	ASSIGNED TO	START DATE	END DATE	DURATION in days	COMMENTS
1	**PROJECT PROPOSAL**	**Complete**		**01-01**	**03-30**	**89**	
1.1	– Thesis Project Plan Outline	Complete	UW	01-02	03-01	59	
1.1.1	— Preparation of Documents (recruitment)	Complete	UW, BCH, VCH, FH	01-01	03-30	89	
1.5	– Ethics Protocol Submission	Complete	UW	01-01	04-30	120	
1.6	– Terms of Agreement	Complete	BC Housing	02-16	03-15	28	
2	**PROJECT DEFINITION AND PLANNING**	**Complete**		**01-01**	**03-31**	**90**	
2.1	– Internet solution	Complete	UW	01-07	03-31	84	
2.2	– Budget	Complete	UW	01-07	04-02	86	
2.3	– Site Selection	Complete	BC Housing	02-16	03-03	16	Identify site and if they need internet
2.4	– Recruitment plan (posters, newsletters)	Complete	UW, BCH	03-03	03-31	29	
3	**SENSOR DEPLOYMENT - PROJECT LAUNCH**	**Complete**		**02-01**	**06-30**	**150**	
3.1	– Test and prepare sensors	Complete	UW	02-01	03-30	58	
3.1.2	— Pack and ship to BC	Complete	UW	03-15	03-31	17	
3.2	– Deployment of sensors	Complete	UW, BCH	05-16	05-20	5	
3.2.1	— Recruitment	Complete	BCH	04-01	05-20	50	
3.2.2	— Schedule visit with tenants	Complete	BCH	05-01	05-20	20	
3.3	– Dashboard	Complete	UW	02-22	06-30	129	
3.3.1	— Alert system for BC Housing (email x2 daily at 0600 & 1800)	Complete	UW	02-25	06-30	126	
4	**DATA COLLECTION - DURING STUDY**	**Complete**		**05-01**	**09-30**	**153**	
4.1	– Monitor incoming data from sensors + alerts	Complete	UW	05-01	09-30	153	
4.2	– Study mid-point	Complete	BCH	07-11	07-15	5	
4.2	— Schedule visit with tenants	Complete	BCH	07-04	07-08	5	
4.3	— Administer mid-point survey	Complete	BCH	07-11	07-15	5	
5	**END OF STUDY**	**Complete**		**09-19**	**10-07**	**19**	
5.1	– End of study	Complete	UW, BCH	09-19	10-07	19	
5.1.1	— Schedule visit with tenants	Complete	BCH	09-19	09-30	12	
5.1.2	— Administer final survey	Complete	UW, BCH	10-04	10-07	4	
5.1.3	— Collect sensors	Complete	UW	10-04	10-07	4	
5.1.4	— Enter participant in draw	Complete	UW, BCH	10-07	10-07	1	
5.2	– Ship equipment back to UW	Complete	UW	10-07	10-07	1	
5.3	– Draw winner for prize pack, notify and give prize	Complete	UW, BCH	10-07	10-07	1	

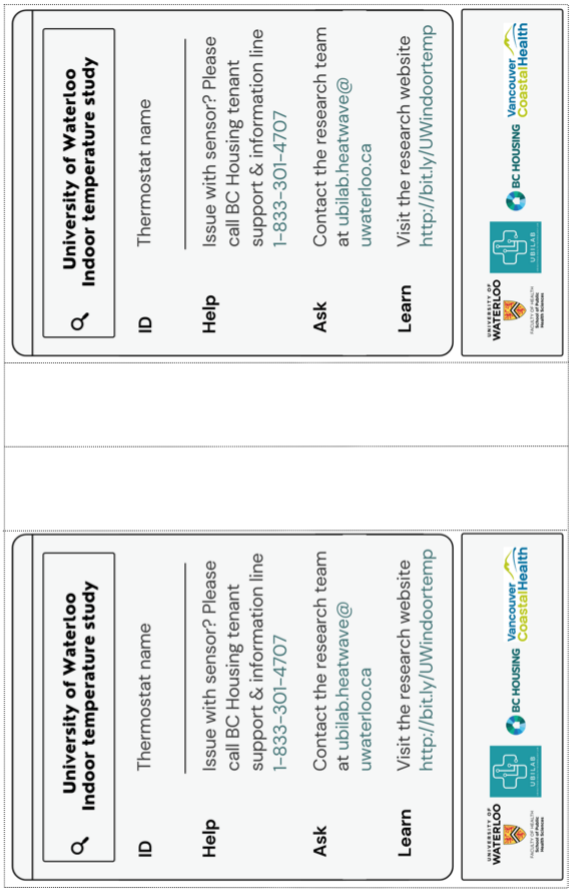
STATUS
Not Started
In Progress
Complete



F.2 Recruitment poster



F.3 Stand graphics



F.4 Email alert template

From	ubilab.heatwave@uwaterloo.ca
To	BC Housing (email group to be created)
Cc	
Bcc	
Subject	UW indoor temp study alert summary Monday April 20, 2022 @ 2PM PDT / 7AM PDT

Good morning/good afternoon,

This is a summary of the past 24 hours.

Level 1 - thermostats that reached 26°C up to 30.9°C, the time at which it was reached and number of consecutive hours spent ≥ 26°C in the past 24 hours.

- Ubilab001 - 12:00 for 8 hr, average temperature
- Ubilab002 - 11:00 for 8 hr, average temperature; 22:00 for 8 hr, average temperature

Level 2 - thermostats that reached 31°C or above, the time at which it was reached and the number of consecutive hours spent ≥ 31°C in the past 24 hours.

- None

Please access dashboard here <insert dashboard link>

Thank you,
Ubilab Heatwave Project

F.5 Threshold trigger examples

Scenario A On April 1, the indoor temperature reaches 26°C at 12 PM for 5 minutes, then drops below.

Not included in the email, must have (8 hrs) ninety-six consecutive 5-minute intervals to be included.

Scenario B On April 1, the indoor temperature reaches 26°C at 12 PM for 8 hours, then drops below.

Included in email as: Ubilab001 - 12:00 for 8 hr, 28°C

Scenario C On April 1, the indoor temperature reaches 26°C at 11 AM for 8 hours, then drops below. At 10 PM, it reaches 26°C and stays at or above for 8 hours, then drops below.

Included in email as: Ubilab002 - 1200 for 8 hr, 28°C; 2200 for 8 hr, 28°C

Rules

- 26°C to 30.9°C must be met and sustained for 8 hours (ninety-six 5-minute intervals) before an alert is included in the email summary.
- 31°C must be met and sustained for 8 hours (ninety-six 5-minute intervals) before an alert is included in the email summary.

Considerations

- Time zone - ecobee data is timestamped in UTC, Vancouver is UTC-7
- Temperature is recorded in Fahrenheit, needs to convert to Celsius
- Alerts sent at 7 AM and 2 PM
- Missing data/null values (due to ecobee servers, thermostat or router issues, power outage, Rogers internet outage, or human/pet interference
- Rule 1: If 100% - 50% of data is available, take the average temperature for the 8-hour period.
- Rule 2: If 50% - 0% of data available, display the message "¡50% of data available, average temperature not calculated." Display the time at which the null value starts.

F.6 Email alert from June 28th, 2022

Scenario A

Subject: UW indoor temp study alert summary Tue, Jun 28, 2022
Date: Tuesday, June 28, 2022 at 9:59:12 AM Eastern Daylight Saving Time
From: UbiLab Email Service
To: Jasleen Kaur, Arlene Oetomo, Ubilab Management, lgreenius@bchousing.org, wtang@bchousing.org, JWurdemann@bchousing.org, sthompso@bchousing.org, mszpala@bchousing.org, emily.peterson@vch.ca, Iris.Chan@vch.ca, amy.lubik@fraserhealth.ca, Ubilab Heatwave

Good Morning,

This is a summary of the past 24 hours.

Level 1 - thermostats that reached 26°C up to 30.9°C, the time at which it was reached and number of consecutive hours spent ≥ 26°C in the past 24 hours.

UbilabA36: 14:05:00 for 8 hours, with average temperature 30.5
UbilabA37: 14:05:00 for 8 hours, with average temperature 27.7
UbilabA02: 14:05:00 for 8 hours, with average temperature 28.4
UbilabA06: 14:05:00 for 8 hours, with average temperature 29.5
UbilabA08: 14:05:00 for 8 hours, with average temperature 28.5
UbilabA09: 14:05:00 for 8 hours, with average temperature 30.0
UbilabA10: 14:05:00 for 8 hours, with average temperature 28.7
UbilabA12: 14:05:00 for 8 hours, with average temperature 30.1
UbilabA13: 14:05:00 for 8 hours, with average temperature 28.6
UbilabA13: 22:05:00 for 8 hours, with average temperature 28.9
UbilabA14: 14:05:00 for 8 hours, with average temperature 29.2
UbilabA14: 22:05:00 for 8 hours, with average temperature 30.0
UbilabA38: 14:05:00 for 8 hours, with average temperature 29.8
UbilabA16: 14:05:00 for 8 hours, with average temperature 26.0
UbilabA18: 15:45:00 for 8 hours, with average temperature 26.3
UbilabA19: 14:05:00 for 8 hours, with average temperature 30.7
UbilabA21: 14:05:00 for 8 hours, with average temperature 29.6
UbilabA22: 14:05:00 for 8 hours, with average temperature 27.3
UbilabA23: 14:05:00 for 8 hours, with average temperature 28.4
UbilabA24: 14:05:00 for 8 hours, with average temperature 29.4
UbilabA25: 14:05:00 for 8 hours, with average temperature 27.9
UbilabA40: 14:05:00 for 8 hours, with average temperature 29.4
UbilabA40: 22:05:00 for 8 hours, with average temperature 28.7
UbilabA28: 14:05:00 for 8 hours, with average temperature 28.0
UbilabA29: 14:05:00 for 8 hours, with average temperature 28.7
UbilabA30: 14:05:00 for 8 hours, with average temperature 28.0
UbilabA31: 21:20:00 for 8 hours, with average temperature 28.8
UbilabA32: 14:05:00 for 8 hours, with average temperature 29.0
UbilabA33: 14:05:00 for 8 hours, with average temperature 26.5
UbilabA35: 14:05:00 for 8 hours, with average temperature 29.0
UbilabA20: 14:05:00 for 8 hours, with average temperature 28.0

Level 2 - thermostats that reached 31°C or above, the time at which it was reached and the number of consecutive hours spent ≥ 31°C in the past 24 hours.

UbilabA03: 14:05:00 for 8 hours, with average temperature 34.1
UbilabA17: 14:05:00 for 8 hours, with average temperature 34.7
UbilabA27: 14:05:00 for 8 hours, with average temperature 35.0

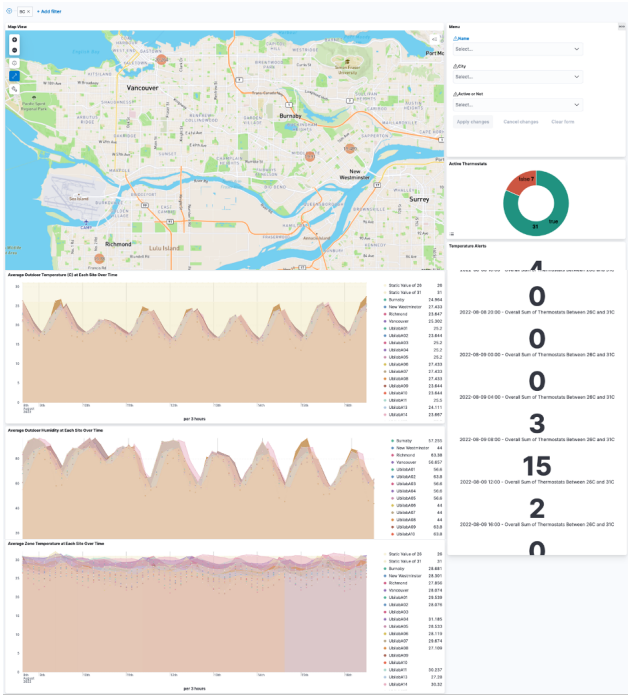
Level 3 - thermostats with no data in past 24 hours.

UbilabA04: 13:59:02 for 8 hours, with NULL data
UbilabA07: 13:59:02 for 8 hours, with NULL data
UbilabA11: 13:59:02 for 8 hours, with NULL data
UbilabA15: 13:59:02 for 8 hours, with NULL data
UbilabA34: 13:59:02 for 8 hours, with NULL data
UbilabA26: 13:59:02 for 8 hours, with NULL data

Sincerely,

Ubiquitous Health Technology Lab (UbiLab)
School of Public Health Sciences
Faculty of Health, University of Waterloo
200 University Avenue West
Waterloo, ON, Canada N2L 3G1
Email: ubilab.heatwave@uwaterloo.ca
Website: bit.ly/UWindoortemp

F.7 Elastic dashboard



F.8 Images from study



Figure F.1: Images captured during the project, including boxes of Ecobee thermostats, thermostats mounted on stands during site visits, and three key study locations: MacLean, Hall, and Ross. Also pictured are Arlene Oetomo (University of Waterloo) and Stephanie Thompson (BC Housing) during the setup phases in May and October 2022.

F.9 Estimation of energy cost to participants

Energy Consumption:

Portable Wi-Fi device: These typically consume around 5 to 15 watts. Assuming an average usage of 10 watts for 24 hours a day, the energy consumption would be: 10 watts × 24 hours/day × 30 days × 6 months = 4.32 kWh over 6 months.

Ecobee Smart Thermostat: The Ecobee thermostat consumes about 3 to 5 watts. Let's assume 4 watts for continuous operation: 4 watts × 24 hours/day × 30 days × 6 months = 1.73 kWh over 6 months.

The thermostat controls HVAC systems, which are the primary energy consumers, but the thermostat itself uses relatively little energy.

Electricity Rates (2022 data):

Ontario: The Time-of-Use (TOU) rates in Ontario were approximately:

- Off-peak: 7.4 cents/kWh
- Mid-peak: 10.2 cents/kWh
- On-peak: 15.1 cents/kWh

British Columbia: BC Hydro's tiered rate was around 9.65 cents/kWh Ontario Energy Board

Cost Estimation:

Ontario: Portable Wi-Fi: 4.32 kWh × 10.2¢ (average rate) = 44.06 cents over 6 months. Ecobee thermostat: 1.73 kWh × 10.2 cents = 17.65 cents over 6 months. Total: 44.06 cents + 17.65 cents = 61.71 cents CAD for 6 months.

British Columbia:

Portable Wi-Fi: 4.32 kWh × 9.65 cents = 41.65¢ over 6 months. Ecobee thermostat: 1.73 kWh × 9.65 cents = 16.70 cents over 6 months. Total: 41.65 cents + 16.70 cents = 58.35 cents CAD for 6 months.

This cost only includes the devices' energy, not any associated HVAC energy consumption.

F.10 Survey 1 - Housing characteristics questionnaire

UW indoor temperature study

Complete this questionnaire during thermostat set-up visit, to ensure consent has been obtained first.

Participant\Thermostat ID _____

We will now ask some questions about your housing characteristics.

Please skip any questions you are unsure of or do not know the answer.

1. Number of occupants (number) _____of adults, _____ (number) of children.
2. Number of bedrooms (number) _____
3. Please tell us how you use your windows during hot days. (Please select one)

    1. I keep my windows closed during the day and during the night
    2. I keep my windows closed during the day and open them at night
    3. I keep my windows open during the day and open during the night
    4. I keep my windows open during the day and close them at night
    5. I cannot open my windows (e.g., they don't open, or they have a window air conditioner in them)

4. Do you use any of the following to cover your windows? (Circle all that apply)

    1. Outdoor window shades (Yes, No)
    2. Indoor window blinds, curtains or shades (Yes, No)
    3. Indoor black out curtains (Yes, No)
    4. Other material(s) indoors (please specify) _____
    5. Other material(s) outdoors (please specify) _____

5. Do you use a window fan to bring in air from outside? (Yes, No)

   - How many? (number) _____

6. Do you use a portable fan to cool yourself? (Yes, No)

   - How many? (number) _____

7. Do you use air conditioning? (Yes, No)

   - If Yes, how many? (number) _____
   - If Yes, what kind do you use? (window unit, portable unit) _____

Thank you for completing this short survey!
Please return it to the research team.

Participant ID \Thermostat ID _____

Questions to be completed by BC Housing team **Unit specific**

1. Type of unit (apartment, townhouse, condo) _____
2. Floor area (in square footage) _____
3. Level of unit (ground, 1, 2, etc.) _____
4. Is this unit on the top floor of the building? (Yes, No)
5. What is the orientation of the unit in relation to the building? (northside, southside, eastside, westside) _____
6. Is the unit shaded by trees? (Yes, Partial, No)
7. Is the unit shaded by another building? (Yes, Partial, No)
8. What is the major window orientation? (N, S, E, W) _____
9. Is there a balcony above the major window? (Yes, No)
10. What percentage of wall space is taken up by the window? _____
11. How many openable windows are there? (number) _____
12. Are windows on different sides of the unit to allow for cross breeze? (Yes, No)
13. How large are the window openings? _____
14. Does the unit have a balcony? (Yes, No)
15. Is there a basement? (Yes, No)
16. Are windows screened to keep insects and vermin out? (Yes, No)

Building specific

1. Age of building (YYYY) _____
2. Total number of levels in building (1,2,3,4, etc.) _____
3. Outside building material (brick, concrete, etc) _____
4. Main type of insulation (fibreglass, rock wool, cellulose, spray foam, other) _____
5. Is there shading film on the outside of the windows? (Yes, No)
6. How many panes are in the windows? (Single, double, triple)?
7. Is there central air conditioning provided? (Yes, No)
8. Are portable air conditioners provided to tenants? (Yes, No)
9. Are fans provided to tenants? (Yes, No)

F.11 Survey 2 - Demographic characteristics questionnaire

UW indoor temperature study

Complete this questionnaire during the mid-study visit.

Participant \Thermostat ID _____

Please skip any questions you are unsure of or do not know the answer.

1. Please indicate your age. (Please select one)

    1. 18-24
    2. 25-34
    3. 35-44
    4. 45-54
    5. 55-64
    6. 65-74
    7. 75-84
    8. 85-94
    9. 95+
    10. Prefer not to answer _____

2. What do you identify your gender as? (Please select all that apply)

    1. Man
    2. Woman
    3. Gender fluid
    4. Non-binary

5. Prefer not to answer
6. Self declare (please specify) _____

3. Please indicate your racial/ethnic background. (Please select all that apply)

1. Indigenous (First Nations, Métis, Inuk/Inuit descent)
2. South Asian descent (East Indian, Pakistani, Bangladeshi, Sri Lankan, Indo-Caribbean)
3. Black (African, Afro-Caribbean, African Canadian descent)
4. Latinx (Latin American, Hispanic descent)
5. East/South East Asian (Cambodian, Chinese, Filipino, Indonesian, Korean, Japanese, Lao, Taiwanese, Thai, Vietnamese, etc.)
6. Middle Eastern (Arab, Persian, West Asian descent (e.g., Afghan, Egyptian, Iranian, Lebanese, Turkish, Kurdish)
7. White (European descent)
8. Do not know
9. Prefer not to answer
10. Other (please specify) _____

4. Is your preferred language something other than English or French? (Please specify)
_____

5. How long have you lived in Vancouver? (Please select one)

1. Less than a month
2. Less than 6 months
3. Less than a year
4. More than a year

6. Which of the following best describes your current living arrangement? (Please select all one)

1. Alone
2. With roommates (student residence, refugees, etc)
3. With family (e.g. parent or grandparent, other extended family member)
4. With partner, no dependents(s)
5. With partner and dependent(s)
6. Single parents with dependent(s)
7. Precarious (couch-surfing, shelters)
8. Prefer not to answer
9. Other (please specify) _____

7. Please indicate the highest level of education you've obtained. (Select one)

1. Some school, no degree
2. High school graduate
3. Some post-secondary, no degree
4. College diploma
5. Bachelor's degree
6. Master's degree
7. Professional degree (J.D., M.D., D.O., etc.)
8. Doctorate degree
9. Other (please specify) _____

8. Please indicate your employment status. (Please select one)

1. Full-time employment
2. Part-time employment
3. Self-employed
4. Unemployed and actively seeking work
5. Unemployed and not seeking employment
6. Student
7. Volunteer
8. Retired
9. Other (please specify) _____

9. Do you work night shifts? (Please specify)

1. Yes
2. No

10. Do you work outdoors or in hot environments? (Please specify)

_____

11. How would you describe your physical comfort in your current home during the summer months (from June to September)? (Please select one)

1. It's usually a comfortable temperature
2. It's usually too hot
3. It's usually too cold
4. I do not know
5. Prefer not to answer
6. Not applicable (have not lived here during the summer)
7. Other (please specify) _____

12. What is stopping you from having a comfortable temperature in your home? (Please explain) _____

13. When the weather is hot, do you have a cool place to stay during the day? (Please select one)

1. Yes, I would set up a sleeping area in my basement, a cooler room or balcony
2. Yes, I would sleep outside
3. Yes, I would stay with family or friends
4. No, I do not have a place to go
5. No, I do not know what I would do
6. Prefer not to answer
7. Other (please specify) _____

14. When the weather is hot, do you have a cool place to stay overnight? (Please select one)

1. Yes, I would set up a sleeping area in my basement, a cooler room or balcony
2. Yes, I would stay with family or friends
3. No, I do not have a place to go
4. No, I do not know what I would do
5. I prefer not to answer
6. Other (please specify) _____

15. When it comes to keeping yourself cool during a hot weather event and your current resources, what barriers do you currently face? (Please select all that apply)

1. I find the information available are difficult to understand
2. I find the information materials are not easy to find or hard to access (e.g. I don't have a computer or internet access)

3. I would prefer to have information in the language I understand
4. I find cool spaces are far away or difficult to get to
5. I find cool spaces I can go to are not comfortable or suitable for my needs (i.e. can't afford to go to a movie or rent a hotel room, and don't like the library because I don't feel welcome, or don't have enough chairs)
6. I have financial barriers (i.e. cost of purchasing portable air conditioners, transportation is required, etc.)
7. There are restrictions from my landlord or the building itself has restrictions (can't handle an air conditioner's electrical need)
8. I prefer not to answer
9. Other (Please specify) _____

16. Do you visit any public green spaces (trails, parks, gardens) when it is very hot in order to cool off?

1. Yes, there is one less than a 5-minute walk away
2. Yes, there is one within a 5-to-10-minute walk away
3. Yes, there is one within a 10-to-15-minute walk away
4. Yes, there is one that is a 15 minute or longer walk away
5. Yes, I drive or take public transit or bike to a public green space
6. No, I do not know of any or there are none
7. No, I do not like them
8. I prefer not to answer
9. Other (e.g. I have a disability and cannot leave my house easily, I have security concerns, I don't like mosquitoes and ticks, etc.) (Please specify) _____

Thank you for completing the survey. Please return it to the research team.

F.12 Survey 3 - Summer activities questionnaire

UW indoor temperature study

Complete this questionnaire during the mid-study visit.

Participant \Thermostat ID _____

We will now ask some questions about the past summer. Please skip any questions you are unsure of or do not know the answer.

1. What is your preferred indoor temperature during the summer (Please indicate a temperature or temperature range) _____

2. Did you experience a heat wave between May 1 and September 30, 2022?

    1. Yes
    2. No
    3. I am not sure/I do not know

2. When was the most recent or severe heat wave? (Please specify date or date range) _____

3. Were you concerned about your health during this heat wave? (Please select one)

    1. Yes, very concerned
    2. Yes, somewhat concerned
    3. No, not concerned
    4. No, not at all concerned
    5. I am not sure

4. Did you feel ill during this heat wave?

    1. Yes
    2. No

5. If you felt ill, can you describe how you felt physically, mentally, and/or emotionally?

_____

6. Were you concerned about the health of a dependent or loved one (child, older parent, etc) during this heat wave? (Please select one)

1. Yes, very concerned
2. Yes, somewhat concerned
3. No, not very concerned
4. No, not at all concerned
5. I am not sure

7. How did you hear about the heat wave? (Circle all that apply)

1. TV (weather channel, news broadcast)
2. Radio (AM or FM)
3. Newspaper (printed or online)
4. Online weather information website (The Weather Network)
5. Weather app on a mobile device (The Weather Network, Apple Weather, Weather app, etc.)
6. Social media platform (Facebook, local weather group)
7. Word of mouth (family member, friend, or neighbour, etc)
8. Other (please specify) _____

8. Did you hear about ways to protect yourself and stay safe during the heat wave? (Circle all that apply)

1. Yes
2. No

3. I am not sure

9. Where did you hear about ways to protect yourself and stay safe during the heat wave? (Circle all that apply)

1. TV (weather channel, news broadcast)
2. Radio (AM or FM)
3. Newspaper (printed or online)
4. Online weather information website (The Weather Network)
5. Weather app on a mobile device (The Weather Network, Apple Weather, Weather app, etc.)
6. Social media platform (Facebook, local weather group)
7. Other (please specify) _____

10. What do you recall was recommended? (Circle all that apply)

1. Keep doors and windows closed during the hottest times of the day and open them at night
2. Use fans to bring cool air indoors
3. Take cool baths or showers to draw heat from your body
4. Sleep with a wet sheet or in a wet shirt
5. Do not rely on fans as your primary cooling method during an Extreme Heat Emergency
6. Put up external window covers to reflect heat
7. Close your curtains and blinds during the day
8. If you have air conditioning, turn it on. It does not need to be going full strength to help keep you safe.
9. Do not use an electric fan when temperatures are above 35°C/95°F

10. Avoid cooking indoors
11. Other (please specify) _____

11. Are you familiar with any of the listed heat related illnesses and their effects? (Select all that apply)

1. Heat rash
2. Heat cramps
3. Heat exhaustion
4. Heat stroke
5. Other (please specify) _____

12. Did you adapt or change any behaviours or plans to protect yourself and stay safe during the heat wave? (Please select one)

1. Yes
2. No
3. I am not sure

13. If yes, please specify what you do. (Circle all that apply)

1. Keep doors and windows closed during the hottest times of the day and open at night
2. Use fans to bring cool air indoors
3. Take cool baths or showers to draw heat from your body
4. Sleep with a wet sheet or in a wet shirt
5. Do not rely on fans as your primary cooling method during an Extreme Heat Emergency
6. Put up external window covers to reflect heat
7. Close your curtains and blinds during the day

8. If you have air conditioning, turn it on. It does not need to be going full strength to help keep you safe
9. Do not use an electric fan when temperatures are above 35°C/95°F
10. Avoided cooking indoors
11. Other (please specify) _____
12. If you answered "no", please specify why you did not change your behaviour. (Please write one to two sentences)

14. How concerned are you about future extreme heat events or waves? (Select one)

1. Yes, I am very concerned
2. Yes, I am somewhat concerned
3. No, I am not concerned
4. I am not sure

15. How dangerous do you feel a heat wave is to you personally? (Select one)

1. Very dangerous
2. Dangerous
3. Neutral
4. Not very dangerous
5. Not dangerous at all

16. Do you feel equipped to protect your health and those around you during the next heat wave? (Select one)

1. Yes
2. No

3. I am not sure

17. Please elaborate on your answer

---

18. How dangerous is the heat wave to your community? (Select one)

    1. Very dangerous
    2. Dangerous
    3. Neutral
    4. Not very dangerous
    5. Not dangerous at all

19. Do you think Canada is prepared to handle more heat waves? (Select one)

    1. Yes, very prepared
    2. Yes, but more needs to be done
    3. No, not at all
    4. I am not sure

20. Please elaborate on your answer

Thank you for completing the survey. Please return it to the research team.

F.13 Project budget BC

Description	**Estimate ($)**	**Cost ($)**	**Value ($)**
Sensors (ecobee)			12,700
Routers	4,000	5,000	
Additional equipment (stands, cable ties, power adaptors, cords, packing supplies, miscellaneous, etc.)	1,200	1,500	
Travel for project lead (2 trips to Vancouver: Transportation, Accommodations, Food)	6,000	5,000	
Internet Plan (Data for 7 months)	2,700	3,616	
Grocery Gift Cards		4,200	
Shipping (Waterloo – Vancouver - Waterloo)	1,000	1,100	
Virtual machine (alerts)		50	
Elastic (dashboard)		450	
Server (database resources)		700	
Equipment written off		300	
Project Total ($)		17,116	

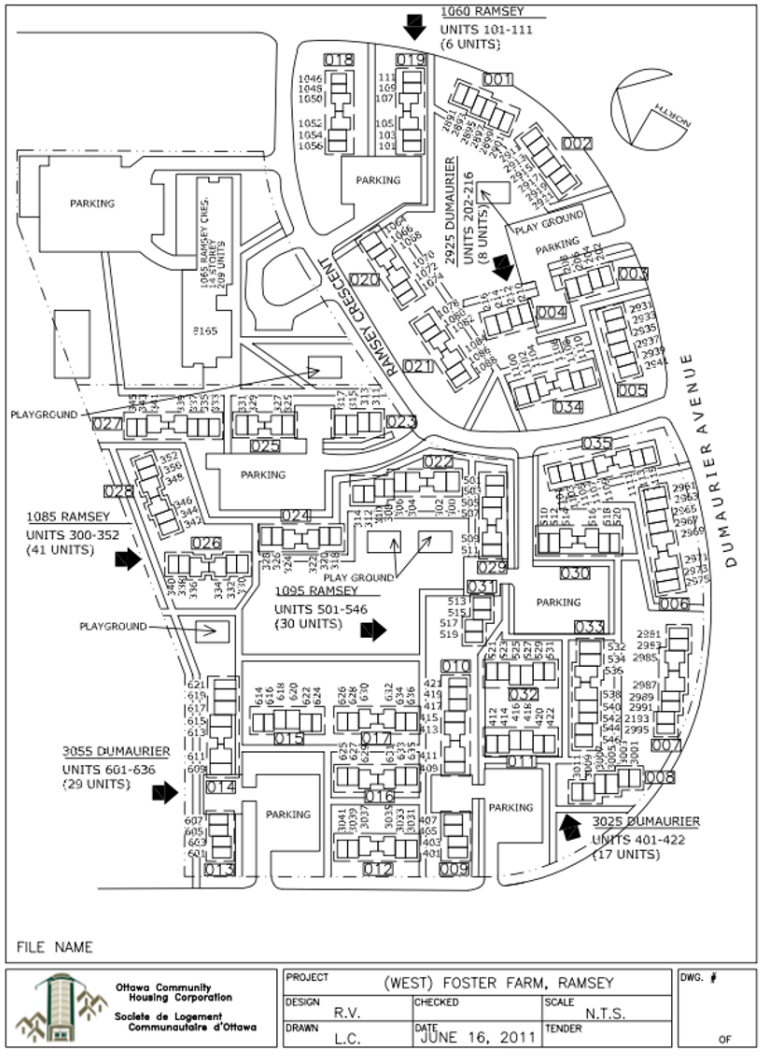
Amounts in CAD

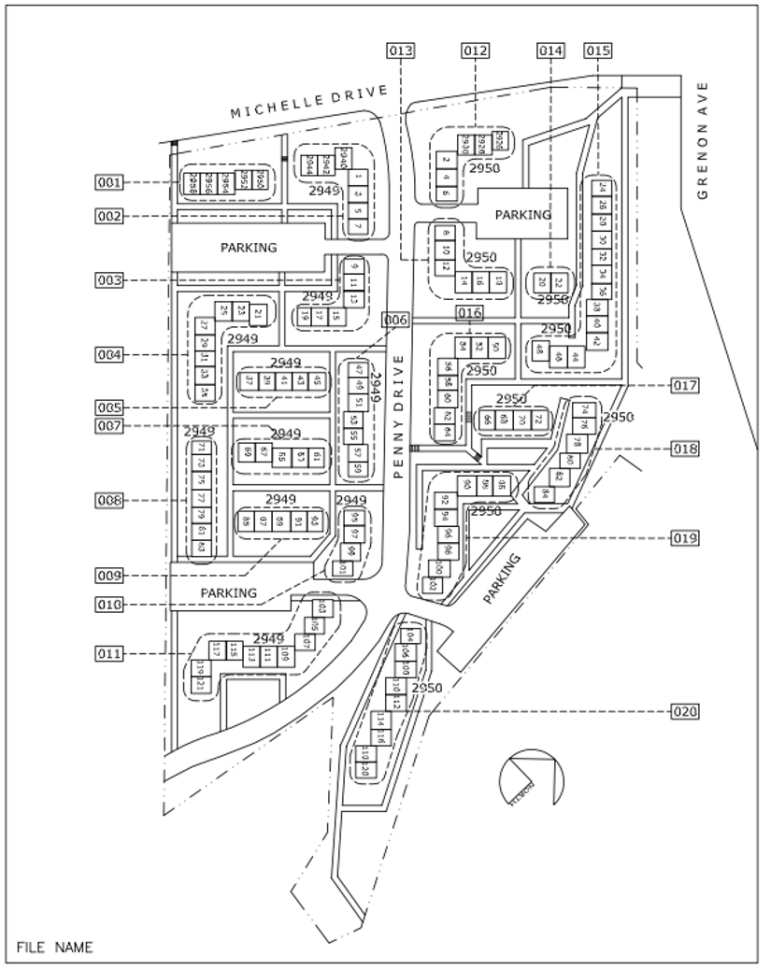
*Not included in budget above: cost of ecobee sensors and personnel on the project (such as time of UW PhD student, UW Postdoc, UW co-op student, UW developers, external partners VCH and FH, and BCH staff and mileage involved in the project).

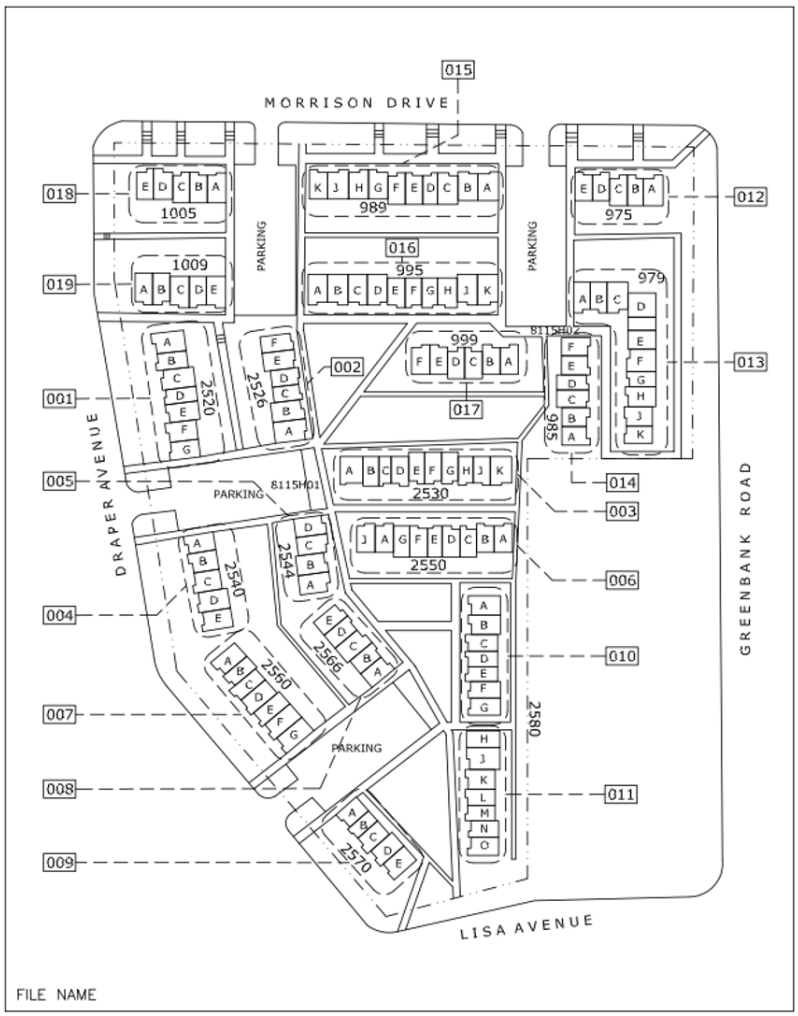
Appendix G

Study Documents for Ontario Sites

G.1 OCH site maps


1060 RAMSEY
UNITS 101-111
(6 UNITS)
2925 DUMAURIER
UNITS 202-216
(8 UNITS)
1085 RAMSEY
UNITS 300-352
(41 UNITS)
1095 RAMSEY
UNITS 501-546
(30 UNITS)
3055 DUMAURIER
UNITS 601-636
(29 UNITS)
3025 DUMAURIER
UNITS 401-422
(17 UNITS)
1065 RAMSEY CRES.
14 STOREY
209 UNITS
RAMSEY CRESCENT
DUMAURIER AVENUE
PARKING
PLAY GROUND
PLAYGROUND
NORTH
FILE NAME
Ottawa Community Housing Corporation
Societe de Logement Communautaire d'Ottawa
PROJECT
(WEST) FOSTER FARM, RAMSEY
DESIGN
R.V.
CHECKED
SCALE
N.T.S.
DRAWN
L.C.
DATE
JUNE 16, 2011
TENDER
DWG. #
OF


MICHELLE DRIVE
GRENON AVE
PENNY DRIVE
PARKING
PARKING
PARKING
PARKING
001
002
003
004
005
007
008
009
010
011
012
013
014
015
016
017
018
019
020
006
2949
2950
FILE NAME
Ottawa Community Housing Corporation
Societe de Logement Communautaire d'Ottawa
PROJECT (WEST) MICHELLE HEIGHTS – 8114
DESIGN R.V.
CHECKED
SCALE N.T.S.
DRAWN L.C.
DATE JUNE 3, 2011
TENDER
DWG. #
OF


015
MORRISON DRIVE
018
012
019
013
001
005
014
003
006
004
010
007
011
008
009
1005
989
975
1009
995
979
016
PARKING
PARKING
002
999
017
985
2520
2526
2530
2540
2544
2550
2560
2566
2580
2570
DRAPER AVENUE
GREENBANK ROAD
LISA AVENUE
PARKING
8115H01
8115H02
FILE NAME
Ottawa Community Housing Corporation
Societe de Logement Communautaire d'Ottawa
PROJECT (WEST) MORRISON GARDENS – 8115
DESIGN R.C.
CHECKED
SCALE N.T.S.
DRAWN R.C.
DATE JUNE 3, 2011
TENDER
DWG. #
OF

G.2 Beat the Heat - English

Ottawa Public Health
Santé publique

Beat the Heat 2022

When both temperature and humidity are high, it can be hard for our bodies to keep cool and not overheat. Extreme heat events can cause heat-related illnesses and in some cases, even death. Environment and Climate Change Canada issues heat warnings for Ottawa based on a forecast of:

- Daytime temperature of 31°C or higher and nighttime temperature not cooler than 20°C for at least two days, or a Humidex of 40 for at least two days.



Canada

Get the WeatherCAN app to get direct notification of heat and other extreme weather warnings to your phone. **Download it now!**

Heat warnings mean extra precautions need to be taken by everyone. People at even higher risk of getting sick from the heat include infants and older adults; pregnant women; those who work or exercise outdoors; those with pre-existing health conditions; people experiencing homelessness; and people without access to air conditioning. It is important to think ahead and plan for ways to stay cool and keep in touch with others who may have difficulty staying cool, especially during a heat warning.

COVID-19 is still present in Ottawa. There is still a risk of transmission and the risk of infection and severe outcomes from COVID-19 is greater for some individuals than others Wearing a face mask when it is hot may require extra breaks from the heat. See below for more information on wearing face masks in hot weather.

Please check the City of Ottawa's website for opening dates, locations and hours of service of on **Ottawa.ca** and **Ottawa.ca/news** for the following public facilities:

- Splash pads, wading pools, beaches, outdoor and indoor swimming pools.
- Parks and green spaces
- Ottawa Public Library current branch services
- Community centres

Protect Yourself and Help Others During Hot Weather

- **Drink plenty of water** and avoid alcohol and caffeine.
- **Avoid heavy outdoor activity.**
- **Wear a hat, light and loose-fitting clothing**, sunscreen, and sunglasses when outside.

03/05/2022

OttawaPublicHealth.ca | 613-580-6744 | /OttawaHealth
SantePubliqueOttawa.ca | TTY/ATS : 613-580-9656 | /OttawaSante

- **Bring a parasol or an umbrella and water** when leaving home in case you need to wait outdoors in the heat, such as waiting in a lineup.
- **Cool off in an air-conditioned space** when available including libraries, malls, museums, and movie theatres.
- **Cool off in the shade** or at a park or green space.
- **Use a fan** and mist your skin with water.
- **Take cool baths and showers** as often as needed or soak hands or feet in cool water.
- **Breastfeed according to your child's cues** and drink plenty of water if you are breastfeeding. See our Parenting in Ottawa website for more info on keeping children safe during hot weather.
- **Keep your home cool** by closing blinds and curtains on any windows facing the sun.
- **Open windows at night** once the outdoor air is cooler than the indoor air; close windows in the morning before hotter air comes in.
- **Use fans at night** to help exhaust warm indoor air and/or bring in cool outdoor air.
- **Talk to your doctor, nurse, or pharmacist if you are taking medications** as some can make it harder to control body temperature.
- **Stay connected with people in your community who may have a difficult time coping with hot weather and those who live alone.** Check on them regularly.

Hot weather concerns and face masks:

Wearing a mask is important to decrease transmission of COVID-19 in any indoor setting where it may be difficult to maintain at least a two metres distance from others, or where the room or corridor is small.

Wearing a mask may not be necessary outdoors if adequate distances (two metres or more) from others can be maintained. Ottawa Public Health strongly encourages everyone to avoid crowded areas, and to wear a mask when physical distancing may be difficult.

Masks do become more uncomfortable in hot temperatures, but they will still work as long as they are not wet. If sweat is an issue, keeping at least one extra mask on hand can help. Plan outdoor outings for cooler times of the day and take breaks in the shade or a cool environment if you are finding your face mask uncomfortable in the heat.

For people undertaking physical exertion in heat, a mask can make the effort more difficult. Decreasing intensity and volume of work, more frequent rests, and more cooling breaks may be necessary. Discuss your health needs with your employer if your work demands will expose you to the heat.



For more information visit our website at **OttawaPublicHealth.ca**
or call us weekdays at 613-580-6744.

G.3 Beat the Heat - Français

Ottawa | Public Health / Santé publique

Combattez la chaleur cet été 2022



Quand la température et l'humidité sont élevées, il peut être difficile de rester au frais et ne pas avoir trop chaud. Les chaleurs extrêmes peuvent causer des maladies liées à la chaleur, et dans certains cas, la mort. Environnement et Changement climatique Canada émet des avis de chaleur pour la Ville d'Ottawa s'il prévoit :

- Qu'il fera plus de 31 °C le jour et au moins 20 °C la nuit durant au moins deux jours, ou que l'humidex sera de 40 pendant au moins deux jours

Canada

Obtenez l'application MétéoCAN pour recevoir directement sur votre téléphone les avis de chaleur et autres avertissements météorologiques extrêmes. Téléchargez-la maintenant!

En cas d'avertissement de chaleur, tout le monde doit prendre des précautions supplémentaires. Cet été, les mesures visant à réduire la propagation de la COVID-19 pourraient nous empêcher de nous rafraîchir comme nous le faisons d'habitude. Le port d'un masque lorsqu'il fait chaud peut nécessiter des pauses supplémentaires de la chaleur. Il est important de prévoir des façons de rester au frais et en contact avec des personnes qui en seraient peut-être incapables, surtout lors d'un avertissement de chaleur.

La COVID-19 est encore présente à Ottawa. Le risque de transmission est toujours présent, et les risques d'infection et d'effets graves liés à la COVID-19 sont plus élevés pour certaines personnes. Le port du masque lorsqu'il fait chaud peut nécessiter le besoin de prendre des pauses plus fréquentes lorsqu'il fait chaud. Vous trouverez ci-dessous de plus amples renseignements sur le port du masque par temps chaud. Veuillez consulter le site Web de la Ville d'Ottawa à ottawa.ca/ et ottawa.ca/sujets-de-l'heure pour connaître les dates d'ouverture, les lieux et les heures de service pour les installations publiques suivantes:

- Les aires de jets d'eau, les plages, et les piscines extérieures et intérieures
- Les parcs et les espaces verts
- La Bibliothèque publique d'Ottawa
- Les centres communautaires

Protégez-vous et aidez les autres par temps chaud

- **Buvez beaucoup d'eau** et évitez l'alcool et la caféine.
- **Évitez les activités intenses à l'extérieur.**
- **Portez un chapeau, des vêtements légers et amples** et des lunettes de soleil et appliquez-vous de l'écran solaire lorsque vous sortez.
- **Apportez un parasol ou un parapluie et de l'eau** en quittant la maison au cas où vous seriez à l'extérieur sous la chaleur, comme attendre en file.

03/05/2022

OttawaPublicHealth.ca | SantePubliqueOttawa.ca | 613-580-6744 | TTY/ATS : 613-580-9656 | /OttawaHealth /OttawaSante

- **Rafraîchissez-vous dans un endroit climatisé,** si possible, comprenant les centres commerciaux, les musées et les cinémas.
- **Rafraîchissez-vous** à l'ombre ou dans un parc ou un espace vert
- **Utilisez un ventilateur** et aspergez-vous d'eau.
- **Prenez des bains et des douches à l'eau fraîche** aussi souvent que nécessaire ou trempez-vous les mains ou les pieds dans de l'eau fraîche.
- **Allaitez votre enfant lorsqu'il vous le demande** et buvez beaucoup d'eau si vous allaitez. Consultez notre site Web « **Être parent à Ottawa** » pour en savoir davantage sur la façon de **Garder les enfants en sécurité par temps chaud**.
- **Gardez votre maison au frais** en fermant les stores et les rideaux des fenêtres faisant face au soleil.
- **Ouvrez les fenêtres le soir** lorsque l'air extérieur est plus frais que l'air intérieur et **fermez les fenêtres le matin** avant que l'air chaud n'entre dans la maison.
- **Utilisez des ventilateurs** pendant la nuit pour évacuer l'air chaud de l'intérieur et amener l'air frais de l'extérieur.
- **Si vous prenez des médicaments,** parlez-en à votre médecin, à votre infirmière ou à votre pharmacien, car certains médicaments peuvent rendre plus difficile le contrôle de la température corporelle.
- **Restez en contact avec les personnes de votre communauté** qui pourraient avoir du mal à faire face à la chaleur et celles qui vivent seules. Prenez régulièrement de leurs nouvelles.

Préoccupations liées au temps chaud et aux masques faciaux:

Le port d'un masque est important pour diminuer la transmission de la COVID-19 dans tout environnement intérieur où il peut être difficile de maintenir une distance d'au moins deux mètres des autres, ou lorsque la pièce ou un couloir est d'une petite taille.

Le port d'un masque peut ne pas être nécessaire à l'extérieur où des températures plus élevées peuvent être plus préoccupantes si des distances adéquates par rapport aux autres peuvent être maintenues. Santé publique Ottawa encourage fortement tout le monde à éviter les endroits bondés et à porter un masque lorsque la distance physique peut être difficile.

Les masques deviennent plus inconfortables par temps chaud, mais ils fonctionnent quand même tant qu'ils ne sont pas mouillés. Si la transpiration est un problème, garder au moins un masque supplémentaire à la main. Prévoyez des sorties en plein air aux moments les plus frais de la journée et faites des pauses à l'ombre ou dans un environnement frais si vous trouvez votre masque inconfortable dans la chaleur.



Pour les personnes qui font des efforts physiques sous la chaleur, un masque peut rendre l'effort plus difficile. Une diminution de l'intensité et du volume de travail, des pauses plus fréquentes et davantage de pauses pour se rafraîchir peuvent être nécessaires. Discutez de vos besoins en matière de santé avec votre employeur si vos exigences de travail vous exposent à la chaleur.

Pour plus de renseignements, visitez notre site Web à **SantéPubliqueOttawa.ca** ou téléphonez-nous en semaine au 613-580-6744.

G.4 Project budget ON

Description	Estimate ($)	Cost ($)	Value ($)
Routers	4,000	5,000	
Additional equipment (stands, cable ties, power adaptors, cords, packing supplies, miscellaneous, etc.)	500	500	
Travel for project lead (3 trips to Ottawa: Transportation, Accommodations, Food)	4,500	4,262.23	
Internet Plan (Data for 7 months)	2,400	2,400	
Grocery Gift Cards	3,200	3,200	
Translation of Study materials	1,000	1,108.66	
Additional Onsite Support		280	
Server (database resources)		100	
Equipment written off			50
Project Total ($)	15,600	16,300	

Amounts in CAD

*Not included in the budget above the cost of ecobee thermostats and personnel on the project (i.e., UW Ph.D. candidate, UW post-doctoral fellow, UW co-op student, UW developers, external partners OCH and OPH staff mileage involved in the project)

Appendix H

Publications

Throughout my PhD journey, I have been fortunate to co-author several academic papers alongside talented colleagues and researchers, contributing to important discussions of public health policy, climate resilience, and environmental health. I am deeply grateful for the support and guidance I have received from my mentors, peers, and collaborators, whose insights and encouragement have been essential in helping me navigate the challenges of research and writing. This collective effort has been key to my growth as a researcher.

H.1 Authored and co-authored related papers

Hanjahanja-Phiri, T., Lotto, M., **Oetomo, A.**, Boger, J., Butt, Z., Morita, P.P. (2024). Ethical Considerations of Public Health Surveillance in the Age of the Internet of Things Technologies: A Perspective. Digital Health Journal.

Morita, P.P., Lotto, M., Kaur, J., Chumachenko, D., **Oetomo, A.**, Espiritu, K.D. (2024). What is the Impact of Artificial Intelligence-Based Chatbots on Infodemics Management? Frontiers in Public Health, 12, 1310437.

Kaur, J., Chauhan, V., **Oetomo, A.**, Wang, K., Morita, P.P. (2023). Leveraging Big Data from Smart Thermostats: A Vision to Evaluate Heatwave Impacts on Sleep Health in the Elderly. IEEE International Conference on Big Data, 2714-2718.

Morita, P.P., Abhari, S., Kaur, J., Lotto, M., Miranda, P., **Oetomo, A.** (2023). Applying ChatGPT in Public Health: A SWOT and PESTLE Analysis. Frontiers in Public Health.

Morita, P.P., Sahu, K.S., **Oetomo, A.** (2023). Health Monitoring Using Smart Home Technologies: A Scoping Review. JMIR Mhealth Uhealth, 11, e37347.

Lotto, M., Hanjahanja-Phiri, T., Padalko, H., **Oetomo, A.**, Butt, Z., Boger, J., Millar, J., Cruvinel, T., Morita, P.P. (2023). Are Ethical Research Issues Appropriate for Infodemiology and Infoveillance Studies to Control Infodemic on Social Media? Frontiers in Public Health, 11, 1130079.

Oetomo, A., Jalali, N., Costa, P.D.P., Morita, P.P. (2022). Indoor Temperatures in the 2018 Heat Wave in Quebec, Canada: Exploratory Study Using Ecobee Smart Thermostats. JMIR Formative Research, 6(5), e34104.

Jalali, N., Sahu, K.S., **Oetomo, A**., Morita, P.P. (2022). Usability of Smart Home Thermostat to Evaluate the Impact of Weekdays and Seasons on Sleep Patterns and Indoor Stay: Observational Study. JMIR Mhealth Uhealth, 10(4), e28811.

Oyibo, K., Sahu, K.S., **Oetomo, A**., Morita, P.P. (2021). Factors Influencing the Adoption of Contact Tracing Applications: Protocol for a Systematic Review. JMIR Research Protocols, 10(6), e28961.

Sahu, K.S., **Oetomo, A.**, Morita, P.P. (2020). Enabling Remote Patient Monitoring Through the Use of Smart Thermostat Data in Canada: Exploratory Study. JMIR Mhealth Uhealth, 8(11), e21016.

Jalali, N., Sahu, K.S., **Oetomo, A.**, Morita, P.P. (2020). Understanding User Behavior Through the Use of Unsupervised Anomaly Detection: Proof of Concept Using Internet of Things Smart Home Thermostat Data for Improving Public Health Surveillance. JMIR Mhealth Uhealth, 8(11), e21209.

Bublitz, F.M., **Oetomo, A.**, Sahu, K.S., Kuang, A., Fadrique, L.X., Velmovitsky, P.E., Nobrega, R.M., Morita, P.P. (2019). Disruptive Technologies for Environment and Health Research: An Overview of Artificial Intelligence, Blockchain, and Internet of Things. International Journal of Environmental Research and Public Health, 16(20), 3847.

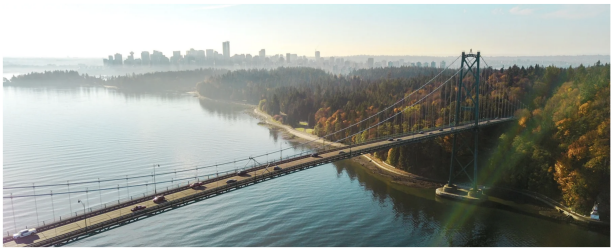
H.2 Features

Source: https://www.ecobee.com/en-ca/citizen/how-ecobee-is-helping-to-protect-community-housing-residents-from-extreme/

How ecobee is Helping to Protect Community Housing Residents From Extreme Heat

by ecobee on 09/12/2023 in Donate Your Data

5 min read



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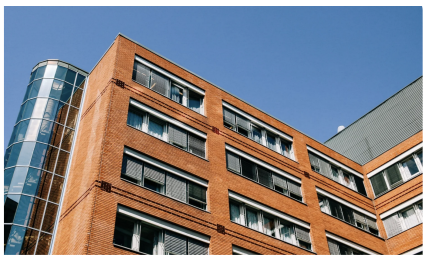
It's estimated that over 17 million Canadians will experience extreme heat over the next few decades, and researchers at Ubilab (Ubiquitous Health Technology Lab) at the University of Waterloo have been helping bridge the gap on what indoor conditions will look like as a result. We sat down with Arlene Oetomo, who has been researching the intersection of our climate crisis and the Internet of Things using ecobee's Donate Your Data program, to learn more about how community housing residents become vulnerable to heat waves – and what we can do to better protect them.

More than 200,000 ecobee Smart Owners have opted-in to ecobee's one-of-a-kind Donate Your Data (DYD) program, creating a unique window into energy use in the home, and making it the world's largest home energy efficiency dataset.

By sharing the anonymized data from customers who have opted in, ecobee is helping researchers around the globe in their studies aimed at creating a more sustainable and healthier future for communities.

ecobee Citizen: What was the goal of your research?

Oetomo: Our goal was to learn about how high indoor temperatures reached during extreme heat events and to understand how residents behaved during these peaks to protect themselves. To do this, we partnered with community housing organizations in BC and Ottawa – using both ecobee thermostats and Donate Your Data (DYD) data. We created a near real-time alert system using ecobees that notified stakeholders when a home reached a specific threshold temperature for a certain period of time, enabling targeted interventions in the form of phone calls or check-ins.



ecobee Citizen: What were your key findings?

Oetomo: We observed large differences between indoor and outdoor temperatures throughout the summer 2022 period, and it varied across the buildings we tested in. Maximum indoor temperatures went as high as 10 degrees Celsius above outdoor temperatures (despite a relatively mild season compared to the 2021 season that experienced the Heat Dome), which with prolonged exposure may be harmful for to residents, especially vulnerable individuals.

ecobee Citizen: How did your research translate into recommendations?

Oetomo: We created a report for BC housing with recommendations on being more prepared for heatwaves, informing their tenants on how to protect themselves, and advocating for more funding to prioritize the health of their tenants. We know it's getting very hot inside and having data to show decision makers is key to creating policy changes at the organizational and governmental levels. In general, the findings from this research highlight that indoor heat continues to be a serious risk to many communities. Solutions come in many forms, while many may suggest increasing provision of AC in such buildings, we must also look for nature-based solutions, such as natural ventilation and external shading that do not contribute more and reduce GHGs.



ecobee Citizen: What can we look forward to as you continue to conduct this research?

Oetomo: In the long term, we want to have indoor temperature legislations for hot temperatures, especially in low income or resource poor settings, all places without air conditioning, to mitigate the effects of climate crisis on vulnerable people. We hope we get more opportunities to do larger and longer studies moving forward to better protect people from future extreme heat events. We are very grateful for the support provided by ecobee and its customers over the years through the DYD program, and especially on this project.



Arlene Oetomo

About Arlene Oetomo.

Arlene is a PhD candidate at the University of Waterloo. She completed a BSc in Health Studies from the University of Waterloo in 2018. As a climate and public health researcher, she uses smart home technologies for in-home health behavior monitoring via IoT and smart home technologies (like smart thermostats), focusing on the impacts of extreme heat events (heat waves) on underserved communities. She's also exploring using Generative AI for public health applications to fight infodemics and extreme weather events while advocating for climate justice and ensuring equitable access to safe digital and physical spaces for all. During the start of the pandemic, she advised the development of a contact tracing app called Covid Watch. She previously worked on the ConnectingGTA project; a regional electronic health record system led by the University Health Network. Her other experiences include a semester abroad in Bordeaux, France, working at a medical research software company in Amsterdam, and leading a health records project at Saint Elizabeth Health Care.

About Donate Your Data.

ecobee offers a one-of-a-kind Donate Your Data (DYD) program that invites customers to voluntarily share anonymized data from their thermostats with scientists and researchers all over the world who are answering critical questions related to the clean energy future. Since we launched the program in 2017, over 200,000 ecobee Smart Owners across North America have opted-in to-date, making it the world's largest home energy efficiency dataset. We've partnered with researchers in over 10 countries – including Yale, UC Berkeley and University of Toronto. __ Interested in joining over 200,000 ecobee customers and helping researchers like Aya Doma better prioritize decarbonization funding? Sign up for Donate Your Data in a few short steps:__

1. Open the ecobee app.
2. Tap the **Account icon** in the top-left corner.
3. Select **Donate Your Data**.
4. Toggle on **Donate Thermostat Data**.
5. Learn how your data is anonymized and your privacy protected, then tap **Accept & Join**.

Glossary

albedo The measure of the reflectivity of a surface or body, expressed as a fraction or percentage. It indicates the extent to which a surface reflects solar radiation relative to the total solar radiation it receives. 22

BTU/h A unit of measurement for the amount of heat energy a system can produce or consume in one hour. 6

deep energy retrofits Deep energy retrofits refer to comprehensive renovations of existing buildings aimed at achieving significant energy savings, often exceeding 50% reduction in energy use compared to pre-retrofit levels. These retrofits go beyond superficial changes or single-measure improvements, involving major upgrades to a building's envelope (walls, roof, floors, windows), mechanical systems (heating, ventilation, and air conditioning - HVAC), lighting, appliances, and sometimes incorporating renewable energy sources like solar panels. 202

Donate Your Data A research program in which ecobee owners voluntarily donate their ecobee data so that researchers may use it. 47

Dry Bulb Temperature The temperature measurement through a thermometer bulb exposed to the air, but shielded from radiation and moisture. Also referred to as air temperature. 11, 74

renewables Renewable energy refers to energy derived from natural sources. This includes sunlight and wind, resources that can be replenished at a higher rate than they is consumed. 87

stroads Describing the common North American city feature of wide city arterials (roads or streets), often with strip malls and drive-throughs designed to prioritize the automobile. 22

thermal comfort Generally meaning that a person wearing a normal amount of clothing feels neither too cold nor too warm. It is influenced by several factors: metabolic rate, the activity level of individuals within a space, clothing, air temperature, radiant temperature (the process by which the body loses or gains heat), solar loading, air speed, and humidity. 22

Urban Heat Island A metropolitan area that is significantly warmer than its surrounding rural areas due to human activities, such as the built environment, materials, lack of vegetation, and heat emitted from vehicles and general equipment use. 29

Wet Bulb Temperature The temperature measurement through a moistened thermometer bulb exposed to the air. 11