Light Weight Look Ahead: Eco-dialogues between buildings and their inhabitants

by

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Abstract

How do people interact with buildings? A building is a system, with many components affecting energy use and thermal comfort. Designers and engineers using energy simulation typically assume inhabitants’ interaction to be fixed, scheduled or rule-based, as opposed to being active. Post-occupancy evaluations have shown that inhabitants are a key reason for vast differences between predicted and actual energy consumption. Engineers and designers are constrained in their work by lack of knowledge and models of how people use buildings. On the other hand, inhabitants do not comprehend the effects of their interactions with building systems and elements, in relation to comfort and energy, because data on both usage and control is not visible in appropriate forms, places and times. Inhabitants experiencing discomfort have multiple options from which to choose but have insufficient information about the effect these options would have on energy usage and comfort.

We propose “Light Weight Look Ahead Options,” an eco-dialogue focused on how personal choices impact comfort and energy use in buildings. We propose three modes of interaction. First “I feel”. Here an inhabitant expresses how (s)he feels in a room, for example, “I feel very cold.” Second, “If buildings could talk”: here the building proposes interaction when inhabitants have been inactive over a long period and the building’s environment differs from norms. Third, “What if?”. inhabitants explore what happens when they interact with different elements, for example, turning the thermostat down or opening windows. A qualitative study shows that inhabitants found each model potentially useful, but preferred the “I feel” model. The system helps them to learn, negotiate and weigh choices.

Keywords: Building inhabitant, Inhabitant insight, Energy modeling, Occupant behavior, Occupant comfort, Thermal comfort, Building simulation, Building control
To Amma and Appa,

for their unconditional love, innumerable sacrifices,
and immense support to chase and fulfill my dreams
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“He who walks with the wise grows wise.” Proverbs 13:20

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# Table of Contents

Approval ii  
Ethics iii  
Abstract iv  
Dedication v  
Acknowledgements vi  
Table of Contents viii  
List of Tables xiii  
List of Figures xiv  

1 Introduction 1  
1.1 Problem ......................................................... 1  
1.2 Motivation ......................................................... 2  
1.3 Inhabitants adaptations depend on various contexts ............... 3  
1.4 What people do matters to building energy consumption ........... 4  
1.5 Proposed Solution .................................................. 5  
1.6 Research Synopsis .................................................. 6  

2 Thesis Outline 8  

3 Background 11  
3.1 Overview ........................................................... 11  

viii
6.2.1 Pilot study 1 ................................................. 59
6.2.2 Pilot study 2 ................................................. 59
6.2.3 Pilot study 3 ................................................. 59
6.2.4 Conclusion ................................................. 60
6.3 Main studies ................................................. 61
6.3.1 Participants ................................................. 61
6.3.2 Procedure ................................................. 62
6.3.3 Pre-questionnaire ........................................... 63
6.3.4 Task Completion ........................................... 63
6.3.5 Post-questionnaire ......................................... 64
6.4 Data coding ................................................. 64
6.4.1 Inhabitants’ profiles ....................................... 66
6.4.2 Adaptations made ......................................... 67
6.4.3 Interaction Models ......................................... 69
6.4.4 Interface design ........................................... 70
6.5 Reliability and validity ....................................... 71
6.5.1 Data Triangulation ......................................... 71
6.5.2 Investigator Triangulation ................................ 71
6.5.3 Environmental Triangulation .............................. 72
6.5.4 Threats to validity ........................................ 72

7 Findings ......................................................... 73
7.1 Inhabitants Profile ........................................... 73
7.1.1 Comfort concerns ......................................... 74
7.1.2 Energy concerns .......................................... 79
7.1.3 Comparing comfort and energy concerns ............... 83
7.1.4 Role in Household ......................................... 85
7.1.5 Cultural Habits declared .................................. 86
7.1.6 Sustainable actions ....................................... 87
7.1.7 Others ...................................................... 89
7.2 Adaptations Made ........................................... 90
  7.2.1 Personal Adaptation ..................................... 90
  7.2.2 Technology and Built environment ....................... 110
  7.2.3 Spatial Arrangement or control location .................. 132
  7.2.4 Agency ................................................... 140
  7.2.5 Design and construction .................................. 141
  7.2.6 Social Context ........................................... 152

7.3 Interaction Models ......................................... 163
  7.3.1 “I feel” .................................................. 164
  7.3.2 If buildings could talk! ................................... 168
  7.3.3 “What if?” Model ........................................ 173
  7.3.4 General .................................................. 177
  7.3.5 System suggestions ....................................... 184
  7.3.6 Appliances and its influences ............................ 185
  7.3.7 Mode comparisons ........................................ 186
  7.3.8 Suggestion to improve system data and visualization ..... 188
  7.3.9 Controlled Automation ................................... 198
  7.3.10 Scenarios ............................................... 199

7.4 Interface Design ............................................ 200
  7.4.1 Annoyance ............................................... 200
  7.4.2 Barriers ................................................ 206
  7.4.3 Trust ..................................................... 209
  7.4.4 Control ............................................... 212

8 Discussion ................................................ 214
  8.1 The Need for LWLA ........................................ 214
    8.1.1 People and their needs are complicated. ............... 214
    8.1.2 Adaptations differ with context, technology, and design . 223
    8.1.3 Interaction factors that influence energy consumption .... 229
    8.1.4 What LWLA considers and does not considers in its design? 237
8.2 Adaptations using LWLA ........................................ 237
  8.2.1 Adaptions using “I feel” interaction model ............. 237
  8.2.2 Adaptations using “If buildings could talk” interaction model .... 238
  8.2.3 Adaptations using “What if?” interaction model ....... 239
  8.2.4 Overall influence of the system on adaptations ........ 239
  8.2.5 Gaps in the interaction models ......................... 241
8.3 Design and improvement ....................................... 242
  8.3.1 Reconstructing donut pie chart ......................... 242
  8.3.2 Improving multiple options ............................. 246
  8.3.3 Incorporating multiple inhabitant comparisons ........ 248
  8.3.4 Overall design suggestions for LWLA ................. 251

9 Conclusions ......................................................... 256
  9.1 Future Work .................................................... 257

Bibliography .......................................................... 259

Appendix A Pre Questionnaire ................................. 265

Appendix B Task Completion .................................... 267

Appendix C Post Questionnaire ............................... 270
List of Tables

Table 6.1 Inter-rater reliability ........................................... 72
## List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Inhabitants’ perspective on behavior driving forces</td>
<td>16</td>
</tr>
<tr>
<td>3.2</td>
<td>Three tier approach to passive design (Lechner, 2009)</td>
<td>19</td>
</tr>
<tr>
<td>3.3</td>
<td>Inhabitants’ reasons for not performing a meaningful interaction</td>
<td>21</td>
</tr>
<tr>
<td>3.4</td>
<td>3-tier approach to passive design and inhabitants’ involvement at each stage</td>
<td>22</td>
</tr>
<tr>
<td>3.5</td>
<td>Direct gain and inhabitant presence in space</td>
<td>24</td>
</tr>
<tr>
<td>3.6</td>
<td>Proposing fourth tier as Inhabitants’ Engagement</td>
<td>36</td>
</tr>
<tr>
<td>4.1</td>
<td>Questions for systems and elements in the building</td>
<td>39</td>
</tr>
<tr>
<td>4.2</td>
<td>Key Concepts of LWLA</td>
<td>40</td>
</tr>
<tr>
<td>4.3</td>
<td>LWLA design intent</td>
<td>42</td>
</tr>
<tr>
<td>5.1</td>
<td>Models of Interaction</td>
<td>44</td>
</tr>
<tr>
<td>5.2</td>
<td>System Architecture</td>
<td>45</td>
</tr>
<tr>
<td>5.3</td>
<td>System Interaction diagrams for the three eco-dialogues: (a) “I feel”, (b) “If buildings could talk” and (c) “What if?”</td>
<td>46</td>
</tr>
<tr>
<td>5.4</td>
<td>Interface design. (1) Header displays study tasks, (2) Floor plans, (3) Summaries of the current building’s state, (4) Donut pie chart for the main rooms, (5) Three interaction models, (6) Three main seasons: winter, rainy and summer, (7) PMV thermal sensation colour coding</td>
<td>49</td>
</tr>
<tr>
<td>5.5</td>
<td>“I feel”. (8) “I feel” buttons and (9) PMV comfort scale, are located in the main rooms.</td>
<td>50</td>
</tr>
<tr>
<td>Figure 5.6</td>
<td>“I feel” Data Visualization. (10) Comparing comfort data for possible options, (11) Comparing comfort and energy data for possible options.</td>
<td>51</td>
</tr>
<tr>
<td>Figure 5.7</td>
<td>“What if?” Model Visualization</td>
<td>51</td>
</tr>
<tr>
<td>Figure 5.8</td>
<td>Building model for energy modeling</td>
<td>52</td>
</tr>
<tr>
<td>Figure 5.9</td>
<td>Conceptual model of LWLA in Grasshopper/Honeybee/Ladybug. (1) Tools used for building geometry and zoning, (2) Vancouver weather data, (3) Input data from server to generate possible options, (4) Component for Python programming to derive values for parallel simulation based on the input conditions, (5) Possible models for Energy Plus with different air schedules, (6) Generates the corresponding files for parallel simulation, (7) Output to specific folder</td>
<td>53</td>
</tr>
<tr>
<td>Figure 5.10</td>
<td>Screen shot of options generator (see Figure 5.9(4)) in Grasshopper. (1) Input data from the server, (2) Python programming component, (3) Possible options</td>
<td>53</td>
</tr>
<tr>
<td>Figure 5.11</td>
<td>Parallel simulation in Grasshopper for What If Model</td>
<td>54</td>
</tr>
<tr>
<td>Figure 5.12</td>
<td>Conceptual model for comfort calculations</td>
<td>54</td>
</tr>
<tr>
<td>Figure 5.13</td>
<td>Exporting data to the server</td>
<td>55</td>
</tr>
<tr>
<td>Figure 6.1</td>
<td>Age range of the participants</td>
<td>61</td>
</tr>
<tr>
<td>Figure 6.2</td>
<td>Residential building types and Thermostat Models</td>
<td>61</td>
</tr>
<tr>
<td>Figure 6.3</td>
<td>Residential building types and Thermostat Models</td>
<td>62</td>
</tr>
<tr>
<td>Figure 6.4</td>
<td>LWLA study procedure</td>
<td>63</td>
</tr>
<tr>
<td>Figure 6.5</td>
<td>(a) LWLA study at a participant dwelling (b) “If buildings could talk” was paper prototyped</td>
<td>64</td>
</tr>
<tr>
<td>Figure 6.6</td>
<td>Main coding themes</td>
<td>65</td>
</tr>
<tr>
<td>Figure 6.7</td>
<td>Coding categories for Inhabitant’s profile</td>
<td>66</td>
</tr>
<tr>
<td>Figure 6.8</td>
<td>Coding categories for Adaptations Made</td>
<td>67</td>
</tr>
<tr>
<td>Figure 6.9</td>
<td>Coding categories for Interaction Models</td>
<td>69</td>
</tr>
<tr>
<td>Figure 6.10</td>
<td>Coding categories for interface design</td>
<td>71</td>
</tr>
</tbody>
</table>
Figure 7.1  Frequency distribution for comfort preferences ................. 74
Figure 7.2  Key points on comfort preferences from qualitative study ....... 75
Figure 7.3  Frequency distribution for energy concerns ....................... 79
Figure 7.4  Reasons for energy concerns ...................................... 80
Figure 7.5  Comparing comfort preferences and energy concerns for couples .. 84
Figure 7.6  Comparing comfort preferences and energy concerns for individuals 84
Figure 7.7  Main points in Role in Household decisions ....................... 85
Figure 7.8  Key points on Cultural Habits Declared .......................... 86
Figure 7.9  Key points on comfort preferences ............................... 88
Figure 7.10 Personal adaptations summary ................................... 91
Figure 7.11  Thermostat adaptations summary .................................. 112
Figure 7.12  Fireplace adaptations summary .................................... 122
Figure 7.13  Fans adaptations summary ....................................... 125
Figure 7.14  Blinds adaptations summary ..................................... 127
Figure 7.15 Windows/Doors adaptations summary ......................... 129
Figure 7.16  Reasons for participants preferring phone for access .......... 134
Figure 7.17  System location choices by participants ......................... 136
Figure 7.18  Preferred control locations by participants ....................... 137
Figure 7.19  Eco-dialogue in order of preference. Out of 21 responses 11 chose “I feel.” Two participants chose “I feel” and “If buildings could talk” as first preferences ........................................... 164
Figure 7.20  A narrative of cost and comfort comparison and its influence on inhabitants. The narration is from the study and the names are not real. ..................................................... 169
Figure 7.21  Scenario: My Choices are not efficient! .......................... 181
Figure 7.22  Model preference and comparisons ............................... 187
Figure 7.23  Model preference and comparisons ............................... 188
Figure 7.24  Data Representations ........................................... 189
Figure 7.25  Visualization suggestions ....................................... 190
Chapter 1

Introduction

A large body of past research has identified the importance of the inhabitants role in building operations and energy consumption. Recent studies reveal complexities involved in understanding inhabitants interactions with the built environment, and effects of those actions on the building’s design. Here I briefly describe problems the inhabitants’ actions create for energy modeling, gaps in current state of the art and approach, and how these gaps can be addressed by a proposed system design.

1.1 Problem

Inhabitants usually adapt to their surroundings. If a window is left ajar during winter and the occupants feel cold, they might close the window, grab a blanket, or turn up the heat. The actions the inhabitants take could either be efficient or not. In this example, closing the window would be efficient in comparison to the other two actions which would cause heat loss. This raises the question of why inhabitants make unsustainable choices when they adapt. More generally, how do inhabitants make adaption choices? Why do they adapt in a particular manner? Is the choice habitual, or is it due to lack of information on what actions they could perform?

It is clear that inhabitants’ interactions with the built environment affect a building’s energy usage. This research focuses on understanding how inhabitants choose to interact with a building’s thermostat, windows, doors, blinds, etc., and the impact of those choices
on energy consumption and savings. In any situation causing environmental discomfort, inhabitants generally have choices for achieving their comfort needs. These choices may be influenced if inhabitants understand the full range of actions available and their possible impact. Other variables might affect choices as well, including the number of people involved, their age, health issues, building conditions, operating systems, and appliances.

1.2 Motivation

Following is a story from my personal experience about adapting to different climatic and building conditions.

To pursue graduate studies, I moved from a warm, humid place to a moderately cold oceanic climate. Well... to me it was anything but moderate—it was most certainly cold! Living in hot-weather conditions for over 20 years had influenced my comfort levels for temperature, the type of clothing I wore and my interactions with building elements and systems. When I moved to a relatively cooler climate, it took me nearly a year to figure out the thermostat settings that were comfortable for me. Also, because I had lived in a warm, humid city all my life, I was comfortable wearing lighter clothing and the change to wearing multiple layers from head to toe was sheer torture. Moreover, I used to love warmth, bright sunshine and working by the window, but Vancouver weather is mostly rainy, cold and dark. To achieve visual and spatial comfort I would leave the thermal blinds open. When I closed the blinds, it reduced the heat loss and made me feel warm. However, it made the room very dark, and inevitably I missed the natural light. So, I adapted by leaving the blinds open during the day, invariably using up more heat.

During December and January, the room became much colder, and the heating was inadequate for me. The studio apartment had central heat with individual controls, which did not make any difference as my room was still very cold. When I first raised the issue with the building manager, he suggested that maybe it was just me, and that I should get a space heater to keep myself warm. I brought the matter up with him a second time as I felt the heater was not working properly, and luckily another resident had made a similar complaint. Ours were corner units of the building, hence making them colder. The
building manager finally agreed to increase the heat because another resident had the same experience. He recognized that spatial location affects temperature—the middle units were warmer than the corner units. Meal preparation raised another environmental issue for me. Cooking would leave a strong odor in the room. To get rid of it I would leave the windows partially open, but the room rapidly became cold, causing me discomfort. Therefore, I would leave the windows open while I was away, and return to a very cold room. Then, not only did I crank up the heat but also used a space heater. These choices raised my energy usage and costs, but the actions did not directly affect me as heating was included in the rent.

The key message here is that an inhabitant’s comfort is affected by many factors. From my personal story, one can see how culture and lifestyle affect choices of clothing type and comfort levels. Agency also affects comfort. The building parameters affect comfort—for example, corner studio apartments have more wall exposed to the outside temperature. Activities and preferred comfort levels affect interactions. These factors are in turn affected by the building type and size, location and household members.

1.3 Inhabitants adaptations depend on various contexts

All these aspects add to the complexity of understanding inhabitants and the effects of their actions. Hence, the research started by probing into the assumptions that designers make about inhabitants in building simulations, and what causes the difference between predicted and actual energy consumption. I found that energy modeling tools do not use detailed assumptions about the inhabitants behavior, as doing so would make the simulations unreasonably complex. Often these data are assumed in a broader context or aggregated for a larger number of people, thereby reducing the assumptions to standard or deterministic values. However, the perceptions of individuals in a building—especially in a residential building—are critical.

The literature identifies that inhabitants use of buildings have a significant impact on the energy consumption and is one of the reasons for the vast difference between predicted and actual energy usage (Cole and Brown, 2009), (Janda, 2011), (Clevenger and Haymaker,
In his literature study De Wilde (2014) consolidates the root causes of the “performance gap” between predicted and actual energy efficiency in buildings. He highlights the importance of how the building operates after being occupied and also identifies the discrepancy between assumed and actual usage by the inhabitants in the buildings. Post-occupancy evaluation and literature studies have revealed that “occupancy hours/schedule” (Clevenger and Haymaker, 2006), (Kimpian and Chisholm, 2011); “expectations of comfort” (Hensen and Centnerova, 2001), (De Dear, 2004), “plug loads” (Kimpian and Chisholm, 2011), “lifestyle” (Vale and Vale, 2010), (Ürge-Vorsatz et al., 2012), “available control” (Cole and Brown, 2009), (Becker and Paciuk, 2009), and “behavior patterns” (Andamon et al., 2006), (Ürge-Vorsatz et al., 2012) are also causes for the difference.

1.4 What people do matters to building energy consumption

The real problem is that people are unaware of the effects of their interactions with building systems and elements, and how these interactions affect comfort and energy consumption. They do not know how the building and its system function. Why? because data on both usage and control are not visible to them. This is understandable—after all, how would inhabitants know all the possible actions and choices available to them? How would they remember these possibilities? How would they understand how each action has its impact on energy consumption? For example, when a person is feeling cold in winter, they usually increase the thermostat. But they can also choose to wear a sweater, have a warm drink, move to a sunny spot, or lower blinds. The last choice—lowering the blinds—is the most sustainable one, as it would reduce the heat loss in the building—but can the inhabitants be expected to know that? Other factors that affect inhabitants choices may include the pressure of time, lack of motivation, negligence, aesthetics, issues with multiple inhabitants, noise issues, and forgetfulness (Hampton, 2011). There is an apparent chasm between designers’ and engineers’ assumptions about inhabitants’ behavior, and how inhabitants actually make choices to affect comfort and energy usage. It is difficult for the designers to consider every detail of the inhabitants use of buildings as usage varies so greatly for different individuals.
1.5 Proposed Solution

My solution to the problem is to help inhabitants actively engage in seeking comfort and saving energy. Current monitoring tools allow inhabitants to engage by displaying data on energy consumed and predicting future usage based on history. These tools do not consolidate how or where inhabitants would need to make changes, nor do they provide an explanation for their actions, comfort or energy usage. Hence, to engage inhabitants in making more sustainable choices, I propose a system called Light Weight Look Ahead Options (LWLA), an eco-dialogue between buildings and their inhabitants. This system provides a quick simulation of inhabitants' interactions with the building’s controls and elements. It offers a set of possible actions to perform and provides feedback on comfort and energy consumption. These available options contain personal adaptations (wearing a sweater), system and elements adaptations (increasing thermostat or opening a window), and combinations of both personal and system adaptations. The research addresses the following questions for residential buildings.

- How do designers consider the inhabitants building usage in simulation tools? (As a literature review only.)
- How do people adapt to and/or change their thermal environment?
- How might LWLA help them to adapt to or change their thermal environment?
- What are the other factors that LWLA needs to consider for inhabitants to actively choose sustainable interactions? Any action an inhabitant takes that saves energy is a sustainable interaction.

Architecture is specific to place, time and culture. What “works” in one setting may not work in another. Yet any study must be done in a specific place, at a specific time and with specific people. External validity across place, time and culture is difficult to achieve in architectural studies. This is just the way it is in architecture. I situated my research in the coastal rainforest climate of Vancouver, BC, which has mild, wet winters and mild, largely dry summers. Why this choice? It is simple. That is where I work, where I live,
where I can access study participants and what I have come to understand deeply. However, LWLA tests some base concepts that will be invariant across any of its implementations. LWLA looks ahead, that is, it uses simulation to predict future environmental states, which people largely cannot see themselves. LWLA is lightweight: its design attempts to reduce personal effort through posing simple question-based dialog. LWLA aims to model a wide range of adaptations that people may want to try.

The literature related to energy use in building addresses people who use buildings as occupants, residents, users or inhabitants. The building simulation community mostly addresses the people as occupants or users. This research addresses people living in the residential buildings as inhabitants. Mclennan (2004) says certain species “found ways to create their own habitat and thus temper the outside conditions to be more suitable.” He calls this species “habitat builders.” He explains how honeybees creates their hive for protection, comfort, and storage. Also, he describes beavers as the civil engineers of the animal kingdom, because they “build elaborate dams and lodges to control water levels and hydrology in a localized area in order to prevent freezing and for protection from predators.” These species adapt to their local environmental conditions. Similarly, people adapt to their surroundings. We build, adapt and change the environment for our comfort. An inhabitant is not passive but actively adapts to his building environment and surroundings (Cole et al., 2008). Habitat in an architectural context combines more than building or space. It combines people, culture, and context with buildings.

1.6 Research Synopsis

The research approach comprises four parts: literature, designing, implementing; evaluating and redesigning LWLA. The literature study reviews assumptions about the inhabitants; and their operation of building systems (like HVAC) and elements (like windows and doors) by designers. Primarily, it identifies the gaps and issues with the assumptions made and recent approaches to bridge the gaps. Secondly, LWLA was designed and implemented based on the literature review to provide possible activities and interactions people can take in a building. The study evaluates LWLA, and concludes that a system like LWLA
can help in decision making and taking sustainable interactions. However, the study revealed that inhabitants' interactions are more complex than originally envisioned. These contributing factors include the following: multiple occupants; effects of current actions on comfort and energy over a period; easy access and understanding of the system; customizing motivating factors; and defining a threshold for comfort and energy. Section 8.3, design and improvement discusses this in detail.

In the following chapter, I briefly discuss the topics that each thesis chapter addresses.
Chapter 2

Thesis Outline

Background (Chapter 3)

In this chapter I first present the literature review on designers’ perceptions of inhabitants in buildings. I discuss current approaches in building architecture for sustainable buildings, including considerations and drawbacks in their assumptions. I also articulate that passive design needs active inhabitants. I review standard occupancy models and current approaches to user simulation for energy modeling, along with their limitations. Secondly, I discuss inhabitants’ engagement, by examining how the current energy display system engages inhabitants, what are its drawbacks and how to facilitate more active engagement.

Problem (Chapter 4)

In this chapter, I briefly describe the problem of how to address inhabitants’ behavior in building design, and how I am approaching it. I describe the system “Light Weight Look Ahead Option (LWLA),” its fundamental concepts, and how the system addresses the problem.

System (Chapter 5)

In this chapter, I describe the LWLA system in detail. Three interaction models—“I feel,” “If buildings could talk” and “What if?”—are described in detail. The interaction models are explained with detailed system architecture. The chapter also covers design principles
for visualization and interface design. Finally, I explain how the data were generated for visualization.

**Evaluation (Chapter 6)**

This chapter explains the need for qualitative research methods, explicitly including ethno- graphic methods. The pilot study showed that conducting the study at the participant’s house and involving couples gives rich data. I then explain the procedure of the main study, which considers 14 houses and 21 participants. I describe data coding, which is categorized into inhabitant’s profile, adaptations made, interaction models and interface design. Each category is explained in detail. Finally, I explain the inter-rater reliability of the study.

**Findings (Chapter 7)**

This chapter summarizes the research finding in four categories. Each category and sub-category is summarized with participants’ quotes. The first category, Inhabitant’s profile, discusses comfort and energy concerns and compares comfort and energy preferences. This section also explains the role of inhabitants in household decisions, cultural habits, and any sustainable practices of the inhabitants. The second category, Adaptations Made, describes how people make personal adaption, (changes to themselves), adaptation in the built environment, the influences of spatial arrangement and control locations, agency in the building, issues of design and construction, and social contexts like conflict and compromise. The Interaction Model category discusses how building design helps the inhabitants to adapt, as well as other issues and parameters to consider in the design. Each interaction model “I feel,” “If buildings could talk,” and “What if?” is coded against their design concepts. Finally, Interface Design discusses annoyance, barriers, trust, and control in the system design.

**Discussions (Chapter 8)**

In this chapter, I consolidate the findings into three categories:

- Why do we need LWLA?
• How LWLA helps in adaptation?

• How can the design of LWLA be improved?

Conclusions (Chapter 9)

In the Conclusion chapter I give an overview of the problem and how my system approaches it. I discuss future work for LWLA.
Chapter 3

Background

3.1 Overview

Designing for sustainability is becoming the norm in building architecture. Architects, designers, and engineers involve sustainable practices at various stages in design—from accessing sites to evaluating indoor environmental quality. Sustainable practices apply in different building sectors, including industrial, commercial and residential. In this research, the focus is on sustainable approaches in residential buildings, including drawbacks in design and implementation. Sustainable design approaches have various names—for example, energy efficient buildings, green buildings, high-performance building, sustainable buildings. However, all these approaches are basically similar, with slight or no variations. Williams, D. E., (2007) says that sustainable design integrates aspects of green building design (for example, local climate and building resources, create healthy interior spaces with natural light, complete recycling and reuse of materials) but furthers the design by maximizing the use of site’s natural renewable resources. Passive house design results in low energy use for space heating and cooling. Net-zero buildings use renewable energy equal to the energy used by the buildings themselves. Bennets et al. (2003) argue that the designer focuses more on the built environment than on inhabitants’ needs for sustainable building. They say, “actual performance is taken as influenced by uncontrolled humans and because their actual actions cannot be easily modeled they are ignored or standardized under an assumption
that everyone acts the same way.” Advancement in computer technology and algorithms enable designers to predict the possibility of inhabitants’ interactions in the buildings and consequent energy usage. However, each model has its limitations; this is discussed in the section 3.2.5 models of the user in design. Post-occupancy evaluations has proved that there is a significant difference in predicted energy to actual energy consumption and an inhabitant’s interaction is one of the main reasons. I articulate sustainable design considerations and drawbacks from an inhabitant’s perspective in the following sections.

3.2 Designers’ perceptions and actions

Building performance evaluation has become an integral part of the design process for designers, architects and engineers. The availability of simplified energy analysis tools in parametric modeling software has increased buildings’ performance. However, are we as designers, architects, and engineers missing any key factors? Are the approaches and methodologies we use feasible for sustainable outcomes? Current simulation tools tend to focus on the physical aspects of the building’s energy usage and, as a simplifying assumption confine considerations of the inhabitants interaction to fixed, scheduled or rule-based behavior. Architects use the following approaches to assess environmentally sustainable buildings.

1. Predictive energy simulation tools like IES, Ecotect, Equest, Esp-r, or Energy plus. These tools are used to calculate the amount of energy a building will consume. The data are displayed graphically or numerically. Architects use these tools for energy assessments to meet the goal set by Green building rating systems like LEED (Frankel and Turner, 2008).

2. Green Building Ratings like LEED (US), BREEAM (UK), Griha (India). For example, LEED has the following categories to be assessed in design: sustainable sites; water efficiency; energy and atmosphere; materials and resources; and indoor environmental quality. The ratings are summarized by an overall environmental rating of “silver”, “gold” or “platinum” (Cole and Brown, 2009).
3. **Measurement of actual energy consumption** by fuel (gas, electricity) or by end use (heating, cooling, appliance). The data can be collected from energy bills or by monitoring data (Pérez-Lombard et al., 2009).

These predictive tools help in refining the efficiency of the building for day lighting, natural ventilation and efficient energy usage. They are useful in refining the form, fenestrations and orientation of the building, and in calculating comfort levels, but they are not able to predict the response of inhabitants to these factors. Advances in technology allow the design to use stochastic models to predict the states of the windows, doors based on outdoor temperature and indoor temperature. Fabi et al. (2012) highlight that the probability of an inhabitant opening and closing doors depends on conditions just before the action is taken. So, considering only outdoor and indoor temperature is not sufficient. Designers have known for some time that the difference between predicted and actual energy consumption is attributed to inhabitants, and recent research shows the complexity of their behavior. Algorithms help in refining the design principles, but how does it impact the actions of an inhabitant? Designers perceive the probability of inhabitants’ interactions, but the interaction itself is dependent on various factors related to context. Indoor environmental quality, for example, depends on the various driving factors (Fabi et al., 2012): physical environment, contextual, psychological, physiological and social. Fabi et al. argue that the “whole process is not a closed system” because the “action scenarios” (like opening or closing doors) influence the driving factors through their effects on energy consumption and indoor environmental quality. This is a cyclic process. Designers can consider it, but what convinces us that the inhabitant will make the decision that is processed or optimized by the system? My argument here is that if we consider a building as a system (Bennetts et al., 2003), it is still a closed system because the knowledge and effect of an interaction and action process, on indoor environmental quality are available to the designers but not to the inhabitants. The inhabitants play an integral part in designing a comfortable building. The following section explains why the inhabitants are key to energy consumption and building usage.
3.2.1 Building performance gap

In architecture, sustainable design has been addressed under various names: High performance building, responsive architecture, green buildings, passive buildings, and net-zero buildings. Though Green rating systems have been recently incorporated into building design, sustainable design has been long approached when natural energy was considered in the design. Architects have been designing the buildings to be responsive to nature, but design approaches should shift to address how buildings responds to its inhabitants. One of the many reasons for this shift is that the post-occupancy evaluation of green buildings and high energy efficiency buildings reveals vast differences between the predicted and actual energy usage—and the reason for these differences is inhabitants.

Simulation tools that predicts the energy use consider fixed occupancy and operating hours, which do not reflect the inhabitants actual behavior. As a result, simulations are often wildly inaccurate. For example, Carbon Buzz, a RIBA CIBSE platform created to identify the performance gap between actual and predicted energy consumption, shows a great difference between them. In fact, on certain projects the actual consumption is twice as much as predicted. This shows that occupancy patterns and interaction are variables that affect actual energy use (Kimpian and Chisholm, 2011). The gaps between predicted and actual energy consumption are driven by these four aspects of occupancy: appliances and IT, extra occupancy hours, the quality of the facilities management and any special functions integrated into the building such as trading floors, server rooms or special equipment such as kilns and furnaces (Kimpian and Chisholm, 2011). Clevenger et al., argue that “uncertainties of the occupant behavior” in building models limit the accuracy of the model predictions. Deviation in an inhabitant’s behavior increases actual energy use. For example, peak demand is impacted more by an inhabitant’s inputs in cold climates than in warm. The parameters that affect inhabitants behavior are equipment load, ventilation rate, infiltration rate, and the inhabitants schedule (Clevenger and Haymaker, 2006). Also, energy usage of different inhabitants living in identical residential units can vary by as much as 200-30% (Lutzenhiser et al., 1987; Clevenger and Haymaker, 2006). Additionally, an inhabitant’s lifestyles has varying influence on the energy usage. Socio-economic-
cultural factors like the fit out by the inhabitant, the equipment added by the inhabitant, the pattern and the use of the building are not considered in the assumptions. Predictive models also ignore the problems arising from the operation, control and maintenance by the landlord and tenant (Bordass and Leaman, 2005). The following are the inhabitant-related factors that affect energy consumption: occupancy hours or schedules (Kimpian and Chisholm, 2011; Clevenger and Haymaker, 2006), occupancy patterns and use (Bordass and Leaman, 2005), plug loads (Kimpian and Chisholm, 2011), occupancy expectations of comfort (Hensen and Centnerova, 2001; De Dear, 2004; de Dear and Schiller Brager, 2001), available controls (Cole and Brown, 2009; Becker and Paciuk, 2009), appliances and IT, facilities management (Kimpian and Chisholm, 2011), cultural and social aspects (Andamon et al., 2006), contextual issues (Andamon et al., 2006), behavioral patterns (Andamon et al., 2006; Ürge-Vorsatz et al., 2012) and lifestyles (Vale and Vale, 2010; Al-Mumin et al., 2003; Ürge-Vorsatz et al., 2012).

There is a large body of recent research on understanding inhabitants behavior; it includes surveys, literature review, evaluation of prediction tools and methodologies, and comparisons of measured data with predicted data. All the research concludes that inhabitants and their behaviors are complex; even more probing and details are needed to project energy usage. De Wilde (2014) notes that discrepancies in measured data and predicted data could happen at the “design stage, construction stage or operational stage.” He concludes from the literature review that the operation of the inhabitants is different from the assumptions made during the design stage. He mentions that the “energy performance gap can only be addressed by changing the current practices in building engineering practice.” While the change in current building practices is crucial, change in how the inhabitants use the building is ignored in most research. Studies have shown that the gap in predicted and measured data is significant (De Wilde, 2014) and is difficult to match (Sun, 2014). Studies of energy efficient buildings show considerable difference between assumed and actual usage (Nord et al., 2018), as the model considers standard values and ignores inhabitants’ lifestyle (Majcen et al., 2013). Simulation tools do not take end uses like household appliances into consideration, and also the relationship between the “dwelling use, dwelling
type and occupant characteristics” is not known (Majcen et al., 2013). Nord et al., (2018) conclude that it is highly relevant to consider inhabitant behavior for better prediction in Zero Energy/Emission buildings. Inhabitants’ adaptation to the buildings is unknown and unpredictable as it depends on various contexts. A study on five dwellings in South Wales showed that the inhabitant’s adaptation to thermal comfort varied and inhabitants had different ways to achieve their comfort (Tweed et al., 2014).

Fabi et al., (2012) summarize the five categories of occupancy driving forces in a broad context (see Figure 3.1). To show the driving forces from an inhabitant’s perspective, I classify the categories based on the literature as individual or internal factors, external factors, building properties (Fabi et al., 2012), action factors (Gauthier, 2016) and social factors (Gauthier, 2016; Fabi et al., 2012). Internal or individual factors pertain to inhabitants, and the parameters that relate to them, like preference, attitude and activities (Fabi et al., 2012). External factors address the surrounding environment of the inhabitants. Building properties relate to ownership, available heating devices or controls.

![Figure 3.1: Inhabitants’ perspective on behavior driving forces](image-url)
Action factors arise when the habitant’s actions are intentional or habitual, and maybe there are other factors. The literature also states that inhabitants have diverse coping strategies especially at home (Gauthier, 2016; Tweed et al., 2014). Coping strategies of inhabitants can be divided into two categories: larger context (heating system, draught) and personal context (activity, clothing). Finally, social factors pertain to the interaction between inhabitants and social pressures on them. Fabi et al., categorize how designers typically approach thermal comfort. As is evident in thermal comfort models, designers tend to focus on the system first and people second. However, designers need to centre their designs on the interactions of inhabitants, and the response of the inhabitants to the context. I discuss this in the following sections.

### 3.2.2 System first, people second

Designers have engaged in systems thinking, that is, understanding, modeling and configuring a design situation as an interacting assembly of parts. However, the physical parts of the building system have been given more attention than the human parts, likely because it is the physical parts that are the product of design. In considering the building as a system, Bennet et al., (2003) mention that sustainable development considers three subsystems: environmental, economic and sociocultural. They argue that this model is useful for general developmental issues and they highlight the absence of two subsystems: the building and the building users. They conclude that building system should address the needs of all relevant stakeholders. In section 3.2.1, Building Performance Gap, we discussed how the operational use of the building resulted in an enormous difference between predicted and actual energy usage. The building design is judged more on the presence of physical components than on its end use by inhabitants. As Bennet et al., (2003) say “people are strangely absent from this image.” and a strong image in design community is that “building itself uses energy and not occupants.” Designers evaluating the performance of the buildings noticed that people use and adapt in various ways (Gauthier, 2016; Tweed et al., 2014). Hence, “buildings don’t use energy, people do” (Janda, 2011). As discussed in section 3.2.1, the complexity of inhabitants has reduced the assumptions to standard or de-
terministic values (Jia et al., 2017). It is difficult for designers to approach the uncertainties of building end-use (Clevenger and Haymaker, 2006). Bennets et al., discuss architects performing “beautiful acts.” A beautiful act is when the designer takes into consideration the “nature, culture and technology,” and makes “responsive cohesion” in all of these contexts in design (Bennetts et al., 2003). It all relates to building design. The author says that performing the beautiful act is difficult. Even if designers achieve beautiful acts, the systems or technology incorporated in the building design influence the interaction and operation of the buildings. Inhabitants need to be an integral part of design considerations and building operations. Designers are not solely responsible for creating beautiful acts—inhbitants play a crucial role in the beautiful act as well. It is time to move from beautiful act to beautiful interactions—in other words, inhabitants interacting with the built environment in a meaningful way to conserve energy. Designers often focus on the physical aspect and ignore the “final realization of the construction, technical installations, and the real use of the built systems operated by inhabitants” (Fabi et al., 2012).

In the following section, I discuss passive design, home automation and intelligence, models of users in simulation tools and the role of inhabitants in each category. The content highlights a general lack of consideration for inhabitants in building design.

### 3.2.3 Passive design

Passive design requires active inhabitants (Hampton, 2011). Passive design uses the solar energy through convection, conduction, absorption, and radiation in building design. These strategies are used to achieve the desired comfort levels for inhabitants by providing natural ventilation, daylight and by eliminating mechanical systems. Passive design approaches include solar heating and cooling, thermal mass, natural ventilation, and daylight. Often, for a passive design to be successful the user needs to operate with the building elements to make the performance complete.

In his widely accepted text, Lechner argues that sustainable design for heating, cooling, and design can be accomplished in three tiers: basic building design; passive systems; and mechanical equipment (see figure 3.2). The first and second tiers are purely architectural.
Building design attempts to minimize the heat loss in winter, minimize heat gain in summer and to use daylight efficiently. Passive systems use natural energy in heating and cooling systems. The strategies in these two tiers can reduce energy consumption by 80% (Lechner, 2009), and efficient mechanical design in the third tier can reduce the energy by an additional 8%. One such strategy is optimizing the energy used in buildings by modeling and simulating; but the post-occupancy evaluation shows otherwise.

What are the designers neglecting in their design process? The engineers are not the primary people responsible for the environmental control in the building—the process begins with the architects. For example, in the basic building design of a three-tier passive design system, windows are among the elements that play a role in the design, as shown in figure 3.2.

![The Three-Tier Design Approach](image)

Figure 3.2: Three tier approach to passive design (Lechner, 2009)
Windows involve inhabitant’s interaction and affects the energy performance of the building. Often, architects assume narrowly rational inhabitant interaction with the windows but the literature proves otherwise.

To illustrate the above, Roetzel et al., (2010) in their study on inhabitants behavior for windows mention that season, temperatures, time of the day, previous window state and night ventilation all affects an inhabitant’s behavior. The behavioral model simulation is better at prediction for windows that are in opened and closed states, but neglects the parameters such as inhabitant control of the ventilation openings, measured energy performance and inhabitant comfort, multiple inhabitant control of the windows, the percentages/angles opened in regard with time, their accessibility and hierarchal relation in interaction with the windows in case of multiple users. These conditions significantly influence passive design. Foster et al., discuss the importance of inhabitant’s control in passive design in their study (Foster and Oreszczyn, 2001). They highlight the need to study inhabitant interaction with building elements like windows, and blinds. Passive design involves active inhabitants (Cole et al., 2010) and they need to be considered in the design.

The interaction of the inhabitant does not affect the first and second tier alone—it also plays an important role in the mechanical design. One example: a mechanical system design needs to include clear consideration of the number of zones in the building. All parts of the building do not have the same heating and cooling demands; so mechanical systems are designed to provide separate environmental control to different areas (zones) of the building. Each zone has its own control systems like thermostat or humidistat. One reason for different zones is the difference in exposure. Lechner mentions that additional zones are required because of the difference in scheduling and occupancy. For example; “a large conference room requires separate thermal control; otherwise, it will be too cold when only a few people are present and too hot when the room is full” (Lechner, 2009). Poorly designed building zones can cause discomfort to inhabitants but also the location of the control panels, setting dials/knobs and their accessibility has an impact on the behavior change. Li & Lim (2013) mention that multi-occupied spaces are a challenge, because people have wide variations in their perception of comfort. This shows that architects and
designers are not only neglecting inhabitants, but also how inhabitants interact and engage with their surroundings. One cannot expect inhabitants to productively engage controls that map poorly to their perceived comfort. So, the question is, how can such information be considered and integrated at the early stages of design? Ania Hampton cites the following examples of users in buildings:

“I’m always hot and stuffy and want the windows open. But Debbie, who sits next to the windows, complains about the draught and shuts them again.” - Huang, accountant in open-plan office (Hampton, 2011)

“We’ve tried having the windows open, but with the noise from the kindergarten and street, plus a crying baby, I can’t hear a word the poor mother is saying” - Helen, maternal health nurse (Hampton, 2011)

Inhabitants’ reasons (see figure 3.3) for not performing an interaction at the appropriate time run the rich gamut of human experience—including the pressure of time, unawareness, lack of motivation, negligence of the inhabitants, multiple inhabitants issues, aesthetics, noise issues, and forgetfulness, to name only a few. These examples again show that passive buildings involve active inhabitants. Ania Hampton (2011) draws two conclusions: buildings should come with a manual of instruction for the inhabitants on how to use the buildings, and inhabitants should be trained on how to use the buildings. However, we know that inhabitant’s attention is limited, and learning is not permanent. So, how can an effective manual be provided to inhabitants? Will the training help the inhabitants to use the

Figure 3.3: Inhabitants’ reasons for not performing a meaningful interaction
building appropriately? Alternatively, will it wear away with time? Is it too much knowledge for the inhabitants to remember and follow?

3.2.4 Passive design implies active inhabitants.

How does interaction play an essential role in passive design? In this section, we explain the need for considering inhabitants’ involvement and interaction in the passive design three-tier approach for heating. Inhabitants’ involvement and interaction varies across the three stages, and the efficiency of the building performance depends on its outcome.

In the three-tier approach for heating (see figure 3.4), the basic building design (Tier one) (Lechner, 2009) is heat retention. Designers insulate the building with high thermal resistant material to reduce heat transfer. The building is made airtight to retain heat. Heat gained from external and internal sources affects indoor comfort levels. In addition to the heat gained through walls and windows, inhabitants generate heat, the amount of which depends on their metabolism and activities performed. Also, appliances generate heat, and the operation of lights produces heat. All these factors add to the heat retained in the building.

Figure 3.4: 3-tier approach to passive design and inhabitants’ involvement at each stage.
Hence the designers need to consider the inhabitant’s operation, activity, and clothes in design. Considering the heat gain from inhabitants and appliances, a tightly sealed building should have proper ventilation for fresh air without losing heat. In the absence of fresh air, inhabitants may open windows or doors causing heat loss. Window designs do not depend only on orientation, size, glazing type, insulation and shading as shown in the three-tier approach in Figure 3.2—they also depend on the inhabitants’ interactions (opening and closing of windows and blinds) (Fabi et al., 2012). These factors affect the performance of the building, and they are widely ignored at this stage. To resolve this issue, the designer not only needs to consider inhabitants end use but involve them at the design stage. Robinson (2003) uses normative scenario analysis at the early stages of design in selecting the site and also iterating the possible scenarios with the different stakeholders. Incorporating the normative scenario analysis at early stages will enable users to understand the consequences of their actions and also help the designers to understand inhabitants’ preferences and beliefs. This underlines the need to understand how inhabitants will engage with the operable system once they occupy the building.

Passive solar heating uses windows, walls, floors, and other building elements to collect and store heat. Common passive heating strategies are direct gain, indirect gain, and isolated gain. For example, direct gain uses south-facing windows to collect heat and retain through thermal massing. Glazing, or windows, play an important role in heat gain, and consideration of inhabitants and their interaction with the windows will influence the outcome of the passive system design. Windows and blinds are inseparable. When one considers the design of windows and their operation, they need to consider the operation of blinds as well. Blinds regulate the amount of light entering the building and influence the indoor temperature. However, the operation of the blinds may depend on issues like privacy, glare and inhabitants’ comfort preferences. South-facing windows not only help in heat gain but also provide daylight (see figure 3.5). Hence the operation of blinds not only affects the thermal comfort but also affects the daylighting. A well-insulated house with passive heating strategies may cause overheating, and this influences inhabitants’ adaptions for comfortable room temperature. However, one can question the efficiency of these in-
These factors are often neglected in the design. It is important to consider inhabitants’ control (Foster and Oreszczyn, 2001) and inhabitants as active in passive design (Cole et al., 2010). So, how will the inhabitants engage with the operable system to promote sustainable actions without compromising their comfort and expectations?

(a) Direct heat gain

(b) Inhabitants affect heat gain through interactions

Figure 3.5: Direct gain and inhabitant presence in space

Finally, the third-tier, mechanical heating, depends on controls, systems and proper design of zones. These zones are dependent on occupancy patterns, which help in deciding the controls and heating system for the buildings. Zoning design is crucial or it can cause partial discomfort to inhabitants. Control location, settings and accessibility plays a role as well (Li and Lim, 2013). This shows the importance of considering operation parameters in building design. The passive house uses smart technologies/thermostats to control the temperature. Inhabitants’ understanding of and ability to use the technology affect the building performance and comfort levels. Revel et al. (2017) discuss how the smart systems lead to more energy consumption than saving. They conclude that inhabitant’s “thought processes” should be considered to encourage energy-saving actions, and the systems should provide the feedback related to that context. In conclusion, inhabitants’ involvement and interaction are integral parts of each tier and its importance increases from tier 1 to tier three, as shown in figure 3.4. The ideal would be to integrate inhabitants in each design stage. However, it seems clear that inhabitant involvement and interaction spans all three technical subsystems.
Home automation and intelligence adds sensing, actuators and computer controls

Home automation, also widely known as smart homes or intelligent homes, is another approach to help inhabitants reduce energy consumption by providing smart technologies and control strategies to perform tasks. This approach seems to embed an assumption that the home and system can, in and of itself, provide comfort and energy efficiency. Thus the technologies focus more on the rules of use rather than the user experience (Woodruff et al., 2007). The actions predetermined by intelligent systems can be frustrating when they do not align with actions that the inhabitants intend (Mozer et al., 2005). Also, people who have more control over and understanding of the automation systems are more iterative in their behavior, as compared to rule-based automation (Brush et al., 2011). Cole et al., argue that inhabitants have been neglected in intelligent building design, and adds inhabitant's intelligence to the five existing attributes of intelligent buildings (Cole and Brown, 2009).

Leaman and Bordass (Leaman and Bordass, 2001) contend that allowing automation to remove inhabitants completely from feedback and control loops is a mistake. Their study describes inhabitants frustration when they are not able to have control over the existing state or condition of the automation. Smart homes are residences wired with features that monitor the well-being and activities of their residents to improve the overall quality of life, to increase independence and prevent emergencies (Demiris et al., 2008). A review on smart homes by Chan et al., (Chan et al., 2008) concludes that one of the design challenges is the requirement to consider the user needs, the inhabitants themselves and their surroundings. Mozer mentions that operations are not initiated by smart homes but by the smart inhabitants (Mozer et al., 2005). Recent research is shifting focus from “smart home” to “smart occupants”. Such studies address inhabitants behavior, motivational strategies and how automation can impact the inhabitants daily life and comfort (Bartram et al., 2011). Smart devices comprise two types: system-oriented, importunate smartness and people-oriented, empowering smartness. System-oriented devices take action based on previously and continuously collected information, whereas people-oriented digital devices keep the human in the loop. A people-oriented device empowers users to make appropriate decision
and puts the in control of the actions (Streitz et al., 2005). Thus the recent studies have been trying to understand how to engage the inhabitant in sustainable actions.

3.2.5 Models of the user in design

Models of users in high energy efficient buildings are limited in their assumptions. In this section, I discuss the standard models and the simulation of users with advanced computer modeling. Thermal comfort is “A condition of mind that expresses satisfaction with the thermal environment” (Handbook, 2001) or “the absence of discomfort: a person feels neither too warm nor too cold” (McIntyre, 1980). There are two distinct models used in analyzing thermal comfort in buildings: Fanger’s PMV (Predicted Mean vote) - PPD (Predicted Percentage Dissatisfied) and the Adaptive comfort Model (De Dear, 2004).

Fanger’s PMV is static

In Fanger’s Model, PMV (Predicted Mean Vote) is used to understand human perception of thermal comfort and is based on laboratory methods (climate chambers); it is widely known as static or constancy model. PMV predicts the average thermal sensation for a large group of people exposed to the same climatic condition. It has four physical variables: air temperature, air velocity, mean radiant temperature and relative humidity. It also has two personal variables: clothing insulation and activity level. PMV is a mean value for a large group and often deviates from the individual values. The votes are based on a thermal sensation scale from -3 to +3. PPD is the percentage of inhabitants that are dissatisfied with the given thermal conditions. It mainly depends on the inhabitants perceiving the conditions as either too warm or too cold. In the model, 5% PPD is the lowest percentage of dissatisfaction achievable (Becker and Paciuk, 2009; Hensen and Centnerova, 2001; De Dear, 2004). The post-occupancy evaluation shows that PMV progressively overestimates the mean perceived warmth of warmer environments and the coolness of cooler environments (De Dear, 2004). Humphreys and Nicole mention that PMV rests on steady-state heat transfer theory and this does not support inhabitant’s daily life, which is based on dynamical thermal equilibrium (Humphreys and Fergus Nicol, 2002). In Fanger’s model
the inhabitants are considered passive, while adaptive model assumes that the inhabitant is active, and interactive, with the building. The following subsection discusses adaptive thermal comfort.

**Adaptive thermal comfort is used only for naturally ventilated buildings**

Adaptive thermal comfort considers the behavioral adjustments, physiological and psychological expectations of the inhabitants: “If a change occurs such as to produce discomfort, people react in ways, which tend to restore their comfort” (Nicol and Humphreys, 2002a). The principle that the model is built upon is that people adapt to a variety of indoor conditions to an extent, depending on the clothing, their activity, and general physical condition. In other words, inhabitants are able to adapt to maintain comfort over a wide range of temperatures. The personal adaptive opportunities are dress code, furniture type, consumption of hot/cold drinks, metabolic rate, and posture. The adaptive building opportunities are operable windows, operable blinds, local fans and spatial variations. The adaptive comfort approach depends on outdoor effective temperature (ET*) (Nicol and Humphreys, 2002b; de Dear and Schiller Brager, 2001). The PMV-PPD approach (Fanger’s model) is more useful for predicting for fully centralized HVAC, while the adaptive comfort model is more useful for naturally ventilated buildings because the inhabitants are interactive with windows or awnings to be comfortable inside the space. ASHRAE 55 suggests adaptive comfort models for naturally ventilated buildings. The reason is that expectations of people in these two types of building vary (Hensen and Centnerova, 2001; De Dear, 2004; de Dear and Schiller Brager, 2001). One field study, which was conducted on 189 dwellings in winter and 205 dwellings in summer, used Fanger’s PMV model. The model showed significantly lower than reported thermal sensation, especially for winter heated and air-conditioned summer groups. The PMV over predicts the load—actual thermal comfort can be achieved at lower loads than predicted. The study found the variances were caused by the contextual variables (local climate, expectations and available control) (Becker and Paciuk, 2009). Another survey conducted on 120 LEED-certified buildings used energy modeling tools for analysis. This research showed that actual energy was more than the predicted energy. Their data
also showed that the ASHRAE 90.1 energy performance standard is more stringent than typical industry practice (Frankel and Turner, 2008). We conclude that the reasons for the gap between predicted and post-occupancy building performance include inhabitants’ behavior, their pattern of use, control, expectations, cultural and social values, management, operation, and schedules.

**Basic standard models are not adaptive**

So, what factors are both the models ignoring? One of these is the *interaction of operational systems and technologies embedded in the built environment*. PMV considers four physical variables: air temperature, air velocity, mean radiant temperature and relative humidity; these variables not only depend on the physical state of the building but changes in the inhabitants’ interaction with windows, blinds or thermostats. Cole et al. (2009) state the need to consider additional control strategies, whether automated or controlled by inhabitants, because they affect the comfort conditions. So the question is how does one consider the models of interaction with systems in the building? Further, PMV does not add the radiant heating from windows into the model, nor does it include the heat generated from the appliances. The CBE thermal comfort tool includes an option that allows the heat gained through the windows to be calculated with the PMV parameters (Tyler et al., 2013). Usually when calculating thermal comfort for the set PMV parameters the comfort parameters meet the ASHRAE 55 standard, but the newly integrated solar calculation, which includes the heat radiation from the windows and, the mean radiant temperature does not meet the standard. Integrating the heat from appliances and radiant heat from window increases credibility of the building simulation.

**User simulation in buildings**

Advances in technology have enabled access to data on occupancy and occupant energy consumption. Models of occupancy began to emerge from the monitoring data and sensors. Hoes et al., (2009) conclude that simulating user behavior is a significant parameter in energy simulations. Based on the literature, the models were ranked into three types:
simple user behavior (standard models or values); advanced user behavior 1 (simulation considers the interaction between the user and environment); and advanced user behavior 2 (simulation considers the interaction between the user and environment as well as complex mobility.) Hoes mentions that user behavior is more complex than simply considering user interaction based on schedules (for example, defining the use of appliances on an hourly basis). For robustness study on an office environment, he concluded that following criteria to be considered in a user behavior model: pattern of occupancy presence is constant or irregular; active vs passive users (user making active interaction with blinds or windows); inhabitants use relates to the different size of internal heat loads. The robustness study concluded that there is no “realistic general design concept.” To minimize the effects of different types of user, Hoes states that we need to use oversized active systems.

Modelling simulation users have moved from standard to probabilistic approaches to address variations in use (Jang and Kang, 2016). The most commonly used probabilistic approach in energy simulation is a stochastic model due to its random nature (Jia et al., 2017) (Jang and Kang, 2016). In stochastic, Markov model is the fundamental process. It considers the present state to predict the future state and ignores the influence of the past state (Jia et al., 2017). This model has been used to study the relationship between inhabitants’ presence and window states, inhabitants’ interaction with windows, activities of daily living like cooking, occupancy duration, and interaction; schedule for lighting and HVAC control based on occupancy presence; and probabilistic mapping between household profiles and corresponding domestic energy consumption. This model is more useful for long-term occupancy assessment and less so for very detailed occupancy behaviors (Jia et al., 2017). Jia et al., (2017) classify the modeling methods into five categories: agent-based modeling; statistical analysis; data mining approaches; stochastic processes modeling and other related models. They argue that no one model is more efficient than the others. Few models are restricted in their assumptions, for example, statistical analysis is limited to specific inhabitant behavior like opening windows. In agent-based modeling the assumption is restricted to the interaction between the agents and the environment or between themselves;
also the model is specific to the researcher’s own interest. Further, the complexity of the model makes the integration difficult and needs further study (Jia et al., 2017).

The user simulation has helped in improving energy usage but concludes actual data are needed instead of assumptions. Simulation of users was not the focus of the research. While these models have been used in energy simulation, the study shows variations in assumptions and actual use. Building simulation researchers are improving assumptions of user behavior, but they are ignoring the engagement of inhabitants and their interaction in the buildings. All of the above models are used by designers in thinking about and specifying buildings and their systems. Separate from the field of design, largely in the social sciences, researchers have developed understandings of how people, individually and in groups, actually interact with buildings. As much as considering the user assumption in the building is essential, inhabitants’ engagement is an important criterion as well. In the following section, I discuss the need for considering inhabitant engagement.

### 3.3 Inhabitants’ engagement

Advances in technology and home automation have enabled designers to provide systems that enable inhabitants to reduce energy consumption in their environments actively, but literature study shows that there is a gap between design potential and actual use of these systems in home environments. More sharply, the current state of professional knowledge on how to bridge the gap remains young and unconvincing.

Paula Melton is an editor at Building Green Inc. and has wide practical experience in designing and operating green buildings. Her voice is typical of well-informed professionals. She states that inhabitants’ engagement is where the inhabitants are aware of their own energy and water usage, water disposal habits and use of toxic chemicals; and also the decisions taken by architects, engineers, building managers or other stakeholders to cultivate the habit of saving energy for the inhabitants. Melton concludes that to make an inhabitant actively engaged, one should consider the following: designing for feedback, transforming social norms and creating incentives (Melton, 2011). Melton gives the framework from
the professional view of inhabitants’ engagement. These concepts are supported by the academic literature, but with significant differences.

### 3.3.1 Feedback

Feedback is one of the effective tools to facilitate energy conservation (Flemming et al., 2008; Gardner and Stern, 1996) and has both positive and negative impacts on the inhabitants’ energy interventions (Abrahamse et al., 2005). Eco-feedback technology provides feedback on individual or group behaviors with a goal of reducing environmental impact (Froehlich et al., 2010). There are different types of feedbacks: direct feedback, indirect feedback, inadvertent feedback, utility-controlled feedback and energy audits. Having feedback allows the user to control energy, but the quality of the feedback systems affect the outcome of the sustainable actions (Darby, 2006).

So, what are the factors that might affect the quality of the feedback systems? Froehlich et al., (2010) discuss the effect of motivational techniques like information, goal-setting, comparison, commitment, incentives/disincentives and rewards/penalties on feedback systems. For example, goal-setting requires feedback on the inhabitants’ performance towards their goal. This enables them to understand the consequences and motivates them in progressing towards their goals. Inhabitants’ desire to know the real-time information on resource consumption (Chetty et al., 2008) and its cost (Cole and Brown, 2009) to save money and keep their home environmentally friendly. The feedback systems should be designed not only to show resource consumption and its effect, but also to enable users to take the next set of actions in reducing energy consumption (Flemming et al., 2008). Froehlich et al. also mention that integrating motivation behavior techniques with feedback will affect energy conservation. In summary, it is not enough to design feedback—the system needs to understand the context and the behavior that needs to be influenced or changed (Froehlich et al., 2010).

Feedback should also focus more on individuals than larger context and social interaction (Strengers, 2008). Fischer concludes in her study that successful feedback on electricity consumption consists of actual consumption, is given frequently, involves interaction and
choice for households, provides appliance-specific breakdowns, is given over a longer pe-
period, offers comparisons and is presented understandably and appealingly (Fischer, 2008).
Though feedback systems have issues that need to be addressed, they still have some pos-
itive effect on inhabitants’ behavior. For example, the energy consumption indicators on
household cooking appliances decreased average consumption by 15% (Wood and New-
borough, 2003). Faruqui et al., (2010) review indicates that In-Home displays encourages
consumers to make efficient use of energy and can reduce consumption on an average by
7% when prepayment of electricity is not involved. When both prepayment and In-Home
Displays are used, they can reduce electricity consumption by twice the amount (Faruqui
et al., 2010). Energy savings have around 5-15% for direct feedback and around 0-10% on
indirect feedback systems (Darby, 2006).

3.3.2 Social Norms

In a group or society, customary rules that govern behavior are called social norms. Pro-
viding social norm information may induce people to conserve energy (Schultz et al., 2007;
Allcott, 2011). There are two types of social norms: descriptive and injunctive. Descriptive
social norms are what others do or approve. What others do and what most others do are re-
lated, but they are conceptually and motivationally different. When many people are doing
something, norm congruent behavior is initiated (many people are doing this so it probably
the wise thing to do). Social controls are decisions that are significantly influenced by the
expected reactions of friends and family. This anticipated approval/disapproval factor is
called injunctive social norm—in other words, what others believe to be the appropriate
conduct. Research shows that compliance decisions are strongly influenced even when the
imagined others are not friends and family but are more generalized society members. This
shows that expectation regarding what most others approve/disapprove can be impactful.
Descriptive social norms that do not involve what others approve also have a strong influence
on compliance decision.

Recycling behavior is influenced by social norms, personal norms, and awareness of
consequences. Residents encouraging their neighbors to recycle influenced the altruistic
norms and increased recycling behavior (Hopper and Nielsen, 1991). Nolan et al., (2008) conclude that normative influence produces a significant impact in conservation behavior compared to other information. These studies show how social norms can have a significant impact in influencing inhabitants’ behavior to conserve energy.

### 3.3.3 Incentives

Feedback, when combined with incentives, encourages energy reduction. Research conducted in dormitories provides evidence that students were encouraged, motivated and empowered in conserving energy when feedback was combined with education and incentives (Petersen et al., 2007). Stern mentions that success of incentives may not only depend on the size of the incentives offered but also on the way they are organized, marketed and implemented. The incentives are classified as reduced-interest loan subsidies, interest-free loans, grants/rebates. The study mentions that the type of incentives makes a difference and people prefer grants/rebates to loan subsidies of equal value. Low-income homeowners and households who are not sure about their future finances prefer grants/rebates to loans while the higher income households prefer loans (Stern et al., 1986). Incentives combined with systems impact energy conservation, for example, programmable thermostats when combined with incentives have a larger impact on reducing energy use than on their own (Suter and Shammin, 2013). Literature study also shows that an incentive has a greater impact on the energy reduction when combined with feedback or appliances than by itself. An incentive is one of the contextual determinants in decision making in residential consumption (Wilson and Dowlatabadi, 2007).

### Interaction Histories

Bateman (2009) and Ivanov et al., (Ivanov et al., 2007) provide unique approaches for visualizing information to facilitate understanding of energy consumption. While Bateman focuses on interaction histories with digital objects, Ivanov et al., focuses on a space-centric approach in monitoring inhabitants’ behavior. Bateman discusses how the study on interaction histories with digital objects has neglected the understanding of shared interaction
history in the day-to-day work of individuals and groups. He focused on Hill and Hollan’s work on integrating visual traces of historical interaction on digital objects. Visual traces of interaction histories will give the user insights about how the object was used in the past and it is used currently. Such information will not only give breakdown information, but also the consumption data that can be compared with past actions. A similar problem exists in understanding the energy use of multiple inhabitants and shared interaction histories in residential buildings. Even the energy modeling tools ignore consideration of multiple users’ interaction and their influence in energy actions. Interaction histories and shared interaction histories can help stakeholders understand the expectations of different users and their conflicts in the decision. Visualizing the information on the activity or objects spatially helps the user to understand the events or activities more easily—in other words, it reduces the cognitive load (Hailemariam et al., 2010). Though Ivanov et al., focus on understanding inhabitant behavior by monitoring large spaces, their mixed-modality system helped in observing inhabitant behavior with less intrusion, and avoided privacy issues. Their mixed-modality system consisted of a large number of motion sensors and fewer video cameras. Their multidimensional data consisted of both the spatial and temporal components to help the building manager in identifying the odd behavior.

Bateman’s research involves collecting interaction of histories at the object level, in contrast to the spatial and temporal visualizations used by Ivanov et al. Both these strategies facilitate the understanding of inhabitant’s behavior. Spatial histories with temporal information regarding home environment will help users and designers to understand the most occupied spaces. This will help the designers to configure spatial zoning to make the interaction more engaging. It will also help in designing spatially integrated interactions to help the inhabitants become more actively engaged. Literature study shows that there is cognitive load in understanding new objects introduced spatially and it can be intrusive in inhabitant’s daily life. This leads us to understand how inhabitants communicate among themselves in everyday life.
3.3.4 Contextual location

Greenberg et al., (2009) focus on the informal use of technology in everyday contexts. They discuss the use of technology in everyday life, and their study focuses explicitly on the role of awareness in domestic coordination and communication. The interesting inference of their research is how contextual location plays a vital role in communication through the interaction of time, ownership, and awareness. The contextual location of the information engages and facilitates the inhabitant’s interaction with their cohabitants (Greenberg et al., 2009). Multiple inhabitants or cohabitants are neglected in the study of inhabitant’s behavior and interaction in building energy. This emphasizes the need to understand how inhabitants engage in everyday life. Greenberg et al. also discuss social grouping awareness, interpersonal awareness, and a technique for maintaining awareness and contextual locations. This study shows how the inhabitant is aware of their co-habitant’s activity. I would also like to highlight the role of contextual location mentioned in Greenberg’s paper. A contextual location is the key location that inhabitants use for displaying, interacting, organizing and coping with communication. This strategy helps us in the spatial integration of digital objects and provides visual feedback without intruding on the everyday life of the inhabitants. Location placements in homes may be static (example: kitchen table) or dynamic (example: a day planner carried in the purse). The main factors that can affect location placements are household size and number of independent adults. Other contextual location factors include:

- *Pathway and routines*, which help in placing the information around the routines that the co-habitants are familiar with.

- *Constellation* (a communication will form additional set of communications to be placed close by);

- *Location attributes and proximity* (the attributes of the location affect the suitability of the information being displayed)
• Visibility and practicality (putting information in a clear place than a crowded area will draw attention towards the information) helps in identifying the suitable location for feedback, digital objects and controls.

These strategies can be used as navigation during the design stage to incorporate digital objects, information displays, and communication for facilitating inhabitant engagement in sustainable outcomes.

These novel ideas present several dimensions for intervening in inhabitant engagement: through artifacts, space use, social patterns and over time. However, the main challenge remains: integrating information back to the design approaches for sustainable outcomes.

### 3.4 The gap: Inhabitants’ engagement

The research highlighted in sections 3.2.1, Building Performance Gap and 3.2.3, Passive Design demonstrate that the needs of the inhabitants are complex. In this section, Figure 3.6 shows that factors like motivation and unawareness play a role in the active use of the building. An “active user” of the building is one who takes action that is more sustainable (Hoes et al., 2009). In addition to Lechner’s three-tier system, a fourth tier—inhabitants’ engagement—needs to be considered. This tier considers how to encourage inhabitants to participate actively in sustainability-related actions. My design approach is to actively engage inhabitants by providing an interactive feedback system. The general problem and approach is discussed in the following chapter.

![Figure 3.6: Proposing fourth tier as Inhabitants’ Engagement](image)

Tier 1
Basic Building design

Tier 2
Passive System

Tier 3
Mechanical Equipment

Tier 4
Inhabitants’ Engagement (In all stages)

36
Chapter 4

Problem

Inhabitant adaptation in buildings is complicated! Individual actions will vary because of comfort preferences, body type, clothing preferences, cultural habits, knowledge of building science, awareness of sustainable practices and the contingencies of life. These parameters are not limited; there might be more of which we are not aware. When there is more than one person involved more complexity creeps in. So how do inhabitants resolve issues of discomfort in buildings? What drives them to take a particular action? Is action based on comfort, others present in the house, the weather, or the economic condition? The questions are murky; their answers more so. It is complicated for designers to consider every parameter of the individuals in a household. How can such parameters be considered in energy simulation by designers?

My research probes following questions:

- How do people use buildings?
- How do designers consider inhabitant's building usage in simulation tools? (As a literature review only.)
- How do the inhabitants understand the design intent of the building?
- Could gaps in understanding be met by revealing information (simulation data) to inhabitants?
• Will inhabitants change their choices on seeing information related to their actions in a building?

• Will revealing comfort and cost information on inhabitants’ interaction with building systems and elements affect their choice of actions?

• Can inhabitants’ decisions be influenced by providing them with all possible options of comfort and energy consumption related to their context?

The chapter provides a brief overview of the need for an LWLA system, its core concepts, and the issues the system addresses.

Figure 4.1 summarizes questions for different systems and elements in the building. The questions aim to understand the reasoning behind inhabitants’ actions in the face of discomfort. Study of these elements will help us to understand the need for providing possible alternative responses to discomfort.

4.1 What is LWLA?

Let us look at the following scenario: I feel very warm. “When Jane returns home after exercising, she finds the room temperature very warm.” Here, the inhabitant has various options to choose from: a) open windows, b) open windows and lower thermostat, c) lower thermostat, d) pre-set thermostat before activity, e) go out of the building for some time, or e) remove jacket. Each option has its effect on building energy usage and also how inhabitants (Jane and others) perceive the effect of Jane’s interactions with the controls and the building elements. Further, every action affects the future, not the present. Some time must elapse before the effects of an action become clear. Some effects, notably energy use, are notoriously hidden from view. It is hardly surprising that inhabitants do not clearly understand the effects of their comfort-seeking actions. Yet, understanding is a prerequisite to effective control.

I propose Light Weight Look Ahead options (LWLA), an interactive data visualization that runs a quick simulation of inhabitants’ interaction with building systems and elements.
How do inhabitants interact with building systems and elements?

Windows, doors & blinds
When and why do people open windows and doors?

Appliances
Does the heat generated by the appliance cause discomfort?

Activities
How does the inhabitants' activity influence the interaction in buildings?

Clothing type
Do they adapt to the temperature by changing their clothes?

Thermostat & Air Conditioning
How often do inhabitants interact with thermostat and why?

Surrounding Environment
Do aesthetics and view influence their building interactions?

Figure 4.1: Questions for systems and elements in the building
LWLA predicts the energy usage and comfort levels in the building in relation to inhabitants’ interactions and compares it with the existing conditions.

### 4.2 Key concepts of LWLA

LWLA core concepts consist of four key points: Lightweight system design; lookahead in alternatives, context and time; interaction models to accommodate different levels of interaction for the inhabitants; and data comparison for facilitating sustainable action’s. See figure 4.2

#### Figure 4.2: Key Concepts of LWLA

**Light Weight**: Energy data in a building can be extensive and complex. Providing all the information to the inhabitants will impose cognitive load. Hence, we propose to design
a lightweight system. This will also reduce the simulation time of predictive models. It is designed to be lightweight so the inhabitants can make quick inquiries on comfort levels and energy usage.

**Look Ahead:** Foreknowledge of the effect of the actions taken in the building may influence current action. For example, an individual leaving windows open in winter might get immediate comfort satisfaction. However, they are not aware of the following things: the actions effect on energy usage, its effect on comfort over time, and how it might cause discomfort for future actions. The inhabitants may be aware or unaware of other options and their effect on comfort and energy usage. Current energy visualizations display energy usage for the actions performed in the buildings. They do not predict the effect of future actions. Hence, we propose Look Ahead for how interactions with building elements and systems affect comfort and energy usage. LWLA provides Look Ahead for three main aspects: context, possible alternatives and time.

*Look Ahead Alternatives:* As described in the scenario “I feel very warm,” inhabitants have various choices to achieve their comfort goals but are unaware of the available options and may not understand them. Hence, we propose “Look ahead alternatives.”

*Look Ahead in Context:* Inhabitants’ comfort levels vary in response to their activities, clothes and body type. Hence, we propose to predict the alternatives with respect to context.

*Look Ahead in Time:* The inhabitants’ interactions in the building affects the future and not the present. Some time must elapse for the actions to become clearer. Hence, we propose to predict the actions in relation to time.

### 4.3 How LWLA addresses the issue

LWLA was designed to understand whether revealing information about the inhabitant’s interaction with building elements and systems, and their effects on comfort and energy usage over time, might bridge the gap between design intent and usage. LWLA’s intent was to understand the effect of information on sustainability motivated actions. LWLA addresses this issue by providing information on comfort and its effect on energy usage, along
with other possible actions inhabitants can take based on the context. The information is provided spatially or located on building plans for easy understanding.

LWLA is intended to facilitate the following:

- low-energy interaction and actions
- encourage personal adaptations,
- influence inhabitants’ choices by providing alternatives to context
- encourage inhabitants to learn about the influence of actions on energy usage and comfort over time.

Moreover, in the long run, we aim to understand inhabitants’ actions on comfort and energy usage as assumptions in energy modeling. See figure 4.3

![LWLA Design Intent Diagram](image)

Figure 4.3: LWLA design intent

We described the overview of the LWLA in this chapter; and we describe the system architecture in chapter 5.
Chapter 5

System

5.1 System Description

We identified three types of interactions based on the literature study. First, “I feel.” This is an expression an inhabitant makes to the system—for example, “I feel very warm” or “I feel cold.” The expression depends on the feelings of the inhabitant, whereby they express their discomfort in simple terms. These feelings are dependent on two factors: existing building conditions and personal variables of the inhabitants. There might be other unknown factors too. The scenario “I feel very warm” was taken from Jane’s experience. In this particular instance, “I feel very warm” has a relation to Jane’s preceding action. The preceding action here was “exercise.” Exercise increases a person’s metabolic rate. This can be the sole reason for the discomfort, or it could be additive based on a building’s current state. Though in this instance the scenario is related to exercise, there can be other actions or situations that cause discomfort. For example, a person cooking in the kitchen can feel very warm because of radiant heat. Appliances generate heat. Cooking is also an activity and it increases a person’s metabolic rate. Time is also an essential factor to be considered. How long the person has performed an activity plays a role as it increases body heat. All these factors add to the existing heat levels in the building. All of them could cause discomfort for the inhabitant now and in the future. The expressions in the “I feel” model align to the thermal sensation scale from Fanger’s comfort model: Predicted Mean
Vote (PMV); see Figure 5.1(a). In the long run, when the LWLA system is implemented in buildings, it would help in understanding the thermal sensation scale model and its issues.

Second, “If buildings could talk” (See Figure 5.1(b)) Here a building acts as an independent agent that uses inhabitants’ profiles to suggest actions. For example, if the building is becoming hot, the system prompts the inhabitants to perform an action to increase comfort. This method also aims to determine who would receive the information, as the inhabitants are of varying ages and have different roles to play in decision-making. Hence specific information could be pushed or prompted to the inhabitants who play a major role in decision-making.

Third, “What if?” Here an inhabitant inquires about the actions, (s)he might perform, for example, opening windows or raising the thermostat. These actions could be impulsive or driven by circumstances (e.g., noise level is high, hence close windows). As
shown in Figure 5.1(c), the “What if?” model allows inhabitants to explore the building’s systems (e.g., thermostat, air conditioning), elements (e.g., windows, doors, blinds), as well as their own activities and clothing types. This interaction allows inhabitants to play with the elements and controls of the building to understand how they affect energy use. These methods of interactions are not limited to those provided, as we might discover other techniques during the research study.

Figure 5.2: System Architecture

Figure 5.2 shows the system architecture of the LWLA prototype. It consists of three main components:

(a) **Interactive data visualization.** The interactive data visualization is a web interface designed with Html5, JavaScript, jQuery and D3.js. This component comprises two-sub-components: inhabitants’ interactions and data visualizations. Here, the inhabitant’s choice of action is sent to the server and it updates the simulation results from the server.

(b) **Server.** The server is a common database, where the inhabitants’ interaction schedule and simulation results are stored.

(c) **Building geometry and energy simulation.** We modelled an existing passive house, considering local weather conditions. The model was built in Rhino/Grasshopper and uses Ladybug/Honeybee for energy simulations. It calculates comfort levels and energy
usage based on the inhabitants’ current actions or expressions. The system comprises python scripts that process the possible options contextually.

5.2 Interactions

System interactions vary for the three proposed “eco-dialogues,” as shown in Figure 5.3(a) shows the “I feel” model. Here, a person expresses to the system their perception of comfort in a room, and the system considers the current conditions of the room (like the window, blinds or door states), possible activities and clothing type, and other factors (e.g., drink something warm or cold). The system runs parallel simulations based on the windows, doors and blind states. It also calculates the different states with possible personal actions. The system displays comparative data of the possible options based on comfort and energy usage. To simplify the model, we have considered only the heating consumption for energy usage during winter, and rainy seasons; for summer we used free-running model.

Figure 5.3: System Interaction diagrams for the three eco-dialogues: (a) “I feel”, (b) “If buildings could talk” and (c) “What if?”

Figure 5.3(b) shows the “If buildings could talk” model. When an inhabitant selects this model, the system initiates conversations when there is a change in the comfort level based on the weather, building state or user preferences (e.g., the system reminds one to
close the windows after an hour). For example, when the building comfort level changes from comfortable room temperature to very warm, the system would prompt, “the building is turning hot! Do you feel hot?” If yes, then the inhabitants can view the possible actions that could be taken. The data displayed is similar to the “I feel” model, the only difference being that the system takes the initiative.

Lastly, Figure 5.3(c) shows the “What if?” model. When the inhabitants select the actions they would like to perform or inquire about, the system sends those data along with the current state of the building to the server. The system returns two simulation outputs: comfort levels based on the current building state and comfort levels based on the action proposed. This model compares only the comfort levels and not the energy usage, because the visualization was complex.

5.3 Visualization

5.3.1 Design Principles

LWLA visualization considers the following five design principles from literature study.

(a) Simplicity. Stephen Few (2009) emphasizes that data visualization should capture the information as simply as possible (and no more so). LWLA uses a simple design to express the information. Simplicity here means using expressions, colours and icons that are easily understood and used socially. The design model uses a simple background, and the foreground uses colour for information display. Using colour only for the data with simple background increases readability and reduces cognitive load.

(b) Spatial data. Information is displayed spatially for easy correlation of the space with actions, elements, systems, comfort and energy data. In LWLA, comfort data is attached to specific zones in the building plan. For example, comfort data for the living room is located in its space.

(c) Hourly timeline data. LWLA considers information over time and incorporates this information into different rooms. A donut pie chart visualization was selected as it
consumes less space and can show information for 24 hours. It causes less visual clutter when incorporating the data in different rooms.

(d) Visual cues allowing inhabitants’ to understand the changes in comfort or energy usage. LWLA uses the PMV comfort scale: very cold is represented in dark blue while very hot is represented in red. This colour representation follows current social norms and is easily understood. LWLA uses green colour for operable elements in the building plan, allowing for easy recognition of objects with which users can interact. These are the only colour codes used.

(e) Icons. LWLA uses imagery for activity and clothing widgets combined with text for easy interaction.

(f) Comparison. Stephen Few suggests comparing data side by side, as the user cannot hold much information in memory. LWLA considers and compares different data side by side to help in decision making.

5.3.2 Interface Design

The interface design comprises seven components. The header consists of the dashboard name and the scenarios for the study design. The system itself can operate for different seasons, but in the study, we focused on specific scenarios only. Hence we used different scenario buttons (see Figure 5.4(1)). The interface displays floor plans of the building, and the user can toggle between the floor plans (see Figure 5.4(2)). The operable elements in the building, such as windows, doors, and blinds, are shown in green for easy identification (see Figure 5.5). Summaries of the current building’s current system and element states are provided at the top for easy readability (see Figure 5.4(3)). Each main room—e.g., the living room, kitchen, bedroom, and office—contains a donut pie chart to display room temperature over time. A small dot in the pie chart highlights the current time (see Figure 5.4(4)). The left side of the interface comprises three elements. First, Expressions shows the three interaction models: “What if?”, “I feel” and “If buildings could talk” (see Figure 5.4(5)). Second, Seasons (See Figure 5.4(6)) displays three main seasons (specifically Vancouver)
for participants to explore. Lastly, the comfort legend (see Figure 5.4(7)) shows the colour coding for temperature based on Fanger’s PMV model.

![Interface design](image)

Figure 5.4: Interface design. (1) Header displays study tasks, (2) Floor plans, (3) Summaries of the current building’s state, (4) Donut pie chart for the main rooms, (5) Three interaction models, (6) Three main seasons: winter, rainy and summer, (7) PMV thermal sensation colour coding

Figure 5.5 shows the information display specifically for “I feel” model. When the user selects the “I feel” expression, each main room shows the “I feel” button (see Figure 5.5(8)) and the user can express what they feel in the room—for example; very warm, cold or slightly cold (see Figure 5.5(9)). When the user selects the “I feel” expression; the system displays the comfort and energy data in two steps. First it shows the possible options for comfort for the given context. The two steps were designed to avoid energy data influence for participants who focus more on comfort and not energy (see Figure 5.6(10)) and when the user clicks on the comfort donut it shows the energy data for all possible options (see Figure 5.6(11)).
Figure 5.5: “I feel”. (8) “I feel” buttons and (9) PMV comfort scale, are located in the main rooms.

For the “If buildings could talk” expression, the system follows a similar visualization display as I feel model, but here the system initiates the process (see Figure 5.8). It is difficult for the system to decide on what the inhabitants are doing (e.g., exercising or reading a book). Therefore, the system asks the participants to select their activity and type of clothing to calculate the possible options. Installing sensors in the building might help in collecting certain data but, for the study, participants needed to tell the system what they are wearing or doing.

The interface design for the “What if?” model is different from the other two models. As this is an individual inquiry, participants see three widgets for thermostat, activities and clothing. The user can select the individual attributes to see each one’s influence on comfort data. The interface has two donut rings; the inner ring shows the information based on the current settings in the building and the outer ring shows the information based on actions they selected. It helps the user to compare the two sets of data.
Figure 5.6: “I feel” Data Visualization. (10) Comparing comfort data for possible options, (11) Comparing comfort and energy data for possible options.

Figure 5.7: “What if?” Model Visualization
5.4 Data

An existing building was modeled to generate the energy data for the study. The building geometry with zones was built in Rhino 5, and the boundary conditions for the energy model were defined in Honeybee/Ladybug/Grasshopper tool. The Honeybee/Ladybug tool uses Energy Plus in the background for simulation. The model considered thermostat, windows, and doors for the study. HRV was not considered as most of the buildings in Vancouver were free running and did not have HRV installed. Blinds were eliminated at the time of study as they caused tricky modelling and simulation issues.

![Building model for energy modeling](image)

Figure 5.8: Building model for energy modeling

Figure 5.9 shows the conceptual model of LWLA in Grasshopper/Ladybug/Honeybee. It shows the concept of files generated for parallel simulation. The model considers Vancouver weather data for energy modeling. As explained in section 5.2, once the values are updated in the server the simulation is processed. Input data update from the server (see Figure 5.9(3)) process Python coding to generate possible options and corresponding values for the attribute.
Figure 5.9: Conceptual model of LWLA in Grasshopper/Honeybee/Ladybug. (1) Tools used for building geometry and zoning, (2) Vancouver weather data, (3) Input data from server to generate possible options, (4) Component for Python programming to derive values for parallel simulation based on the input conditions, (5) Possible models for Energy Plus with different air schedules, (6) Generates the corresponding files for parallel simulation, (7) Output to specific folder

Figure 5.10: Screen shot of options generator (see Figure 5.9(4)) in Grasshopper. (1) Input data from the server, (2) Python programming component, (3) Possible options
Changes in window or door states and thermostat states require a separate energy model. For example, when the door state is open, the air infiltration and temperature in the building changes in comparison to closed doors. Hence the need for different models to set air schedule based on the building conditions (see Figure 5.9(5)). Once this is set, Energy Plus creates the file for parallel simulation.

Figure 5.11: Parallel simulation in Grasshopper for What If Model

Figure 5.12: Conceptual model for comfort calculations
Figure 5.10 shows the screenshot of possible options generated in Grasshopper. Once the output files are updated, Energy Plus runs the parallel simulation. Figure 5.11 shows the parallel simulation model for “What if?” model; hence it shows two models running parallel (see Figure 5.11(2)), but for “I feel” and “If buildings could talk” model it will have more files.

The last process is generating comfort data. Figure 5.12 shows the continuation of Figure 5.9. The comfort model considers the output data from the parallel simulation and corresponding values generated by the Python component for activity and clothing. The calculated data are exported in CSV format for the front end. Data is cleaned and wrangled before exporting (see Figure 5.13).

![Diagram](image.png)

Figure 5.13: Exporting data to the server
Chapter 6

Evaluation

In this section, I describe the structure, process and techniques used in evaluating the LWLA prototype.

6.1 Methods

In designing LWLA, I imagined how people would use the prototype. The purpose of evaluation was to discover how people might actually use the prototype and to discern potential future directions for development. To understand the threat of design to validity, I collected information about the prototype’s usability, but this was not the main focus of evaluation. Like all tools, LWLA changes the task environment in which people act. Thus, it was important to collect information on attitudes and actions both without and with the LWLA prototype in play. Overall, the study took the form of structured interviews with participants, either individually or together as couples. To gain a sense of how people actually conduct themselves, I ran these sessions in participants’ own dwellings.

6.1.1 Qualitative Research Approach

Qualitative research is useful in understanding the nature of problem within its context or environment, and the responses of people to such problems. Creswell (2007) summarizes nine characteristics of qualitative research in the order of importance. For this research, the first three points: natural setting, researcher as key instrument of data collection and
multiple sources of data play a significant role. *Natural setting* refers to the environmental setting of the building, its design (two bedroom or three bedroom units or houses), and its type (e.g., apartment, residential, individual houses or townhouses). All are essential for this study to understand participants’ responses to comfort issues. These parameters influence actions and choices. Environmental context help the people to remember or recollect their experiences. Also introducing a new tool to their environment may influence their behavior or actions. *The Researcher is key instrument of data collection.* The knowledge of design, building architecture, energy modeling and green buildings design helps in collecting and interviewing the people on comfort issues related to different environmental factors. For example, comfort issues may relate to building design or to activities or body type. *Multiple sources of data are essential.* Semi-structured interviews, video and audio recording, photographs, observation, field notes and sketches of building plans helps in making sense of the issue and categorizing themes.

In conducting the qualitative study, I aimed to understand choices of inhabitants’ activity in context. Creswell describes five types of qualitative inquiry: narrative, phenomenological, grounded theory, ethnographic and case study research (Creswell, 2007). Each research inquiry varies in its approach and may be suitable for different research. This research uses ethnography and grounded theory strategies but not in its entirety.

### 6.1.2 Research Methods

My goal with LWLA was to have a deeper understanding of inhabitants’ interaction in buildings. Ethnography involves understanding people’s practices in their daily lifestyle (van Donge, 2006), “watching what happens, listening to what is said and asking questions (O’Reilly, 2009).” The system was not installed in the participant’s house, and the study was conducted as tasks for few hours and not for a long period. But, conducting the study at the participant’s house gave clear contextual data. I could not watch what they do daily over a period, but the participants were asked to narrate the experiences. And conducting the study at their house gave them the opportunity to explain the problem by acting it out or interacting with the elements. Performing or enacting the issues or context provided
very rich contextual data. The data collection methods in this study were semi-structured interviews, participant observation, and field notes.

Participant recruitment. The participants were recruited from different community groups and by the spread of word through friends and faculty. The criteria considered were age, family size and building type (like apartments or individual home). The study mainly focused on families with or without children and with or without seniors living with them. Children were not participants for ethical reasons.

Interviews. I used the semi-structured interview method, as data collection was conceptually driven. I asked few quantitative questions regarding comfort, energy concerns and ratings for different interaction methods. The interviews were audio and video recorded. For ethical reasons, the video does not reveal participants’ faces.

Participant observation. Participants were observed while performing tasks and were questioned about their actions for further clarification. For example, how they interacted with the three models and resolve comfort issues, or whether they were stuck after performing a set of actions.

Field notes. Sketches of the building plans, locations and other necessary details relating to comfort were collected through notes and photographs.

6.2 Pilot studies

I conducted a pilot study to check the feasibility of the following.

Questionnaire and task completion to check if the participants were able to understand the questions and for practice as well.

Time How long the questionnaire and task completion take

Location To verify that conducting the study at participants’ houses helps us in collecting contextual data.

Participants To check if there is a data difference between conducting the study for individuals or couples
Sustainability enthusiast  To understand how sustainability enthusiasts and non-sustainability people respond to LWLA system.

6.2.1  Pilot study 1

The first pilot study was conducted with an individual participant at their house. The participant had a computational design background, and their house was located in an apartment complex. The study revealed a few interface issues, and these were fixed in the following study. Conducting the study at participant’s house helped them to share the issues by interacting with elements and systems in the building. Hence, the session provided very rich data. The participant was able to recollect their interactions and performed them as well. The study took time as the participant had to take care of her child in between and I had to keep that in consideration for families with children.

6.2.2  Pilot study 2

The first pilot study was conducted for an individual and the data did not address interactions among family members. Hence this study was conducted for a couple, and it provided useful conflicting data compared to the first pilot study. The study took just over 2 hours. The data for this couple was even more productive as the spouse was working from home. The participant working from home had more discomfort experience and operations varied in context. For example, the noise, smoke pollution and privacy during the day affected the operation of windows.

6.2.3  Pilot study 3

The first two pilot studies made it clear that conducting the study with couples provides rich data. The participants for the two studies were aware of sustainable design and actions but were not enthusiasts. The third pilot study was conducted to understand the influence of a sustainability enthusiast—defined as an individual who is active in the sustainable community and is aware of its sustainability in decision making. Participants were excited about the interface design and the influence it could make on the people. This led me to
decide to balance the participants who are sustainably active with those who are less active. The participant for the pilot study was living in an individual house, and the data were different compared to the other two participants who lived in apartment units. The third study was conducted at the university and it was hard for the participant to contextualize her comments.

6.2.4 Conclusion

The pilot concluded that the time required varies according to the participant’s background, household members and experience in sustainable actions. As these factors influence the data gathering, I decided to adopt the structured questionnaire based on the context. Data was richer in context, hence I decided to conduct the study in the participants’ dwellings. This data were richer in context as it helped the participants to narrate experiences and issues. Most of the time participants’ enacted stories with actions and interacting with the systems and elements in the buildings to explain issues and concerns. As a researcher, it gave me the first-hand experience of the environment, and as an architectural expert, it enabled me to connect my knowledge of buildings to participants’ actions.

Couples provided very different data than individual interviews. Hence, I decided to balance individuals and couples. For example, the experiences of comfort issues were linear; it is evident at times if they did not have kids. But, conducting the study as couples gave varying responses. One person says I do this action; the other person starts to explain the conflict they have in their choice. Also, they helped each other in remembering the issues and struggles they faced in achieving comfort or understanding energy usage. The only disadvantage is a personal opinion may be overpowered by the other. The study is balanced as it considers 7 individual and 7 couples.

Sustainability involvement and awareness leaned towards a positive response to the tool, hence I decided to balance participants with the different backgrounds.
6.3 Main studies

6.3.1 Participants

Participants were individuals or couples of varying ages. In total there were 21 participants. The participants age ranges were 1 from 25-30, 7 from 30-35, 4 from 35-40, 3 from 40-45, 2 from 45-50, 1 from 55-60, 1 from 65-70 and 2 from 70-75 (See Figure 6.1). The study had 7 couples and 7 individual interviews. The participants’ background varied from homemaker to engineer, interface designer, sustainability enthusiast and architect. There were 4 families with children between the age group of 3-6 years and 3 families with teens. One participant was pregnant during the study and gave different comfort requirement data. The study was conducted at 6 apartment units, 3 town houses, 4 individual houses and 1 passive house. There were 9 conventional thermostats and 5 programmable thermostats. See Figure 6.2

![Figure 6.1: Age range of the participants](image)

![Figure 6.2: Residential building types and Thermostat Models](image)
Figure 6.3 shows the overall data for the study. It also shows the hours each study took. Participant’s ID for couple starts with the same letter followed by M and F for male and female. Similar ID was generated for individuals. The data also shows the number of children in the families. During the study one of the participants (LF) was pregnant, and this resulted in understanding different issues compared to other participants.

<table>
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<th>Teen/youth</th>
<th>House Type</th>
<th>Number of Bedrooms</th>
<th>Floor Level</th>
<th>Thermostat Type</th>
<th>Audio Minutes</th>
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<td>-</td>
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<td>1</td>
<td>Conventional</td>
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</tr>
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<td>-</td>
<td>Apartment</td>
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<td>7</td>
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</tr>
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<td>-</td>
<td>Apartment</td>
<td>1</td>
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<td>Conventional</td>
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</tr>
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<td>-</td>
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<td>3</td>
<td>GF</td>
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<td>-</td>
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<td>3</td>
<td>GF</td>
<td>Conventional</td>
<td>01:32:18</td>
</tr>
<tr>
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<td>-</td>
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<td>-</td>
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<td>-</td>
<td>2</td>
<td>Individual</td>
<td>3</td>
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<td>Individual</td>
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<td>3</td>
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<td>-</td>
<td>Town house</td>
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<td>-</td>
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<td>Town house</td>
<td>2</td>
<td>2</td>
<td>Programmable</td>
<td>00:54:10</td>
</tr>
</tbody>
</table>

6.3.2 Procedure

The study started by getting participants’ consent then a pre-questionnaire, task completion, and post questionnaire. The task completion phase provided separate demos for each interaction model followed by the task to be completed. A portable computer with a large monitor was used for the study and placed in the participant’s dining or living room. Large monitors help in visualizing large data, and the portable computer (See Figure 6.5 (a)) was used for its speed in computing parallel simulations (see Figure 6.4).
6.3.3 Pre-questionnaire

In the pre-questionnaire the inhabitants were asked about their approaches to comfort levels in the buildings and how they achieved comfort. Did they face any discomfort during different seasons of the year and, if so, how did they resolve such issues? What tools would help them resolve such issues? These questionnaire were addressed to couples or individuals in the family. The data were collected through field notes (written and sketches) and audio recording. (See Appendix A.)

6.3.4 Task Completion

In the scenario-based tasks, the inhabitants were provided with the interactive visualization and asked to perform tasks for the following days: a typical cold clear winter day, a hot clear summer day and a cool rainy day (typical for the Vancouver climate). These tasks included semi-structured questions on how the information helped participants’ decisions or actions taken. Tasks were provided for each of the three proposed interaction models, “I feel,” “What if?,” and “If buildings could talk.” The order of tasks was changed for credibility. “I feel” and “What if?” tasks were computationally collected while “If buildings could talk” tasks were paper prototyped (See Figure 6.5 (b)). The data were collected through field notes, video recording of the screen and screenshots. (See Appendix B.)
Figure 6.5: (a) LWLA study at a participant dwelling (b) “If buildings could talk” was paper prototyped

6.3.5 Post-questionnaire

In the post-questionnaire the inhabitants gave feedback on the interactive visualization design. They were asked whether they will use such information, their willingness and ability to trust the information and their comfort in using the information. They were also asked where they would like to have the interface located, and to post the paper prototype on preferred locations in their dwellings. They were asked to post in the order of preference. Data were collected through photographs of the prototype posted (these do not include the participants), field notes, video and audio recording. (See Appendix C.)

6.4 Data coding

Coding can be concept or data-driven. Gibbs, G. R. (2007) mentions that categories or codes “may come from the research literature, previous studies, topics in the interview schedule, hunches you have about what is going on, and so on.” Saldaña (2009) also discusses having codes “determined beforehand to harmonize with your study’s conceptual framework or paradigm.” Provisional coding is one of the exploratory coding methods that consider a list generated from anticipated categories or responses to the research. Coding for the LWLA
The study uses a predetermined list of themes from literature and conceptual design of LWLA. During the analysis, the categories were refined and modified based on the content, and new categories emerged from the data.

The four central themes are inhabitants’ profile, adaptations made, interaction models and interface design. They are categorized based on the research query to understand inhabitants’ interaction with building elements and systems to achieve the desired comfort. (See Figure 6.6)

**Inhabitants’ profile** describes the inhabitant’s attitude, preferences, expectations, roles in decisions and concerns related to comfort.

**Adaptations made** identifies the actions related to the context of the issue. It consolidates how inhabitants deal with conflicts in the environment or when they are uncomfortable.

![Figure 6.6: Main coding themes](image_url)
**Interaction models** covers issues with the three proposed models, “I feel”, “If buildings could talk” and “What if?”. It addresses questions on how the three models help inhabitants to adapt.

**Interface design** covers how the interface gets in the way of the adaptation.

Initial codes for all the categories were developed from a literature study and the conceptual framework of the interaction design. These codes were very detailed. After reading sample data multiple times, the coding was simplified and in the end a combination of pre-designed codes and emerging codes was used. Once the structure of the coding was stabilized, the data was analyzed using NVivo 11 software.

### 6.4.1 Inhabitants’ profiles

The inhabitant profile was used to capture behavior, attitude, roles, and concerns for energy and comfort. It initially started with three categories: comfort concerns, energy consumption concerns, and role in household decisions (see figure 6.6).

![Figure 6.7: Coding categories for Inhabitant’s profile](image)

*Comfort concerns* aims to understand the importance of comfort, and its weight in decisions for actions. Comfort concern rates the preferences on a scale of one to ten, where one is unconcerned, and ten is very concerned. Similarly, *energy consumption concerns* aim to reveal the importance of energy usage. The preferences are rated on a scale of one to ten, where one is unconcerned, and ten is very concerned. During the interviews, participants
spoke about the experience from their home country and the habits developed at various locations. Hence, I added a new category, cultural habits declared. Also, during the analysis a few participants explained the sustainability actions they had taken, so the data were coded under the category sustainable actions taken. Data that could not be coded under these categories were coded under the category others.

6.4.2 Adaptations made

Attitude is what people say; action is what they do. I collected information about how people adapt to their lived context. The main categories are personal adaptations, technology and built environment, social context and others. See figure 6.8.
The Personal adaptations category is used to understand how people make changes to themselves like wearing a sweater or moving to a new location. The PMV comfort model considers activities and clothing type as variables. One of the criteria was to understand if participants make changes to the clothing and the thermostat. Personal variables include habits and actions around clothing, levels of activity, food and drink, and choice of location in a dwelling.

The coding considers the elements that facilitate or hinder personal adaptation. In Technology and built environment, the initial coding categories included adaptation using controls, spatial arrangement or control location, and design. Reading the first interview added the following categories: understanding a situation and agency. Adaptation using controls considers the interactions a participant makes with the blinds, windows, doors, thermostat or air conditioner. These interactive elements affect the indoor temperature of the building, and it was necessary to understand inhabitants’ reasons for performing the actions.

Spatial arrangement or control location considers the influence of furniture arrangements and also the location of thermostats in the building. How does location affect the choices of people and energy usage? Understanding a situation tags the reasoning behind an action. For example, some participants did not understand why the building was still cold after increasing the thermostat. It is further classified into two subcategories: reasoning about action and trade-offs. Trade-off considers the quotes from the participants, where they choose adverse decisions like opening windows during winter instead of lowering the thermostat. The general agency question asks: who has agency? where does agency lie? does the built environment keep the inhabitants from exercising agency? Design construction is related to the built environment, materials used, issues related to ventilation, heating, cooling, orientation, insulation, and comparing buildings (e.g., the current apartment compared to a previous apartment).

Social context covers data related to others in the buildings— for example, children, seniors or other members. The category is divided into group and children. In group, there are three subcategories collaborate or consult (What helps the inhabitants collaborate
or consult?), conflict (How do participants resolve conflicts in comfort or other decisions related to comfort?) and negotiation (How do they negotiate?). Negotiate was a code that emerged during the data analysis while collaborate or consult and conflict were expected.

6.4.3 Interaction Models

*Interaction model* considers the three models, “I feel”, “If buildings could talk”, “What if?” and general (data that applies to all the three models) as the primary categories (see figure 6.9).

![Figure 6.9: Coding categories for Interaction Models](image)
The subcategories are defined by the conceptual framework of the interaction models. “I feel” considers participant’s sense of comfort, multiple options, heat cost comparison and the voice assistant. “I feel” was designed for participants to express their comfort at that moment but during the study, participants expressed both their sense of comfort and the fact that expressing comfort is important. For that reason, I created a separate subcategory for My sense of comfort.

Similarly, the voice assistant is consolidated from data analysis. “If buildings could talk” has three categories reminder of building state (like state of the windows or doors), reminder of user actions (for example, remind the inhabitants if they forget to close the windows) and user preferences (The user could schedule the system based on their needs). “What if?” comprises of two categories: exploration or play (when participants mention that they would use the system to have fun or explore) and planning (when participants mention that they would use the system to plan). Finally, the general category comprises elements that relate or are common to all the interaction models. General categories are broadly divided into the following subcategories: multiple occupant comparison, I need this data, visualization, implementation, learning, missing features, scenarios, mode comparison and others. Most of the coding categories for this were emergent except for multiple occupant comparison and visualization.

### 6.4.4 Interface design

The interface design comprises five categories: Annoyance, barrier, trust, control and other. An annoyance is a small issue in the interface that can be easily fixed (like color, font size). Barrier codes the data when the participants do not know about their next step or when the design is detrimental to their actions or understanding of the content. Trust tries to understand whether the participants can trust the system. Finally, control tests if the participants feel they are in control of the system and its decisions. (See Figure 6.10.)
6.5 Reliability and validity

The study considers the three methods of triangulation, Data triangulation, Investigator triangulation and Environmental triangulation (Guion, 2002).

6.5.1 Data Triangulation

I recruited 21 participants in total for this study. Six studies were conducted for couples and six for individuals. Studies with couples revealed issues related to social context. The age group of participants’ varies and helps in identifying issues that are common to them. Also, participants were recruited from different backgrounds (for example, working or stay at home, engineers, designers, environmentalists) and this revealed the different operation of controls and understanding of building performance. Feedback suggestions varied, based on knowledge and experience. The study balanced sustainability-enthusiast participants with non-enthusiasts to moderate enthusiasts’ bias towards LWLA.

6.5.2 Investigator Triangulation

The main studies were investigated only by me. For the data analysis, my senior supervisor coded along with me for the initial set, and we agreed on the content. A second rater coded for three households (two couples and one individual). The data were partially coded and
considered two major sections of the study: adaptations made and interaction models. The inter-rater reliability was evaluated in NVivo 11 using Kappa coefficient and percentage agreement. I found that adaptations made has good agreement and interaction models has moderate agreement.

Table 6.1: Inter-rater reliability

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<th>Sources</th>
<th>Kappa</th>
<th>Agreement %</th>
<th>A &amp; B %</th>
<th>Not A &amp; Not B %</th>
<th>Disagreement %</th>
<th>A &amp; Not B %</th>
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<td>D1&amp;D2</td>
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AM is Adaptations Made; IM is Interaction Models

6.5.3 Environmental Triangulation

The study was conducted in different housing types (apartments, individual house, passive house, townhouse). Apartment and townhouse had similar issues with varying depth. Individual houses had different issues in context to size. While the issues were common across with different dwelling types, the depth of the issues varied. The issues were predictable after conducting the studies for three apartments with couples, but couples with children revealed different data. The study reached saturation for apartment after conducting six studies, and the data for individual houses kept varying.

6.5.4 Threats to validity

A few of the participants were known to me before the study, and their responses may bias towards satisfying me. During the questionnaire and task completion, I wondered if there were any questions that led the participants' responses. Generating simulation data took time causing impatience in the participants, and that may have influenced their responses towards LWLA.
Chapter 7

Findings

7.1 Inhabitants Profile

People have varied preferences for comfortable room temperature. Their preferences may depend on different aspects like body type, local climate, building type, past experiences, culture, and economy. Another influencing factor may be personal preference for comfort over cost, or vice-versa. The economy of the family may influence preferences, as a family with low income might have different investment and buying decisions. So, how do these factors affect inhabitants’ preferences of comfort? Moreover, to what degree do these factors influence their choice of actions? How can designers, engineers, and architects integrate personal, social and economic issues into energy models? Are these effects negligible or significant?

In the pre-questionnaire we asked specific questions related to comfort preferences, energy concerns, and roles in household decisions. Comfort preferences and energy concerns were quantitative on a scale of 1 to 10, 1 being unconcerned and 10 being very concerned. The participants were also asked to narrate their experiences. Inhabitants profile was themed to understand the inhabitants’ criteria that need to be considered for energy simulation. The key attributes are comfort preferences, energy concerns, roles in household decisions. We also discovered two other attributes during the study: any cultural habits declared and...
sustainability reasons. I support each with quotes from participants. The attributes for the personas are not limited to this section.

7.1.1 Comfort concerns

The driving question for comfort concerns is: do inhabitants’ decisions and actions highly depend on comfort? The quantitative study on comfort preferences\(^1\) confirms that comfort is an essential criterion for most participants. Figure 7.1 shows the frequency distribution of comfort rating ranges. 10 out of 21 participants said they were highly concerned (rating between 8-10), 7 out of 21 participants mentioned they were concerned moderately (ratings between (5-7), and 4 out of 21 participants stated that they were least concerned (ratings between 0-4).

![Figure 7.1: Frequency distribution for comfort preferences](image)

The qualitative data revealed two key points (See 7.2). First, body temperature personality. This is being addressed as a personality because inhabitants often identified themselves as a warmer or colder “type” in regards to comfort. Participants often mentioned that they were cold or warm “types”. Individuals who are “colder types” would want a warmer place; those who are “warmer types” want less heat. This is often a conflict among household members because of differing body temperature personalities. Secondly, seasonal comfort preferences, as comfort varied during different seasons. Few participants considered simi-

\(^1\) How concerned are you about comfort (like cold or warm) in your residence? Tell me when and how much you are concerned? Use a scale of 1 to 10 (1 - Unconcerned, 10 - Very concerned)
lar preferences for rainy, and winter seasons, hence these could be grouped as cold season. During winter, some participants prefer cozy or warm, and a few participants like to feel slightly cool. In Summer most participants said that the temperature was unbearable, these participants mostly lived in apartments while a few others stated that they would enjoy the heat at certain times of the day.

Figure 7.2: Key points on comfort preferences from qualitative study

Comfort choices of the inhabitants vary based on their body temperature.

(I am colder, and she is warmer!)

FM and FF articulate the reason for a multiple comfort model as their family has three children and have various comfort preferences. FM says that he is colder in comparison to his wife and he often needs to wear a sweater to feel comfortable. FM “And also to keep the relation in the warm-blooded organism, female and male have different perception, as in cold and warm. I am more a colder person, and she is a warmer person, she does not get cold that easily compared relative to me, even children will have different, the temperature we chose will be higher, this a parameter you need to consider when you are doing models like this.” He mentions that children’s temperature varies as well. The temperature an adult chooses will be higher in comparison to the temperature a child prefers or is comfortable with. Hence, he suggests the need for multiple comfort personas to resolve the issue. Participant
FM emphasized the need to consider differences in design that show the conflicts they are facing in temperature settings every day. Moreover, this highlights the need to know how to approach the situation. It is a challenge to consider multiple occupants with varying body temperature personalities for energy modeling.

Most couples mentioned that they had a difference in body temperatures preferences. One preferred warmer and the other colder. OM “I think this is not untypical, I often prefer it to be a little cooler than she does. But it is not like a constant turning up and turning down.” For some couples, it was a battle while a few others would adjust their clothing or compromise on the thermostat settings. Out of the seven couple and seven individual studies, only one couple mentioned their similarities in comfort preferences. GM “I think we like the same temperature,” hence, it was not a constant struggle for them.

Dwelling place needs to be warm or cozy when the weather is cold outside. (I like it warm!)

Most participants are concerned about the indoor temperature during cold weather. They took extra care to keep the place warm. FM “When outside temperature is very cold we try to see if we can make the house a little warmer but otherwise we try to use the lowest temperature we can.” Outside temperature influences the thermostat settings. LF also mentions she prefers a cozy place. LF “It is my aspiration to be cozy.” During the explanation of the winter scenario during the task completion study, participant NM mentions “wearing heavy clothes, thermostats at 20, am cooking and am feeling fine.” He concluded by saying that at that parameter he is comfortable. The comfort data displayed were for the passive house, and with those specific parameters, the place is hot according to the data. However, NM’s building condition is different, and he says the temperature will be fine for him. So, looking at the system scenario and its suggestion, he mentioned: “Well since I am warm I will just be happy that I am warm.” He further clarifies the meaning of warm to him, “When I say I feel warm, I am warm enough. Yeah, not too warm!” He says it “makes sense to be warmer.” Similarly, GF discusses the gas stove and its comfort. GF “I like the gas stove that we have. It makes the kitchen a lot warmer than the electric stove. It is just a preference for comfort.” GF compares the heat generated by the electric stove with
the gas stove and finds the gas stove contributing to more heat and comfort. In summary, the study shows most participants like their room to be warm during cold seasons.

**Dwelling place needs to be slightly cool during winter. (I prefer it cooler!)**

Very few participants preferred their room slightly cold during winter. **GM** and **GF** are participants with similar comfort preferences; they lived in an apartment that has a gas fireplace in their living. **GM** says, “I prefer it cooler and that you can always heat some up” and he argues that it is easier to heat a cool place than to cool down a warm place unless the apartment has an air conditioner. Most buildings in Vancouver are free running buildings, meaning there is heating and no air-conditioning. He states “Yeah, we like slightly cold.” but continues to say that he is active and that is also a criterion. “I like feeling slightly cold. It is careful to be safe, and it is not often like I sit and watch TV while **GF** does something else on a Monday.” He explains his situation for the day he is at home as he is often doing something. It shows that activity also influences him in wanting to feel slightly cold in the house. **HF** lives in the same apartment building as **GM** and **GF**, and she mentions that she likes it cold too. She finds the chilly air refreshing and says, “Cannot handle the closed in feeling.” On questioning about the kids, she mentions “they are not going to be cold.” Building type and the gas fireplace heating may have influenced these participants. Three units were studied from this same apartment building. Participants were all warm, and the study was conducted at various times of the day. Participants mentioned that the gas fireplace heats the whole unit fast. Hence, the gas fireplace could be one of the reasons for the inhabitants to prefer the units to be slightly cold or it could just be their comfort preferences.

While these units may be influenced by the gas heating system others mention that a colder place helps them sleep better. **FF** lives in a townhouse and says, “Just for a particular period, right now because we are not using any heat that is why the window is open because I like to feel a little bit cold that’s how yeah, I sleep better.” **FF** was speaking about their bedroom and how they like to keep it cool to get a better sleep. **LF** mentioned they keep the doors between living and bedroom closed to keep it cooler. **LF** “He likes it to be cold like cool when he sleeps and then during the day at certain times, I think I
actually, may be opened these doors before you came. But normally, recently, we have been closing them, and they stay, those rooms stay pretty cold.” People adapt and interact with systems during the winter to create a comfortable room temperature. Material comfort items like bedding may also influence the room temperature preferences. NM “Very rarely I like sleeping in a cold room you know sometimes may sound little crazy but sometimes I like the room really cold, I like that because we have a duvet and being underneath it, you can sleep really well. It is quite nice. We put a feather Deckbette on our mattress and a duvet, it makes you warm. It is like a cocoon, NM does not mind she kind of likes it.” In another instance, activity influences the person in wanting the place to be cold. During the winter scenario, a participant mentions they will choose the colder options suggested by the system. “Yes, if I am cooking it is very warm, I am using light clothes or warm clothes, I would prefer cold, the coldest one, probably the one over there, I would choose that.” The option chosen by the participant was not efficient. The option chosen had the doors open while the heating was on and that caused heat loss. However, on seeing the energy consumption data, the participant changed his decision. We further discuss this in the model preference. Here, what the participant wanted to convey was that during specific activities he would prefer the room temperature to be cooler.

Summer heat is unbearable! (It’s just unbearable!)

Participants reaction to the heat during summer was in unison. DM “I like warm in winter, but I am concerned in the summer when it gets like 30 degrees outside, then for me, it is sometimes major issues.” DM lives on the 7th floor of a tall apartment building. The apartment orientation is north-west and gets much sunlight during the end of the day. The apartment unit has no buffer from the heat, such as other buildings or vegetation. Moreover, there is also no cross ventilation or air conditioning to cool the unit during summer. However, DM also says “I have a bias too, I am ok with cold temperature, but I am not ok with warm.” Also, Vancouver buildings are built to retain heat, so most of the buildings become hotter during summer. Overheating is an important design issue to be addressed for the North American climate. EM “We go out, it is just unbearable, and we do not have air conditioning so, and the room becomes very hot right?” Most participants
mentioned that they go out during summer as the building is very hot and unbearable to stay in. IM says, “That the weather is good unless it is hot!” Most people adjust with a fan during summer; the participants surveyed did not use air conditioning in their house. On the contrary, IF said, “you have very few days in Vancouver in summer, you might as well as sit outside on the deck as often as you can.” Few participants mentioned that they would sit on the deck in the evening when the sun goes down, as the building is very hot. Participants adapted by moving to various locations to get comfort for short times.

7.1.2 Energy concerns

Are people concerned about the amount of energy consumed in the building? Does energy usage matter to them? When and why are they concerned about energy usage? To understand these questions participants were asked about energy concerns quantitatively and qualitatively. The frequency distribution for energy concerns showed that 16 out of 21 participants were highly concerned, 2 out of 21 were moderately concerned and 3 out of 21 were least concerned. See figure 7.3

![Figure 7.3: Frequency distribution for energy concerns](image)

The energy preferences were asked on a scale of 1 to 10, 1 - Unconcerned, 10 - Very concerned. Total number of participants were 21

The study on energy concerns revealed that most participants were concerned about energy usage during peak times in winter. Few others took energy decisions purely for

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2How concerned are you on energy use like electricity, gas in your residence? Tell me when and how much you are concerned? Use a scale of 1 to 10 (1 unconcerned, 10 very concerned)
sustainable reasons, and an elderly couple was concerned about energy usage because of low-income. Finally, there were some who were not concerned about energy usage (Figure 7.4).

Figure 7.4: Reasons for energy concerns

Mostly concerned about energy usage during winter due to building design.
(In winter it goes up a lot!)

Participants were concerned about power usage during winter. People are aware of energy usage through monthly bills and find it high during winter. DM “Yes, we get a monthly bill, so we can measure how much we consumed and sometimes during the wintertime the bill is quite significant.” DM also say that their concern is not related to money alone but also “I do not like to burn energy too much. Because like I think it is not good for the environment in general, so I try to keep it low unless it becomes uncomfortable for the living.” Comfort is still a parameter of influence for energy usage. JM and JF say they are energy conscious from the beginning. JM “We were conscious from the start.” They stated that living in Australia has made them energy conscious. JF “We lived in Australia. There the energy was super expensive. Over 200 dollars, right? For two months!” How a person handles the current energy usage depends on past experiences in usage.

While few participants mentioned concerns during winter, some participants were highly concerned because of the building design. KF lives in the Burnaby mountain, and she stated she was mostly concerned about energy during winter because “this unit has very high ceilings and it becomes very difficult to keep it warm”, and it is “expensive.” She says that the bills they get are “really erratic. We do not actually know how much they will be. It is unexpected sometimes. Especially in the winter, we find there is a huge peak, and we do not believe in heating too much.” KF’s apartment unit has a lot of heat loss because of the high
ceiling and large glass windows. They do not have thermal blinds, hence heat is not being retained in the building. Since she and her husband work they do not use heat much but get high bills. She was wondering why that was happening. KF says “We are not the couple who leave the heater on 24 hours a day. We switch it on and off on a daily basis multiple times. If we leave the house, we switch it off. Moreover, even when we put it on, we put it on at a very low setting. Considering that we hardly use any heating, we get very high bills in the winter.” She wanted further detail on her energy billings. She further wanted to understand why the bills were so high. KF also lives on the first floor—because hot air rises they are spending more energy than the upper units, and the building design does not help as well. “We find that we never get to see the meter for electricity. We do not know what our usage is. And we do not know how the strata divides its electricity bills among its residents.” KF also narrated an instance where the energy bill was very high (around 600$-$700$), and she mentioned that space was tiny but got a very high bill. She said she was not able to recollect how it was resolved and said it was an error or something. Similarly, LF “Our heating costs here are really expensive.” LF stays in an individual house with no proper zoning and mentions that the heating cost becomes high during winter. When moving to a new building a person needs to adapt to it comfortably. MM lived in the house only for 16 months and said: “In our first year, the electricity bills were quite high and they have come down this winter mainly because we have toned down.” The reason here could be that the participant took the time to understand the interaction between building elements and systems.

**Participants are energy conscious purely for sustainable reasons.** (I am concerned for sustainable reasons.)

People are interested in saving energy because of sustainable influences. OM “I guess fairly concerned and increasingly concerned as the energy cost goes up and as the importance of sustainability increases.” OM is also concerned because the energy cost is increasing. QF is an active participant in sustainable activities. She is simply concerned about “the environment” and explains “this house is single-paned windows and not very insulated, so I know it is a leaky house, energy leaky and I do not like to keep it too warm because I
know the energy is going out. So, the only thing I did last year, I replaced the roof, and I added a number of energy efficient windows upstairs, and that made them a lot more energy efficient.” Her main concern is the leaky house, so to keep it sustainable she reduces the heating. Inhabitants who have energy usage included in the rent have no reasons to be concerned with energy consumption. EM’s energy consumption is included in the rent, and it does not affect the monthly expenditure, so he says “I mean just for being green, that is the only reason I am really concerned.” FM reasons more with climatic conditions of Vancouver “during the winter time, beginning of the spring also, darker hours mean that you have to use more light relative to summer time. My point of view how concerned I am, I am very concerned, yeah we know that climate change is going on and we need to change our behavior and preference need to minimize the use of energy.” Being aware of sustainable issues and approaches may influence the people’s behavior and choices of actions.

Low income influences the people’s decisions on energy usage. (Limited income, so we keep our costs down)

IM and IF are senior citizens and have low income, so they are mindful of energy usage. IM “Limited income, so we try to keep our costs down.” They had been living in a house that was not well insulated and recently moved into a well-insulated apartment. IF says that well-insulated buildings have lowered their “heating bills even though this is larger, is probably half of what it was before.” She often mentions that she prefers to make her decision as she is the one who is more aware of the economic problem in their household. We did not have many participants who had low income, so it would be good to study a broader sample with different income range and energy usage constraints.

Few participants are less concerned about energy consumption in the building because it does not affect the cost. (Not concerned, gas is inexpensive!)

PM lives in a passive house and says “So it is nice to keep your bills low. But I do not think we stress about it too much. We just want to be warm and comfortable when we come home.” Comfort is a priority for him compared to energy. A person not worrying about energy consumption in a passive house might be influenced by the design itself. Similarly, GM says that they do not use “much heating” and have “better light because we are
“facing the sun more.” GM “Yeah, am not pretty concerned. The gas is pretty inexpensive. It is quite cheap. The electricity we switch off lights the whole time. We do not worry about it.” The participant had lived in the house only for few months, so he was not able to give an experienced answer about the usage during different seasons. The participant may not be worried about the energy consumption because it is cheap or renewable energy. The households that we studied did not have any renewable energy incorporated into their building design apart from the passive house discussed above. Hence we do not have enough data to discuss the influence of renewable energy and its influence on energy consumption.

7.1.3 Comparing comfort and energy concerns

We had seven couples and seven individuals for the study. To compare the data among families and within families, we separated the data into two charts, couples and individuals. Figure 7.5 compares comfort and energy usage for couples. We found most participants are more concerned about energy usage than comfort, while others gave an equal preference for comfort and energy consumption. The comparison between the spouses gives clarity in their perceptions and preferences for energy usage or comfort. Figure 7.6 illustrates the comparison for the seven individual participants who took part in the study. The data is rich for couples due to the variance in preferences for comfort and energy. If the study had children as participants than there would be more complexity in comfort preferences.

Inhabitants questions on what they could do to be comfortable and save economically. (What could I do to be comfortable and save economically?)

Most participants either preferred comfort or energy but few gave equal importance to both energy and comfort. Conversation with an elderly couple concluded with a question that a system needs to consider “What could I do to be comfortable and save economically?”

Researcher: “Between comfort and economy which one would you choose?

IF: “Probably it is both.”

IF: “But the other option is also what could I do to be comfortable and save economically”
Figure 7.5: Comparing comfort preferences and energy concerns for couples

Figure 7.6: Comparing comfort preferences and energy concerns for individuals
7.1.4 Role in Household

The study on roles in household decisions concerning energy usage and comfort concerns revealed the decisions are equal among the spouses and, in a few cases, people who lived at home had more control over decisions.

Mostly Equal

Primarily me (As I stay at home)

Figure 7.7: Main points in Role in Household decisions

The decisions regarding energy and comfort are equal among participants. (It is equal!)

Most participants mentioned that no specific individual takes the major role. DF “’no one person would make a major decision, and so it is both of us. FM says “we play roles, differently. FF is more in charge of the bills and reducing the consumption; I am more concerned from the environmental point of view.” He continues to say that “even children like the older daughter she knows the importance of energy conservation.” GF says it is “both of us.” GM continues by saying they have conversations on why “electricity bills are higher” and discuss why the “electricity was higher this month, or maybe we need to switch off the lights more or something.” GM says they reason out the issues together and how to take sustainable actions. GF “it is good for me to know that so that I can take that into consideration.” Conversation between the spouses helps them in understanding affordability and decision making.

Primary decisions are made by the individuals staying at home. (I am the one who drives it!)

IF is an elderly participant, who stay mostly at home while her husband travels a lot. She says, “it is me because I am here more and you (her husband) are out more.” QF is

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3Who plays the major role in your family on the decision concerning comfort and energy use? Why do they play the major role?
an elderly person too; she says her “husband is away a lot” and she is there mostly at home. QF “So, I am here most. My daughters out and my husband works in Toronto. So I am here.” In the two situations, the participants make the major decisions as they stay at home. MM, a middle-aged participant, also mentions that his wife who stays at home makes the major decisions. He says that she likes to “go barefooting around because warm floors are attractive” it drives her to take the decision. Comfort is a driver here. HF says, “I am the one who drives it but then my husband has a different temperature level than I do. So, he cranks the heat up more than I do.” Even though HF mentions that she takes the initial decisions, her spouse’s body temperature drives the decisions as well.

7.1.5 Cultural Habits declared

Cultural habits declared is where people narrate their experiences related to a particular city or country. We specifically noted down a few that surfaced during the study, where the participants spoke about their energy experiences, clothing type, etc.

![Figure 7.8: Key points on Cultural Habits Declared](image)

**Past experiences and habits affect the decisions on energy consumption. (It is engrained in you)**

HF discusses her past experiences with high bills; she comes from Ontario. She says “In Ontario, you have to pay for your hydro, but it is a lot more expensive than it is here.” She lived in a house that was leaky and that had caused her to be energy conscious. HF “So coming from there to here, like it is ingrained in you like a young child that you have to be conscious about it.” So, it has built a habit with her. HF “turning lights off, turn the heat down when you are not there, save as much energy as possible.” Similarly, JM and JF lived
in Australia before they moved to Vancouver; the electricity was expensive there, and so they were trained to be aware of on how the energy is spent. JM “We were really conscious from the start.” JF “Yeah, we lived in Australia. There the energy was super expensive. Over $200, right? For two months.” Moreover, she also discusses how she forgets to turn the heating on because she is from Mexico. They do not have heating there, so they wear a sweater if it is cold. JF “Yeah, we always forget like Mexico, it is not common to have any heating or anything.” While demonstrating the “I feel” model one of the participants mentioned that her friend who moved from the Philippines dressed light as she used to dress in the Philippines and increased the heat to a comfortable room temperature. A specific study of culturalism and its influence on adaptation will give clarity to guide people in making energy conscious decisions. Vancouver is a multicultural city, and such studies will help in understanding the adaptation of individuals who migrate from different nations.

QF: “We are not amphibians. We cannot self-adjust our body temperature.”

Researcher: “but that is why we need to do certain things. Certain things are more actionable, actions taken by you. But we want to make people make their choices because otherwise what you know is what you are going to be influenced by people maybe by seeing more data.”

QF: “Yeah”

Researcher: “and with all the studies I have done I can see people with their knowledge from different countries …they carry that through and the way they use the building has an enormous impact on their actions.”

QF: “absolutely a friend of mine a Philippine always dresses in light dresses and flip flops inside and has her temperature turned up because that is how she was in the Philippines. She wore like dresses and sandals.”

7.1.6 Sustainable actions

Sustainable actions are when participants made changes to buildings or had thoughts of saving energy. We identified two factors related to sustainable actions: retrofitting and sustainable decisions.
**Sustainable actions during comfort adaptation.** *(If we decide to open the windows we will turn off the thermostat.)*

During the study, a couple mentioned how they would shut down the thermostat before opening the windows to save energy. **DF** “I was thinking about the previous case, whenever it is hot, and we are probably cooking, even if we decide to open the windows we will turn off the thermostat first.” **DM** “Yeah that is right.” **DF** “Because we do not want to waste the energy.” Turning the thermostat off before opening windows during winter was not a common action (See Section 7.)

**Participants retrofitted or changed building structure or elements to save energy.**

**LM** lives in a individual house, a not a very sustainably designed building. The building had thermostats in every room, and it was not well zoned. They had a staircase leading to the attic, and there was no door between these two rooms. Since **LM** was an engineer, he did a small smoke test and found there was leakage through the attic. He temporarily made a trap door out of cardboard between these two rooms and said that changed the temperature level in the living room. **LM** “When you walk past the attic, the stairs lead to the attic from the middle of the house. Also, when you are walking past it, now it feels warmer, but before it was colder, and I have noticed that in the summer we get hot up there, we just open a window and its fine. Also, starting September and October, the heat started coming on, and I remember noticing that heat’s on and hot air rises. Everybody noticed that. Also, the attic is cold up there. And that is when I wondered ’Ah this is a waste of heat’” So, he concluded that it is going to save them a lot of energy.
OM talks about using an energy efficient eco fan that works based on renewable energy. OM “It is a mild climate and so often in the winter unless it is cold we have to physically open the sliding glass door to let cool air in because it is too hot in this area. We do have a little eco fan that sits on top of the cast iron stove.” He further explains “It is heat based, so there is no electrical requirement, so it generates its own, because of temperature difference and it is marvelous. It takes about technically 15 mins for the stove to get hot and then it starts to cool the place around.” They use an eco fan to cool themselves during winter as it gets hot. He also speaks about the adaptation he made to reflect the sunlight during summer. OM “On the other hand, we have an essentially enclosed porch that is 95+% glass, and then in the fall and spring, it is wonderful to go and sit out and enjoy the outside without being outside. And then in the middle of summer, it gets too hot, much too hot to enjoy. So, it is basically a shed, a green shed shaped greenhouse against the house and so on the top slanted part, I have fitted eight different very large sheets of cardboard with aluminum foils reflecting on top of it, that reduces the temperature probably by 10 degrees.”

These participants spoke about the adaptation to the buildings and buying energy efficient appliances, while GM talks about replacing to energy efficient bulbs. GM “One of the things we have done, as light bulbs burn out, we put energy efficient bulbs because the efficiency is higher. We bought a whole bunch in the US. It is cheaper there and subsidized by the company, the Costco ones, a whole lot of them.” GM raised an idea for the system to suggest replacing existing or burned out lights with rates and efficiency details. Adaptations happen from micro to macro details in buildings.

7.1.7 Others

Two attributes surfaced during the study that became part of inhabitants profiling, Party person, and indoor plants. One participant mentioned that he was concerned about comfort when entertaining guests. PM “We spend more time entertaining guests. So, having a nice dining table because we cook a lot was really important.” The participants also spoke about the spatial arrangement of their couches and dining table for entertainment. PM is also very fond of plants; he mentions that its need much sunlight and plays a “huge determining
factor” if he moves to a different house. Having indoor plants can affect the interaction with building elements. For example, in summer, PM “During the day, we usually leave the blinds up because of the plants.” PM lives in a passive house and gets much sunlight during the day. In summer it becomes hot, but they do not pull down the blind to block the heat as the plants need the sunlight. Hence a person’s hobby or interest will affect their adaptations.

This section summarizes a few key points with respect to inhabitants’ profile, but other attributes emerge from adaptations made.

7.2 Adaptations Made

Adaptations made covers six significant adaptations in the buildings. Personal adaptations are the adaptations an inhabitant makes to themselves to feel comfortable, like changing clothes and activities. Technology and built environment consolidate the adaptation an inhabitant makes to the built environment to achieve comfortable or desired room temperature (for example opening windows or increasing the thermostat). The Spatial arrangement and control locations show how the locations of the controls facilitate or hinders sustainable interactions and decisions. In agency, we discuss the disruption buildings cause in adaptation. Design and construction is a significant topic that focuses on inhabitant’s understanding of the built environment and their reasons for actions. Finally, in social context, we discuss how inhabitants collaborate, consult or have conflict with other household members. We also discuss specifically children and their influences in comfort adaptation.

7.2.1 Personal Adaptation

Personal adaptation describes the adjustments the inhabitants make to themselves to be at a comfortable temperature. During the study, the participants mentioned how they adapt during the different seasons, like winter, rainy and summer. We have broadly categorized the adaptations into clothing type, activities, and spatial relocation. Our literature study on the various thermal models (see section 3.2.5) identifies the two variables, clothing types
During the study, we noticed that participants discuss how they use clothes in general, and the most frequent word for clothing insulation were sweater and blankets. The occurrence of these clothing adjustments might be because the study was at participants’
residences. An office environment could have brought the participants to discuss different clothing insulation types. For activities (metabolic rate) the participants discussed the following things that would keep them warm or cold; drink/eat something hot/cold and shower. Lastly, spatial relocation emerged from the study and is not a variable in the existing thermal comfort models. Figure 7.10 summarizes the personal adaptations observed with the participants during the study.

**Clothing Types**

How do people dress for discomfort? Moreover, why do they dress in that manner? How do they reason their clothing adjustments? Vancouver houses people from different cultural backgrounds; understanding how they adjust to cold weather would be a great asset for modeling tools. During the study participants were questioned about the actions they would perform during the winter, rainy and summer season. General questions to understand were: What do the inhabitants do when they feel cold? How do they resolve the situation when one person is warm and the other is cold during winter? The data were collected through semi-structured questions, as few participants remembered or recollected their experiences during task completion. For further details on questionnaire see Appendix A.

**Few participants do not mind layering during the cold season.** *(I do not mind layering or Sweater for me!)*

Types of clothing vary in a home environment, and only a few participants mentioned that they would not mind layering. To the question “What would they do when the room is cold?” these participants responded that wearing a sweater was their first preference. During the study, DF mentioned that she would also consider wearing a sweater as opposed to her husband who does not like to wear sweater DF “*I will do the same as DM but also put on a warm sweater, socks.*” GM and GF had similar comfort requirements as opposed to other participants, the immediate response to the questions was, GF “Sweater for me.” GM “*Yeah, we do wear like long sweaters, but we do not like the house too hot cause we sweat. I think we like the house cooler.*” They both prefer the house to be a little cooler during winter. Their habits were not sustainable because they had their heater on while
leaving the doors open. Often to keep the building cool they would leave their gas fireplace on while leaving the windows slightly open. In this case, wearing a sweater and leaving windows open during winter is not sustainable. Initially, they mentioned that when they are cold, would turn the thermostat up and wear a sweater, but also mentioned that they do not mind layering when they are cold. **LF** “Yeah a little bit of both. Sometimes I have a thick lumber jacket kind of a sweater have been wearing recently. So yeah, I think that neither one of us feels that we need to be comfortable in t-shirts in the house. We both are into like put on some layers.” This couple were comparing wearing heavy clothes with light clothing. And were the only couple who mentioned that they do not mind layering. The natural tendency of people is to wear light and comfortable clothing at home. The reason we did not have more participants discussing this could be because of the age groups. If the study included teens and youths, there might have been more insight regarding clothing because their lifestyles are different. And also, they do not have responsibility in paying bills. **LM** further argues that people who feel cold are the ones who do not wear the sweater. **LM** “Not really, Well sort of. But, in my mind, people are always cold, but people are people who are used to wearing sweaters when it is cold. You know it is cold let’s put the sweater on”. **IF**, a senior citizen with low income mentions how she raises her comfort without affecting her economic level. **IF** “You know, in winter it is quite easy. I would put more on, if the sweater is not warm enough, I would pick my cashmere shawl and put it on, I can raise the comfort level without changing the economic level.” **LF** was pregnant at the time of the study, and she mentioned that changes in body temperature affected her actions. She says that layering helped her to be at a comfortable temperature during pregnancy. **LF** “I think also being pregnant, you cannot regulate your body temperature as well so like sometimes I will be like really hot or really cold. So, the other morning, I was shaking and shivering because I came out of our bedroom which was really cold. I guess I just put on some bunch of layers and I got warm. I sort of like rarely fiddle with thermostats. He tends to do more of the thermostat stuff. I am more like just on put on layers. We do not tend to have many conflicts related to heating.” Layering helps participants’ comfort by adding or removing clothes. **NM** “But if I think If I feel too warm, I would say I would take something
off.” HF narrates another perspective where she mentions that her husband “wears his hat in the house so I am ok with that so that he can stay warmer” Adaptation varies for different people.

During summer participants dress down to light clothing. (Takeoff everything or dress down to shorts.)

During summer participants mentioned that they would dress light or take off clothes when they feel hot. Here are few quotes from the study DM “If it is hot, the first thing we do is, I would take off everything I can take off and yeah, first of all, make sure we do not wear anything heavy and then probably open all windows. DF is that right?” To the same question, IM “Yeah. I would probably put some shorts on.” IF “But you would have already dressed that way to start with.” In, Vancouver during summer we have only a few days that are hot, and people manage the heat with light clothes or go out to mall or restaurant, or they might use electric fans to cool themselves. Clothing type during summer may vary among different cultural backgrounds; during the study we could not cover all the different types.

The nature of activities affects the clothing type. (If I am cooking will take off a layer.)

FF is a sustainability enthusiast. She mentions that she would remove her jacket if she finds it warm while cooking. FF “Basically I am cooking I take the jacket off,” she narrates the process of her choices in actions FF “For example, I was trying to picture myself. During winter, when I wake up, I still feel cold. I will wear my sweater, and I will start cooking, and once I am cooking I feel warmer, and I take the sweater off, and If I still feel that I am warm then I would lower the thermostat, and still feel warmer I would drink something cold.” She narrated her process of choices of action to make herself comfortable during winter. Her choices of actions are sustainable and constructive as opposed to her husband who mentioned that he would open the window or door when he feels hot during winter. He also mentions that he would open it only for few minutes. IF is a senior citizen and she mentions how working affects her choices between thermostat and sweater. IF “And it depends on what am doing. If I am doing physical work and am cold in here, I am more
likely to turn the thermostat up. However, I am sitting and reading and thinking usually, and he is working doing something and thinking if it is not cold in here, I will tend to put more clothes on.” The participant highlights a key point for activities. If a person is doing a physical activity and they are feeling cold, it could be either be health issues or simply they need to turn up the thermostat. 

GF “I think that normally I would cook in medium.” The participants expressed their preference for dress while cooking. DM throughout the study mentions that he would open the window or door if it is hot during winter. He mentions that if he is going to be cooking for long hours, then he would wear light clothes and open doors. DM “If I have to keep cooking, then like doors and clothing.” He kept mentioning this during task completions for different model types. DM “So the room is warm, what I would do is first I would put on something light, that is for sure, and then if I am cooking, I think we should open some windows. What do you think?” However, his choice of action changes once he sees the data comparing actions with energy consumption. NM “wear a sweater but then if I am working at the desk and I find it the desk is too cold and my arms are getting cold then I would turn on the heater.” NM also describes how activity influences his thermostat setting.

Agency affects the participants clothing type

EF mentioned that their previous apartment heating was centrally controlled, and the building was hot during winter. EF “Here you have to wear slippers or socks, but in the previous apartment, it was so warm, that we walk on the warm floors, and usually, you go to kitchen its warm, you go to the bathroom its warm.” She mentioned they walk bare foot in that apartment as it was hot, and they had no control over the mechanism. Agency may determine the pattern of dressing. Though only one participant mentioned this issue, it can happen the other way around too. If people do not have good access to their control it can result in other adaptations.
Sweater

Participants wear a sweater because it is freezing/very cold. (I put on a sweater)

Participants wear a sweater when the weather is cold outside (I put on a sweater). Considering the Vancouver climate, colder months are less severe compared to other colder cities or countries. So, people can manage with light clothing. But when the weather is cold outside, they wear a sweater. **FF** “If it is cold I will check and see the thermostat, to see where the temperature is if the temperature is very cold. I just turn it up a little higher, and I also wear my sweater and ask the kids to wear sweaters and socks especially to keep them warm.” **FF** mentions that if she finds the outside weather cold then not only does she wear the sweater, she asks her children to wear them too. This answer was to the question, what do you do when you are very cold? Most people replied that they would wear a sweater. **IF** “Wear a sweater,” **NM** mentions “To feel more comfortable?” that he will “wear warmer clothes.” He continues “or put on a sweater or a fleece jacket. I will you know dressing appropriately is a good idea. Also, if I feel really cold I would go, we have a programmable thermostat, If I am here and not where am expected to be, and if it is not too cold I will turn off the thermostat.” **NM** also highlights that if the room is not too cold dressing appropriately will resolve the current discomfort. **PM** mentions that changing clothes solves his discomfort. **PM** “I would honestly think all I have to do is change my shirt.” **PM** lives in a passive house and has converted the garage into working space. The garage does not have a heater, and he manages his time there by wearing a coat. **PM** “There’s no heat, and it is cold in there all the time, So I wear a coat in there.” **QF** mentions that if it is cold, her primary choice would be to wear a sweater and then she will consider other options. **QF** “Definitely, a sweater and then a coat”. For **QF** her first preference is to wear sweater. **QF** “No. If it is really cold that day, I will put more clothes on, or I will start a fire in the kitchen and close the fire.” Wearing a sweater in the house is questionable as few people would like to wear comfortable clothes but few participants mention that they would wear sweater only when it is very cold. The sample was not large enough to evaluate quantitatively how many people would use sweaters for comfortable clothing. **LM** “Well, I just cover it, wearing long underwear. In winter time it makes your
whole body feel warmer. Except for cold chest, cold toes and hands that I always used to have during winter times were resolved by wearing long underwear. So yeah that’s one of my things. And I just wear the sweater. I always wear them.” LM expresses his comfort with garments that keep him warm during winter. LM’s house is drafty as it is not well insulated. A building’s condition will also influence the inhabitants’ clothing type.

Participants wear sweater when there is a conflict in comfort preferences. (She or I will just put on a sweater.)

Participants wear sweaters mostly as a trade-off or as a compromise during conflicts in comfortable room temperature. IF and IM are senior citizens with different comfort preferences and IF mentions that she compromises on her clothing when her spouse is around. The person who feels cold seems to be making the adjustments as people who are warmer cannot do anything in that scenario. IF “Because he is usually warm. I am the one that is always cold. So, I just, as I have gotten older, I have switched to wearing woolens or alpaca which is even warmer than wool.” IF mentions that as she has grown older she has developed a habit in her of wearing warmer clothes. Her husband adds that he wears slippers and shoes. IM “Yeah. Also, I keep my shoes on or my slippers on.” Comparing the situation here where IF needs to layer more compared to her husband. Here’s what another participant DF says “Yeah but for cold, we try to reach a compromise so than something that will be more comfortable for DM and something that will not be too hot for DM and something that would not be too cold for me. Maybe I will put on more clothes then it will be ok, so he is in a tee shirt, and I am in a sweater.” In another instance, IF continues to say that she would adjust her clothing when there is a difference in activity between them. “And it depends on what am doing. If I am doing physical work and am cold in here, I am more likely to turn the thermostat up. However, I am sitting and reading and thinking usually, and he is working doing something and thinking if it’s not cold in here, I would tend to put more clothes on.” Activity affects the body temperature, and that defines clothing. OM “No I mean it’s a very typical issue between husband and wife right or between one person and another who are living together, adjust the thermostat a little
bit, if it is really quite cold we will put on an extra layer of clothing, we got a wonderfully warm thick sweater, I’ll put it on if it gets uncomfortably cold.”

IF’s thought processes on interaction affected her adaptations; she felt that changing the settings often is not okay for the mechanism. IF “I do not think it is a good idea to put the heat up and down, up and down. So, even in my office, because that room is not heated, if it is too cold in the day, I just put my sweater.” Most participants mentioned they would wear a sweater. It is a typical scenario between couples. However, does continuously updating the thermostat affect the performance or is it a misconception? Here are few other quotes from participants. LM “I get up and say It is cold in here and then meanwhile I am standing there, and I feel cold, so I will be like it is not cold to her. She will put on a sweater, have a shower or something.” The study observed that people who feel colder are the one that makes the adjustments. KF “That happens very often. Well, the person that is warm will tell the person who’s cold to wear a sweater.”

A sweater is the first choice for few participants if they are sustainability enthusiasts. (I wear a sweater and ask the kids to wear sweaters.)

During data analysis, several participants said their first choice is to wear a sweater when they feel cold. They also encourage other members of the household to do the same. During the study, it was observed that their background was either related to energy or was involved in sustainable practices. FF, HF, QF are sustainability enthusiasts while GF is moderately enthusiastic about sustainable actions.

FF and FM live on the first floor of a townhouse built with concrete walls while the second floor has walls constructed of wood. FF is a sustainable enthusiast and an active participant in the sustainability community. Her being a sustainable enthusiast affects their choice of actions. Her husband is also an active participant in sustainable actions, but his health conditions influence the choice of interactions and actions. When FF feels cold, she mentions her first choice will be to wear a sweater or a blanket to make her feel warm. If she continues to feel cold, then she will increase the thermostat settings. However, they also mention that one time the heater was broken, and it took a couple of months to notice it. However, irrespective of the situations, their choice is to wear sweater first. FF “First thing
I do is, I wear a sweater if it still cold I will go and check, one time it was broken.” FM “the heater.” FF “But first I go and wear a sweater because I like to feel a little warmer and take a blanket and put it.” FM “Yeah she likes to hibernate like a bear.” FF “I wear a sweater and a blanket, I like that” FM “Yes, we wear a sweater.” FF is a person who likes to feel warmer, and this also drives her action to dress in a sweater. She is the main motivator in making other family members to make sustainable actions. During colder season, she discusses checking the thermostat and increasing it if it is lower and encourages her children to wear sweaters and socks to keep themselves warm. FF “If it is cold I will check and see the thermostat, to see where the temperature is, If the temperature is very cold I just turn it up a little higher, and I also wear my sweater and ask the kids to wear sweater and socks especially to keep them warm.” Her husband wears sweater most of the time due to health issues and also because FF is a warmer person.

HF is a sustainable enthusiast too; she is working on monitoring energy consumption and committed to sustainable activities. She lives in an apartment that has an electric and gas fireplace. Her house was warm during the study, and her thermostat was set to a low temperature. She also mentioned that they get heat from the neighboring houses. HF “Yeah but during the day if anyone is cold we just put sweaters on and wear slippers.” In her house, most of them wear sweaters if they feel cold during the day and they turn up the thermostat only during the evening times. HF “Yeah, it is more with the sweater than the thermostat. They stay at 0 until the evening then maybe turn it up a bit to warm up the house then we turn it off when we go to bed. So, then it stays warm pretty well.” The study conducted at the three units in the same apartment building had a similar response to heating. They mentioned that gas fireplace was enough to heat the whole apartment. HF mentions that if a person is feeling cold, they make them wear sweaters, hats, etc. HF “then we make that person wear sweaters, hats, yeah unless they are freezing. It has never come to that point where it is like you need a jacket, and if it is a light jacket, then we turn the heat on.” She mentions that there was never a time when they had to wear a light jacket. If it comes to that, then they would turn the thermostat up. She also mentioned that they leave the windows open during the night time in winter to feel comfortable. On questioning about the
thermostat setting, **HF** mentions “we would not turn the heat on. Yeah, we just put extra blankets, turn the heat off, and open the windows. Yeah, we sleep with our window open, but then the kids’ window is not open.” Here, building and heating type facilitates their action. The three units in this apartment were warmer when compared to other apartment units considered for the study. Hence this could be their reason for adaptation.

**GF** lives in a similar apartment unit as **HF**, and she mentions that her first choice would be to wear a sweater before turning on the thermostat. **GF** and her husband are involved in sustainable activities, and both of them wear a sweater during winter. **GF** “I put socks on when it is cooler in the morning. My first thought is to put a sweater on before switching on the fireplace.” When the apartment is overheated during winter, they choose to leave the windows open and wear a sweater. On questioning about the thermostat setting, they mentioned that they would leave it on as well. This is during colder periods, but a question is how sustainable are their actions and are they aware of the effects? When offered an explanation of how their actions affect the heating demand and cost they mentioned that it does not matter because the gas is cheap. I would position **GF** as average enthusiast toward sustainable decisions as their choices lean more towards personal comfort. Wearing a sweater and lowering thermostat is a more sustainable action than wearing a sweater and opening doors or windows.

**QF** lives in an individual house and prefers to wear a sweater over increasing the thermostat. She also mentioned that her house was friendlier to personal adjustments than adjustments to building systems. **QF** “put a jacket on a sweater or a jacket and then if I am still cold, I will put a fleece on over that. I have lots. If you walk into my house, you would see coats everywhere. It is a coat house. I have different layers of jackets so, and then I will put some slippers on, and I will pull my sweatpants above my jeans and put a blanket. Only after I do all those things if am really cold I will turn the heat up.” **QF** is a very active sustainable enthusiast in the community. So, yes, coats were hanging in her house!
Participants wear sweaters because they are reluctant to change the thermostat as it delays heating to a comfortable room temperature or the interaction is complicated.

An exciting part of the study shows that participants would wear sweaters not for sustainable reasons but for technology issues like thermostat or delays in getting a comfortable room temperature when raising the thermostat. MM’s house is not a passive house, but the building is well insulated with double-pane windows. MM says he would make adjustments to the windows or clothing rather than operating the thermostat. During the interview, MM wore a long-sleeved tee, and he mentioned he would dress like this when he was going out. His clothing looked warm. MM “I think I would probably dress like what I am now. I would probably wear a sweater; and in another season, I would not wear that. The programmable thermostat, we do not touch it much so pretty much I do not think we would not adjust anything inside and the only thing we might watch is open windows, but it is not like it be going to a cold day we try out, and on a warm day we turn it down. We just let it run. Ya so the only thing in it would be we might latch up the windows open and I mean the clothing I wear is more anticipating to go outside.” He mentions that he would not adjust the programmable thermostat as it is complicated. MM “Well, the furnace is on. Probably October through May when it is on its keeping it at a comfortable temperature. Again, in the shower season as when we like have a bit of debate on turning the furnace off my spouse will say no no no, we will leave it on for another two weeks or so until it is warmer. So, once it is off, then there might be a cooler day when we know we sit back and say cooler. And then the action what we would do is sometimes MF will turn on the furnace for a few hours in the morning and turn it off. You know the other action would be putting on some warm clothing.” He also mentions that his wife barefoot. While one participant is wearing a sweater and the other is not, it influences not only the thermostat setting but the behavior of the other person. Wearing a sweater is a sustainable action but lowering thermostat will reduce carbon footprint. The question is “how can we make the interaction easy?”

PM lives in a passive house with an energy monitoring dashboard. He mentions that turning the thermostat up does not have immediate effect hence dressing well is a better
option. PM “We had some issues, so we just bumped a lot and wore slippers. Ya. Moreover, because it is a heated concrete slab you are not going to get a really fast reaction so if it is too cold just turning up the thermostat will not have an immediate effect, so the first reaction is to dress appropriately.” Changing or making personal adjustments to themselves gives more immediate comfort satisfaction than increasing the thermostat. PM “We just dress appropriately. We change what we are wearing.” He also explains if they face a situation where the room feels hot they would open the windows rather than lowering the thermostat. He also reasons out how an activity affects their comfort. PM “I think it was because we were out exercising, and it was really hot because you know if you got to bed, when you are cold you become warm and when we go to bed hot it is hot all night. So, we open a window. Yeah.” PM “I just slept on top of the covers.” Simulation system does not show the time delay in getting the room to a comfortable temperature. How long does it take to heat the room is still a puzzle!

One of the participants mentioned that he would wear a sweater if it’s just him. (I will put on more clothes if it is just me!)

One participant mentioned that he would wear a sweater if it is only him at his house but if there are other people he might change the thermostat. MM “The difference would be I would probably put on more clothing, but if there were others in the house, I would probably increase the thermostat.” He narrated an instance when his father was visiting in which that he had to increase the thermostat because his father is old. Multiple occupancies affect adaptation preferences.

Wearing a sweater is not a personal preference. (I do not like wearing a sweater, but I should!)

DM mentions that he does at like to wear a sweater at home; this finding is important because there might be more people like him. They might prefer to increase the thermostat rather than wearing a sweater. DM “Drink something hot: yes, but I do not wear a sweater I should, but I do not.” KF says that they wear a sweater mostly because the air gets very dry. KF “Wear a sweater. That’s honestly just because we both feel it gets very dry. So, we
try not to put it on, but sometimes we have to. So those are the days we put it on. (I wear it because I need too.)” They wear it mostly because there is a need.

Due to health problems, the participants have to dress warmer. (because of health issues, I need to dress warmly.)

FM argues that his spouse is warmer compared to him. He also says that his health problem adds to it. He mentions how he needs to dress warmer as compared to his partner. FM “She is not cold right, I use socks most of the time, and she does not use it. Also, the degree of health issues and I cannot be allergic to the cold right? I need this (sweater) because of the cold too, I need to be a little bit warm sometimes.” The conversation expressed the participant’s frustration in not being able to increase the thermostat as it will be uncomfortable for another person. LF was pregnant during the study; she expresses that pregnancy affects the body temperature. LF “I think also being pregnant, you cannot regulate your body temperature as well so like sometimes I will be like really hot or really cold. So, the other morning, I was shaking and shivering because I came out of our bedroom which was really cold. I guess I just put on some bunch of layers and I got warm. I sort of like rarely fiddle with thermostats. He tends to do more of the thermostat stuff. I am more like just to put on layers. We do not tend to have many conflicts related to heating.” LF also mentions that temperatures may vary for people like having cold hands or going through menopause. LF “Some people wear sweaters, but their hands are always cold. Like some people are like that. Some people are hot all the time. Like when women go through menopause.” Health or body type will affect the body core temperature, and people need to know what to do to keep themselves at a comfortable room temperature.

Primary action will be thermostat, and secondary action would be changing clothes. (First, we turn thermostat up or down and then we change clothing.)

Many participants mentioned they would keep the thermostat on and then adjust the clothing if the weather is very cold. Some participants mentioned that they would change the clothing more than changing the thermostat. However, DM mentioned that they would modify the thermostat first and clothing is secondary to them. DM likes to wear comfortable (light clothing) in his house. DM “I guess that is right first of all we turn on and off and
second of all we probably, yeah DF puts on more cloth.” There is always a conflict among partners, and it is rare to have similar comfort preferences.

Blankets

A blanket solves the comfort issues when one person is warm, and the other is cold or when the room is very cold. (We cover up with thick blankets.) DM and DF talk about their differences in comfort temperature while sleeping. DF mentions that at the temperature her spouse is comfortable, she is uncomfortable. They have resolved the issues by buying a blanket to keep them warm and the room temperature cold. DF “What he is comfortable for sleeping I am cold when I am comfortable he is hot. So, one good thing was that we got a down blanket and then we can make the room temperature colder but still stay warm under the blanket.” DM mentions the blanket they used is “Goose down, it is sufficient to keep warm. DF was happy about that!” Families with children either layer or use blankets during colder seasons. EM “We have a blanket.” EF “Blanket, Socks, adding one layer.” FF mentions that they use blankets in the living room when it is cold. FF “In the living room many time we take our blankets.” GM and GF are well prepared for the colder weather, and they are ready with blankets in a box in the living room. GM “I think we like the same temperature. We use blankets that are next to our couch.” GF “So we have a bag full of blankets just around the corner. So even if one of us is feeling cold, or even in the autumn evening when it is not quite ready for the fireplace, we just throw a blanket on ourselves.” GF showed the box of blankets during the study. GM “Winter, make use of blankets.” Similarly, JF and JM cover themselves when they are cold, and if they still feel colder, they would wear a jacket. JF “Put a blanket on.” JM “Yeah. If that is not enough, then a jacket.” JF “Yeah a jacket.” JF “Complain to him.” They also mention that when one person gets cold and the other person is warmer they use blankets. JM “Yeah. I do not use a blanket. I just get cold and sit and tell her you take the blanket.” NM says that he would either increase the thermostat or cuddle when they feel cold. NM “I will turn on the gas fireplace this one or the one in the family room or we will get blankets and kind of cuddle up.” NM further mentions that he likes to sleep
in a colder room and his spouse likes it too. NM “In the winter? Very rarely, I like sleeping in a cold room. you know sometimes, may sound little crazy but sometimes, I like the room really cold, I like that because we have a duvet and being underneath it, you can sleep really well. It is quite nice. We put a feather decker on our mattress and a duvet, it makes you warm. It is like a cocoon, NF does not mind she kind of likes it.”

In the pre-questionnaire, I asked the participants what they would do if one person was warmer and the other colder during sleep. Most of them responded that they would remove the cover, but they also said one of them needs to compromise. IF “He used to take the covers off and hope it will cool down.” EF “One of the person has to compromise either you put on one layer.” EM “You just throw away the duvet.” JM “Yeah and then take off the blankets and then I complain to call and get off the blankets.” NM mentions that removing the blanket would be his first option, but he would check the thermostat too. He would reduce the thermostat if it is very high. NM “Yeah that has happened. I would just take off those blankets, or I will adjust the thermostat. It’s not like we override the thermostat, but you wake up in the middle of the night whoa it’s hot, and you find that it’s set at 23 so you just put it back on the program, and everything comes down and kind of lot quieter because I mean the furnace is pretty quiet, but it is nice when the furnace it turned down.”

During the what if model study the participants DF and DM mentioned that they would use thick blankets to cover themselves, the rainy scenario closing all the doors and windows and turning the thermostat up will increase the heat in the building. So, they mentioned that they would leave the windows open slightly. DF “I would say that we cover up with thick blankets.” Covering themselves with blankets is a sustainable action but leaving a window open at the same time is not sustainable. During rainy scenario, grabbing a blanket could be a psychological effect on people as they like to be cozy. GM “That is when we grab our blankets.” When questioning about winter few people discussed using blankets, but most of them responded with using blankets during the rainy season. LM “pair of blankets.”
Activities

Performing activities like exercising or cooking is considered as a metabolic rate in the building simulation tools. There are many activities a person can perform in the building; regular activities like cooking, cleaning, etc., but participants discussed few activities that they would perform to keep themselves warm.

Eat/drink something hot or cold to warm up or cool off. *(Drink to cool off! or If you are cold, eat cookies!)*

During the task completion with the different models, especially during “I feel” and “If buildings could talk” models, participants narrated other activities they do to keep themselves warm or cool. During the demo of the “I feel” model, GM suggested that he would eat cookies if he felt cold and also grab a coffee or hot chocolate. The two models “I feel” and “If buildings could talk” had drinking warm or cold options but not eating cookies. This is something we need to consider for design. GM “If you are feeling cold then you could eat cookies.” GM “Or a cup of coffee.” GM “Yeah what I would do is grab a coffee or a hot chocolate.” QF also acknowledged that she would drink something hot or cold based on the season. QF “I would have a cup of tea. A hot tea in the winter and cold tea in the summer.” During the winter scenario of the “If buildings could talk”, QF remembered how she ate an orange when the kitchen was hot. QF “I think like the other day when I felt hot in the kitchen I have an orange. I ate something cold.” Most of them hardly spoke about eating or drinking when they are cold or warm in the pre-questionnaire but having it as an option helped the participant recollect their actions. DM “It definitely makes sense to have a hot drink and close the door. What would you say DF? My first impression is often when we are cold during the rainy date we get hot tea or something.” Drinking something warm is an option that they would consider keeping themselves warm. DF “First thing would be to close the door or the window, the second one would be to put on some warm clothes and after that have something warm.” DM also compares with his preference between drinking something hot and wearing a sweater. DM “Drink something hot: yes, but I do not wear a sweater I should, but I do not.” Another participant, EM, mentions it is rare that he would eat or drink to keep himself warm or cold. EM “I am saying it is highly unlikely that I would
drink something because I am feeling hot or I am feeling cold. Oh, when I am feeling cold I would drink something, but when I am hot, I will not drink anything unless I really want to drink something when I am thirsty.” Habit of a person determines their action as well. The conversation was for winter scenario. EM “when I am cold yes we all drink something.” A few participants mentioned they would drink something to cool themselves during summer. FM “Yeah may be to sit down or watch tv, yeah or perhaps have something fresh to drink, yeah drink to cool off.”

Shower

Taking shower regulates body temperature. (When it is really cold will take hot shower.)

Participants said they would sometimes take a shower when it is very cold. DM “For example, if it is really cold outside, first of all, I definitely turn the thermostat up that is for sure and also sometimes when I am really cold, I can get a hot shower.” GF talks about transitioning from the cold outside temperature to inside room temperature by taking a shower to regulate her body temperature. GF “And if I feel kind of very cold from when am coming from outside to inside, I always turn on the thermostat and take a warm shower and then the temperature comes back up.” Taking a shower is still a secondary option as she mentions that she would increase the thermostat. LM says similar things but also mentions how many hours he will spend in the shower. This leads to another aspect of sustainable practice: domestic water usage. In this research, we did not include water use to reduce the scope of the project. LM “Sometimes I will take a shower, when am cold I will be like ‘Let me take a hot shower’ and I will be there for like 20 mins.” LF “Yeah. What I will do is sometimes I will turn the heat up on the floor in the shower and then get in close the door, have a shower, blow dry my hair and do stuff with the door closed so the bathroom remains this luxury little warm domain.” LM “Yeah I do that too.” A bathroom is a small space and retains heat well. Hence it can give immediate comfort relief. NM narrates his adaptation experience from one city to another. NM “Yeah the same. I would think of the rainy day in March is being pretty close to like this. Sometimes I take a bath. When I used
to live in Ontario, I never took baths. Ontario in winter is a really dry place. In the winter it is like super dry. It is cold, but it does not feel the same. When we moved here the first time in my whole life as an adult, I started taking baths because there was nothing else I could do to feel warm when it is that raw wet weather. It is not as cold like actually at this temperature, but it just feels way less comfortable to me because I am from Ontario. So, I started taking baths, after a year in this hot water and I finally feel comfortable. I actually will do that sometimes.” He concludes by saying that taking baths helped him in adapting to the Vancouver weather. Ontario has a continental-type climate which is mostly dry as it is far away from the influence of oceans, but Vancouver has a maritime climate with cool summers and cool winters. There is a fair amount of humidity present in the atmosphere. Hence NM felt the difference and took time to adapt to the temperature!

During summer participants wash their faces to cool themselves. DF “And also wash my face with cold water” Many participants mentioned that they would take a shower before going to sleep and that cools down their bodies. FF “No what I usually do is just take a shower before going to bed, and then I turn on the fan, and then I am ok.” Here’s what another participant says, IM “So we would normally take a shower maybe before we go to bed or something.” QF “I’ll hop into a shower.” NM lives in an individual house and felt it is a rare experience to feel too hot in summer. NM “never been. It is very rare that it is too hot. It is one of the nicest things. When that happens, and it does happen, we open everything we open all the windows and some us might go for a cold bath or a swim in the pool before we go to bed.” Opening everything during summer can increase the hot air in the building. While opening a door can help keep the air circulation.

Spatial relocation

Change room locations when there is conflict in comfort preferences. (Sometimes we will be in different rooms.)

One participant mentioned that they would use a sweater or blankets when there is a conflict, another mentioned that they would use different rooms to achieve their desired comfort levels. NM “that will sometimes happen. We will be in different rooms, so NF
will go into the family room and crank the fireplace up and shut the door and if I feel it is too hot for me, I will just sit somewhere else, some other room.” The participants here are expressing their solution in terms of thermostat interaction, but different rooms have different room temperatures. Participants visualizing the comfort data from various rooms can also move to those locations.

Changing locations during summer to avoid heated room!

IF and IM live in a well-insulated and spatially designed house. They mentioned how, during the summer, the bedroom’s orientation to the sunset causes it to be very warm. Changing their sleeping locations would give them a comfortable room temperature, but since they lacked cupboard space, they decided not to change. IF “It becomes warm and our bedroom is at that end and that’s where we get the sun in the afternoons, but we cannot switch cause that bedroom is bigger than the master bedroom in the past, in the house, we had before but it doesn’t have any closets.” IF “Otherwise we would switch the two rooms.” People need to make spatial adjustment as well to maintain a healthy environment. LM also mentioned they move to cooler locations during summer. LM “Oh we go to the other rooms. The living room is cool.” Currently, the system design does not provide this detail, and it is a useful criterion for the system to consider.

Go outside if it becomes too hot. (I will go outside to cool myself)

Participants living in apartment buildings mentioned that they would go outside when the building is very hot during summer. DM “Actually sometimes when it’s really really hot, I remember like it was three years ago or something, essentially we were coming home and we could not stay here and so we had to go outside and wait until the sun went down. And also, sometimes we actually had our dinner on the balcony because it was not comfortable inside.” Sitting on the balcony and eating was a common practice for most people. EM “Yeaaaah, we go out.” His wife expresses similar response. EF “We go out, it’s just unbearable and we do not have air conditioning so the room becomes very hot right?” Vancouver buildings are free running and the houses in which I conducted the study did not have any air conditioning. HF “you should not be in your house go outside.” Going out to the beach is a habit that the people have developed to beat the heat. NM “well, I don’t know we are much higher
You know like to go sailing. Waterfront. Go for the sail and the waterfront is much more comfortable. Yeah and sometimes we go down to the beach over here in the sun dip ourselves in the water.” NM has a creek near the house it takes only five minutes to go there. He mentions that his wife and children visit it frequently during summer. NM “Also there’s a creek down here a quarter about a walk away. So, my wife and kids go down to this and float around in the pools, whenever they can.” OM is a senior citizen, and he says that he would “go for a swim” when it is very hot during the summer. Participants also mentioned that when the outside temperature is warmer than the inside, they will sit on the porch or balcony to enjoy the sun. IM “So in the summertime, if the house is warmer than outside like when the sun goes down, we can also go and sit on the deck.” Another participant QF shares a similar experience “onto the porch.” In Vancouver, very hottest days are dealt by going out to the mall, to restaurants where there is air conditioning or to the beach, park or for a swim.

7.2.2 Technology and Built environment

Adaptation using controls

During the study participants, were not questioned about the thermostat set value; however, a few mentioned their set points. Most participants preferred their set point at 20 degrees. For some it was between 20 and 25 and for some when it was very cold they would turn it to 23. comfort preferences vary based on housing type and body type.

Thermostat

Primary interaction is to adjust thermostat during cold weather or when there is a comfort issue. I guess for both of us, thermostat up is the first thing to do!

The response by most participants on the immediate actions taken during colder days to be comfortable is turning up the thermostat. DM and DF have different comfort preferences. DM emphasizes in his conversations that their first action will be to increase the thermostat irrespective of other choices they might consider. DM “For example if it is really cold outside, first of all, I definitely turn the thermostat up that is for sure and also sometimes when I am really cold, I can get a hot shower.” Though DM was reasoning about other
actions, he emphasizes “thermostat up is the first thing to do” for both of them. “DM” I guess that is right. First of all, we turn on and off and second of all we probably, yeah DF puts on more clothes. Turning the thermostat higher and lower shows that their initial thought process to resolve their comfort is interacting with the thermostat. Couple FM and FF are similar to DM and DF, but here FF is warmer than FM. FF and FM are both sustainably driven, and this affects their choice of interactions. “FM” It is colder that’s when we are concerned a little bit that we should keep increasing the thermostat little bit to keep the temperature little warmer when it is really cold, yeah. The least is 15, the most we use is 20 Celsius, FF will probably go lower 15. Even if FM is aware of sustainable practices, his health issues affect his choice of interaction. FF “If he is very cold for sure I go check the thermostat, if it is below 15 or if the thermostat temperature is higher and the room is colder than I turn the thermostat little bit higher.” He is colder compared to his spouse, and FF considers this in her decisions. FF “If it is cold I would go check and see the thermostat, to see where the temperature is, if the temperature is very cold I just turn it on higher little bit and I also wear my sweater and ask the kids to wear sweater and socks especially to keep them warm.” LF prefers wearing a sweater to interacting with thermostat, but she too mentions that she will turn the thermostat on when it is very cold. LF “Well, sometimes I will turn on the thermostat on. If I see that you know.” OM also mentions a similar instance in his household as his wife is colder compared to him so turning the thermostat on will be the best adjustment for either of them. But he also mentions that he will wear a thick sweater when it is uncomfortably cold. OM “No I mean it is a very typical issue between husband and wife right or between one person and another who are living together, adjust the thermostat a little bit, if it is really quite cold we will put on an extra layer of clothing, we got a wonderfully warm thick sweater, I’ll put it on if it gets uncomfortably cold.”
Participants often increase their thermostats to make the room comfortable without knowing that there was an issue with the heating system. In the pre-questionnaire, they were asked whether they felt cold after turning the thermostat up and wondered about it. They said yes, and the issue was mainly because the system was broken. FF “Yeah sometimes because the heater was broken, we call the person in charge to check this.” While FF was discussing the issue with a broken heater, FM was complaining about the heating system being slow to warm the house. It is a different problem compared to the broken heater. FM “Yeah usually here we in this building, the heater is not that high, the warming
up here is slow, slower compared when we used to live in SFU there it was high, here it takes time to warm up the home.” Immediate comfort influences the interaction. PM had similar issues, and he had to bump the thermostat. PM “We had some issues, so we just bumped a lot and wore slippers. Yeah. And because it’s a heated concrete slab you are not going to get a really fast reaction so if it is too cold just turning up the thermostat won’t have an immediate effect, so the first reaction is to dress appropriately.” PM not only discussed the broken system but the time it takes to bring the room to a comfortable room temperature. Moreover, it took him a couple of months to figure out the issue and resolve it.

Keeping the room cooler is GM’s and GF’s preferences, their ideology is they can increase or lower the temperature to their comfort needs. GM “Ya I don’t know Celsius wise. We use thermostat lot more just like turn on or off to set the particular temperature. It’s like turn the fire on turn off when you feel uncomfortable.” According to this couple interacting with thermostat often solves the discomfort. GM “Alright. I prefer it cooler and that you can always heat some up when it’s hot or cool unless you have air conditioner.” However, some participants interact with the thermostat only in extreme comfort situations. IF “But he is often the one who programs the thermostat unless I think it’s too hot and I turn it down.” IF also say they interact with the thermostat only when it is needed. There rarely adjust the thermostat. IF “Yeah. Normally we have it set at a certain temperature, and we leave it there.”

Participants override programmable settings during extreme weather conditions. (It was so cold, I did override about 8 days!)

In the previous section, we discussed the use of conventional and programmable thermostat in general. Since the programmable thermostat settings consider the different temperature for night and day, it was interesting to understand how many times the people overrode the set temperatures. Since Vancouver climate does not have extreme weathers, most participants adjust the initial set temperatures on rare situations especially when the weather was very cold. NM “I will override make it a few degrees more and we make sure we keep the doors closed so we don’t always do that.” What do participants do when it becomes very hot during the night time? NM mentions he will either put the blankets
off or turn down the thermostat. **NM** “Yeah that has happened. I would just take off those blankets, or I will go adjust the thermostat. It’s not like we override the thermostat, but you wake up in the middle of the night, whoa it’s hot and you go find that its set at 23, so you just put it back on the program and everything comes down and kind of lot quieter because I mean the furnace is pretty quiet but it’s nice when the furnace is turned down.” Even here the overriding is performed only when the set temperature is high—e.g., 23 degrees. **NM** “It’s only because we are here at the time we did not expect it to be here. If I end up working at home and if I was had something I had to be home I will override it because am home and set it as 19 degrees or something.” When **NM** works at home he overrides the setting during the day. **QF** “The last couple weeks. Yes. It was so cold, I did override about 8 days. I turned up the heat in the basement because the cold air; the cold is coming up from below as I turned up the heat in the basement it was about 16 degrees and I turned it up to 19. So that was unusual though. We don’t usually get that cold. And I don’t need to do that today, it is not that cold though. So yeah it is unusual.” During the study, Vancouver had a cold spell, and hence a few participants mentioned that they overrode the programmable settings. Apart from that, the set temperatures are typically low—e.g., 15 degrees Celsius for apartments—but for individual houses it depended the housing size.

Participants increase the thermostat when they feel cold while working in winter. *(If I am doing physical work and am cold in here, I am more likely to turn the thermostat up!)*

**IF** is a senior citizen while **NM** is above 50 years, both of them mention that, if they feel cold while working, then they will increase the thermostat. **IF** “And it depends on what am doing. If I am doing physical work and am cold in here, I am more likely to turn the thermostat up. But I am sitting and reading and thinking and he is working doing something and thinking if it’s not cold in here, I would tend to put more clothes on.” Feeling cold while working could depend on several reasons. In **IF** case it could be the age, physical tiredness causing the cold sensation. However, in **NM** ’s case, when he is sitting and working at a desk for long hours may have less physical movement, and that could be a cause of him feeling cold. **NM** “Wear a sweater but then if I am working at the desk and I find the desk
is too cold and my arms are getting cold then I would turn on the heater." Activities by inhabitants and their body temperature influence interaction with thermostat.

**Increasing the thermostat for children or older person or guests (Only when we have guests that are sensitive to cold)**

EF lives in an apartment that is usually warm with just the gas fireplace on, (s)he never used the heating in other rooms. She mentions she used it once when she had a baby.

EF “We never really use it unless it’s necessary, like I remember I used it when my second boy was young when he was a baby, you know you want to control the temperature, but it’s manageable without the thermostat.” Similarly, MM says when he is alone he could wear a sweater to adjust, but when other people are present, he would prefer to increase the thermostat.

MM “I don’t. Well I do now sometimes when we have guests, my father is in his 80’s, MF’s parents are in their early 80’s and sometimes especially my dad feels a little cool we punch the heater one or 2 degrees when he comes. That’s probably the only time that we adjust this.” Older family members affect the usage of the thermostat. MM also states that he considers the guests who are sensitive to cold and increases the thermostat.

MM “Only when we have guests that are sensitive to cold. You know so if parents come over. If friends come over or sisters come over, we wouldn’t change it typically.” People’s age seems to have an influence in thermostat settings.

**Heat is turned up to avoid mold or humidity or moisture. (If you do not turn on the heat when it is cold outside it will create mold!)**

DF shares her reason on why the thermostat should be left on “Also What happens is that, for example in the den if you don’t turn on the heat when it’s cold outside it will create mold, it’s not good to have mold in the building that’s why we have to turn the heater on in order for it to be dry but also the air in the room gets little dry, and it’s uncomfortable, and then we have to open the window.” DF shares two points in this, first she keeps the thermostat on to reduce moisture but also says that it becomes very dry. To resolve the issue they open the window, in other sense, the heat is on, and the windows are open. It is not an effective action to save energy. DM also explains they leave the thermostat on to avoid humidity. DM “That is the first thing, the second thing is when it’s rainy it becomes
humid and to make sure the humidity is not in the apartment we sometimes turn on the temperature.” DM also mentions that, to avoid moisture in the building walls during the rainy season, they will keep the thermostat up. Moisture and humidity are the main causes for mold. The room needs to be dry to avoid mold. DM “You mentioned it but also you mentioned it’s rainy, it’s rainy and it’s March so probably we will turn the thermostat on to make sure there is no moisture in the room. 20 is fine!”

**Lower thermostat**

System influences the decision towards lowering the thermostat. If you reduce the thermostat that would be the most energy efficient way?

Lowering the thermostat was not a common response during the pre-questionnaire. During the task, participants considered it as an option to reduce energy usage. The system compares the current thermostat set levels with lowering it by 2 degrees. DM and DF are a family that typically increases the thermostat or leaves the windows open when it is very hot to cool the building during winter. DF “If it gets hot in the room and am cooking, if it gets hot what I will just reduce the heat.” When DF heard the scenario her first response was to reduce the heat, but when she saw the possible options with the current thermostat settings. She recalled her actions and said she said she would try changing clothes. However, later when they saw the energy consumption of the different actions: DF “And then if you reduce the thermostat that would be the most energy efficient way?” Each action with energy data was explained to them, and DM concluded by saying that it “makes sense,” and he would “definitely change the thermostat.” As we were going over another scenario, DF was quiet and was pondering over the explanation and then said “I was thinking about the previous case, whenever it’s hot and we are cooking probably even if we decide to open the windows we would turn off the thermostat first.” This option was not there in the system that provided the multiple options, the system default suggests lowering the thermostat by two degrees. DM was still tied to his practice, he kept mentioning lowering the thermostat and opening the door. It resolves his discomfort but is not an efficient way to save energy. Also, the efficiency depends on how long the doors and windows are open. DM “I would probably
lower the thermostat and open the doors. Should I say one?” EF also mentioned that she would “Lower the thermostat for sure.” if it would cut costs.

**Lower thermostat because of practice or sustainable enthusiast.** We don’t turn the fireplace on until the evening.

HF is a sustainable enthusiast, and she mostly wears sweaters through the day and turns the heat up during the evening. Their family has a habit of wearing a sweater and being well dressed during winter. HF “So we turn down the thermostat we put on sweaters during the day and then we wear slippers also because it’s concrete floor underneath us, so your feet aren’t cold and then we don’t turn the fireplace on until the evening. Partially to save money but also partially, so the kids don’t touch it by accident….safety.” They warm the house for a short time during the evening and turn it off during the night. HF “Yeah its more with the sweater than the thermostat. They stay at 0 until the evening then maybe turn it up a bit to 2 to warm up the house then we turn it off when we go to bed. So, then it stays warm pretty well.” Sustainable practices prevail. Lowering the thermostat worked for this apartment because, generally, the units in this apartment building were warm. This could be one of the reasons the participant is able to have this practice. Another participant mentions that he will lower the thermostat if he is at home and if it is not cold. NM “Or put on a sweater or a fleece jacket. I will you know dressing appropriately is a good idea. And also, if I feel really cold I would go, we have a programmable thermostat, If I am here and not where am expected to be and if it’s not too cold I would turn off the thermostat.” Habits exhibited by these people could be shared through a system to encourage or motivate other users.

**Lowering thermostat does not give immediate effect.** I am feeling hot because am working in the kitchen, the room is cold the way it should be, I am not going to touch the thermostat.

LM has been lowering the thermostat in the bedroom and would increase the thermostat in the morning, but eventually, he lost interest in doing that often. During the winter scenario task, LM and LF were discussing among themselves lowering the thermostat. LM “Sure the cold drink is a good idea but I might not think about that first depends on
how hot I am. If I am feeling hot, I would probably open the door or a window. For at least a little bit.” LF is more tuned towards sustainable actions, and she enquires “You would do that before turning the thermostat down?” LM’s hesitation in lowering the thermostat is because it “will eventually take a long time.” People like immediate feedback on their actions and that does not happen as it takes time. LF says “Eventually I would also if it seems like it’s too hot, eventually I would lower the thermostat. I think.” LM argues the room state is not changing but his metabolism so concludes by saying he will not lower the thermostat. LM “Yeah for me, I don’t know it depends. If I think the room is too hot, then I would turn down the thermostat, but I am going to just know I am feeling hot because am working in the kitchen, the room is cold the way it should be, I am not going to touch the thermostat. Personally yeah.” Participants mentioned that they would not alter the thermostat setting. DF “Actual thermostat because I don’t like to lower the thermostat compared to the clothes and after that probably if it’s still too warm then I would lower thermostat.” Time taken to heat the room deters the lowering of thermostat.

Regulating the thermostat during a particular period, seasons, short trip/long trips or at a particular time of the day. (For example, I am just going to the town for shopping, I am out for the day, I don’t change the thermostat.)

Participants adjust the conventional thermostat in the morning and evenings. OM “In the winter, hmm, I would say we do adjust the temperature, major adjustment twice a day, in the morning when we get up, evening we go to bed and typically only minor adjustments.” OM states they light the natural fireplace during winter for its warmth and coziness. OM “hmm, ok a more complete answer would be thinking about day time, if it’s moderately cool, I would turn the thermostat up, so we get a 70-72 degree. If it’s really cold, and especially in the evening, we will light a fire in the fireplace. And honestly, we do use that for heat. It looks lovely, its cozy, its warm, its inviting, its everything you would imagine but it also generates a lot of heat, which we enjoy and make good use of. And in winter time, typically we will have a fire in the evening, but we wouldn’t have a fire in the daytime, unless it was very cold, or unless we lost power, and that happens, and in which case the fireplace goes on, we have some ash mantle lamps, are bright enough, coil lamp,
interface we can read, and so we have gas stoves, and the gas grill, and so we are ok.” He also explains that he would use the fire if there is a power outage; otherwise he uses it during the colder time periods. While OM talks about his interactions for the day, MM does so for seasons. MM has a programmable thermostat and prefers not to disturb the settings. He explains the adjustments for seasons. MM “Well, the furnace is on. Probably October through May when it’s on its keeping it in a comfortable temperature. Again, in the shower season as when we like have a bit of debate on turning the furnace off and my spouse will say no no no, we will leave it on for another 2 weeks or so until its warmer. So, once it’s off then there might be a cooler day when we know we sit back and say cooler. And then the action what we would do is sometimes my spouse will turn on the furnace for a few hours in the morning and turn it off. You know the other action would be putting on some warm clothing.” MM lives in an individual house, and room temperature and requirements are different compared to the apartment units. However, still, the question arises as to whether the temperature should be set at a constant value from October to May or be adjusted periodically. LM was initially very active in adjusting the thermostats during the morning and evening times. LM “Yeah. But I think I’ve noticed that it takes a while for the heat to come up and it’s not going to get up, not going to heat up, it’s not actually warm for the next hour so. I just sort of question is it really worth it? How much are we really saving that much. And it’s probably not that much.” Not being able to see the information on the energy savings, LM was demotivated from continuing his routine adjustments. He expresses the need to install a programmable thermostat. LM “And this would be the reason why I would love there to be an automated thermostat ’cause it could turn itself up an hour before I get up.” Do people turn the thermostat off on short trips? IF explains how she will not lower the thermostat if it is a short trip to shopping compared to long trips. IF “We went to Whistler for three days on a retreat or when I go away I turn the thermostat’s down. Like I am just going to the town for shopping, I am out for the day, I don’t change the thermostat. But if am going away for a week, several days or a week longer, I turn the thermostat down. But then when you get home, the weather has really dropped, the house is going to be cold, I would turn the fireplace on to warm the house quicker and wait till the thermostat has gone
up to there and turn it off. Or it’s like we turn it on just for the ambience. No priority. Not very often. We use it just to warm the house.” She also explains the nuance of coming back to a cold house and was asking if there is remote access to control the room temperature. **IF** is a senior citizen and very inquisitive with technology while her husband is not that tech savvy.

Participants do not like to adjust the thermostat for various reasons. *(Because it is programmable we are just going to leave it, we adjust)*

What restricts the people from interacting with the thermostat setting? What is stopping them from lowering or increasing the thermostat? **MM, LM** and **PM** give a glimpse into the questions. **MM**, does not like to change the thermostat settings because it is a hassle. It is not friendly, so he prefers to adjust his clothes or interact with doors and windows. **MM** “I think I would probably dress like what I am now. I would probably wear a sweater, and in another season, I wouldn’t wear that. The programmable thermostat, we don’t touch it much so pretty much I don’t think we wouldn’t adjust anything inside and the only thing we might watch is open windows but it’s not like its be going to cold day we try out and on a warm day we turn it down. We just let it run. Ya so the only thing in it would be we might latch up the windows open and I mean the clothing I wear is more anticipating to go outside.” **MM** was dressed warmly during the study interview, and hence he clarified that this was not his normal clothing at home. When asked why he would not modify the settings based on the weather, he mentions “No. Because it’s programmable we are just going to leave it, we adjust.” The assumption here is that programming is complex. The thoughts arose during task completion, as the participant never chose any options that involved lowering thermostat. **MM** “I don’t think so. No. the only reason I wouldn’t change the thermostat is this thermostat is usually I find it unfriendly.” He continues to say it would be easier to speak to the thermostat about the settings. **MM** “What I prefer to have in a thermostat I want to say, it’s easier to say, lower it for two hours.”

**PM** lives in a passive house with a programmable thermostat. When questioned about the programmable settings he had no clue on its settings. He believed that it should be just left as it is and not to be disturbed.
PM: "Yeah it’s just like whatever it is set up to."

PM: “No”

Researcher: “No?”

PM: “We try not to touch the thermostat”

Researcher: “Why?”

PM: “It’s not often that we are too hot”

Researcher: Ok so just. Do you have a default setting you are following in the thermostat?

PM: Yeah it’s just like whatever it is set up to.

Researcher: So, it’s a default setup? You don’t operate it?

PM: “Yeah its supposed to get colder during the day and over the night. So, it’s supposed to warm up again around 3 o clock it will kick in and heat up the room. Yeah so right now it feels pretty hot.”

Researcher: “yeah it is”

PM: “like very warm. I would think it would be colder during the daytime but again because it’s a heated concrete slab, any changes are not like the same as it’s supposed to be there. So, a slight like you know. If the boiler turns off during the day the concrete slab still stays really hot all day. So that’s the good thing about this system. It just needs to feel a little bit heat and maintain the temperature. It’s important not to touch it.”

The participant was probably advised by the manager to not meddle with the settings as it might affect the function of a passive house.

MM and PM had different reasons for not interacting. QF’s reason for not touching her thermostat settings because she was comfortable. QF “and it goes down at night to 16 and up to 17 and half during the day, but I never touch it except for the last few days when it got really cold. I don’t play with it.” QF uses a Nest thermostat and says her husband handles it and she overrode the setting only during extreme weather conditions. The study occurred during a cold winter. Technology may be complex and unfriendly, but LM mentions while cooking he would not lower the thermostat as it does not affect the room temperature but
the way he feels. So, he would just adjust and not change the thermostat setting. **LM** “Yeah for me, I don’t know it depends. If I think the room is too hot, then I would turn down the thermostat but I am going to just know I am feeling hot because am working in the kitchen, the room is cold the way it should be, I am not going to touch the thermostat. Personally yeah.” His reasoning including the delay in feedback.

**Fireplace**

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<thead>
<tr>
<th>Fireplace Adaptations</th>
<th>Gas fireplace</th>
<th>Heats the whole place</th>
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<tbody>
<tr>
<td></td>
<td>Powerful in heating</td>
<td></td>
</tr>
<tr>
<td>Electric fireplace</td>
<td>It’s aesthetics; not that effective</td>
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<tr>
<td>Natural fireplace (wood)</td>
<td>Use it because its lovely</td>
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<tr>
<td></td>
<td>Pleasant</td>
<td></td>
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<td></td>
<td>Coziness</td>
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Figure 7.12: Fireplace adaptations summary

The fireplace was a topic of interest among the participants as it either heats the entire place. Or it is cozy. Or aesthetically pleasing or ineffective. The study brought three types of the fireplace into conversation: gas fireplace, electric fireplace and natural fireplace (wood). First, three families living in the same apartment building preferred a gas fireplace as it heats the entire house and is perceived to be more powerful than electric heating. They prefer using the gas fireplace for the warmth and comfort it gives, but recognized that the city is moving towards renewable energy. Will participants change their usage if they see information on renewable and non-renewable energy on the interactions they make? Second, participants did not like the electric fireplace even though it was aesthetically pleasing. Third, three households spoke about the natural wood fireplace as it gives good heat, warmth, and coziness. A participant described how the act of collecting wood for the
fireplace also increased the body metabolism. The natural fireplace has a pollution problem but seems to involve people in action and provides warmth.

**Gas fireplace was highly preferred as it warms the entire house compared to electric heating.** *(Gas fire place, its great it heats up like the whole space without having to turn on the individual baseboards)*

In the pre-questionnaire, we asked the participants to describe the best feature of their houses. Participants from this particular apartment building all named the fireplace. One of the reasons for their choice is it heats the entire place quickly. A general observation on all the three apartment units is that they were warm, despite visits occurring visited during different times of the day. **EF** “We barely use the thermostat, because we have these electric ones in every room including the kitchen, which we barely use them. We only use the fire.” **EF** feels “the house is not as cold” and “does the work for the whole house.” **EM** clarifies “I think you meant most of it that. Whatever heating to be increased is done with the one at the fireplace, and we don’t use the white ones.” **EF** was emphasizing “it warms the whole house.” **EM** “When we turn it gets really hot,” the heating is fast with the use of the gas fireplace. Since gas fireplace has real flames, it contributes more heat when compared to electric heating. **GM** and **GF** are participants who prefer more comfort than energy costs. **GM** “During the winter time, we prefer having the window open and switching on the fireplace when we need to. In the summertime, we definitely struggle especially at night time.” **EM** mentioned how fast the building gets hot when they turn the fireplace on but **EM** lives on the 4th floor and **GM** lives on the first floor. Heat could be one of the reasons **GM** and **GF** leave the windows open and also by nature they prefer a cool environment. Generally, their first floor is cooler, but the house is warmer because of the heating source. Leaving the windows open is not an efficient way of interaction. **GF** thinks the fireplace was more efficient than electric heating. **GF** “In the previous apartment, we had an electrical fireplace, and I don’t think that they were nearly as wise in use of their power as well as their use.” **GM** was mentioning that gas was cheap, and they do not care much about its usage. **GF** prefers gas appliances compared to electric appliances. **GF** “And I really like having the gas oven, and gas range, stovetop as well as the gas oven and I prefer that over
the electrical.” GM repeats the actions he would do when it is very cold GM “turn on the Gas fireplace, and then we crack open the windows for fresh air.” But GF does mention that she wears sweater and socks in the morning before switching on the fireplace. GF “I put socks I put it when it’s cooler in the morning. My first thought is to put a sweater on before switching on the fireplace.” HF narrates similar experiences as the above couples but takes very sustainable actions, HF “yes so because we only turn the fireplace on the kid’s room we don’t turn their heater on, we have a fan there, and we turn that on and it kicks the heat in.” Inhabitants adapt for safety issues.

**Electric fireplace is aesthetically pleasing but not that effective. It’s mostly for show**

Few participants felt the electric heating was not effective as the gas fireplace. They feel it is more aesthetics and does not give enough heat as the gas fireplace. KF “Generally we would put on some heating and then also the fireplace is there. It’s mostly for show. It does throw some little bits of warm air. Its electric and we have lots and lots of woolens.” IF also mentions that, when two options are available, they would use the gas fireplace compared to the electric heat. IF “When we lived in Kamloops we used the gas fireplace almost more often the electrical baseboard heat.” Maybe the design of electric fireplace could be improved to provide more heat, but it cannot replace the heat felt from real flames.

**A natural fireplace is lovely, pleasant and cozy. (I can sit in the kitchen and put a little fire there and have my cup of tea. That’s really pleasant!)**

OM’s house is in Bowen island and he describes how they like heat from the natural fireplace. He also says its cozy, inviting and warm. He also explains that they mostly use it during the evening and not during the day but OM says using natural fireplace is airtight and refreshing: this is a misconception as most fireplaces have chimneys that cause to air leakage. OM “So we are using heating and cooling but it’s pretty natural fireplace burning wood, of course, that is airtight so that is that as refreshing as it can get.”

QF lives in a detached house too and has an old-fashioned wood fireplace. QF “yeah the real wooden old fashioned. So, the best is in the morning when the house is cold I can sit in the kitchen and put a little fire there and have my cup of tea. That’s really pleasant.”
Natural fire will give more warmth compared to electric ones. HF talks about the natural fireplace with a different perspective, and she was asking a rhetorical question. “whether it would actually matter to people, who have houses, that have a wood burning fire places as opposed to the gas fireplaces?” HF “so if they were doing something like because one of the houses when I lived in Victoria we had a wood burning fireplace, and there was electric baseboard heat but we would just if you build a fire the wood boards and burning fireplace that the action of building the fire itself warms you up.” HF states that the act of chopping wood and bringing it will warm the person, but in today’s context, people prefer easy work and natural fires cause pollution. HF “so if you had to go and carry the wood if you had to chop up kindling then you bring that back in and in Ontario too we had a wood burning fireplace so then you the fireplace will create heat cost minimally but then that action itself.” HF was only suggesting it as a what if? and was questioning about its effect on comfort.

**Fans**

The study shows that most participants use fans during summer when it is hot. Depending on the household size and participant age the number of fans used vary. Most participants mentioned that they use two fans, one in their room and the other in the children’s room. Some participants used fans during winter too; these people mostly lived in an apartment.

![Figure 7.13: Fans adaptations summary](image)

Fans are mostly used during summer than air conditioners to cool themselves. *(If there is not fan I cannot sleep!)*

DM lives in a high-rise building; Usually, in summer they do not have very hot indoor temperature because of the building shadow. DM “First of all we would open the windows, sometimes that doesn’t help. If it’s too too hot then we use the fan, one thing is that sometimes it also depends on the time of the day because usually what happens on a hot
summer day is during the day from morning until 3pm usually its ok because we have the shadow here, then when the sun comes here, it becomes too hot and then usually for most of the day we would have the windows open, and when the sun comes here then we close the window and the blinds, so the heat doesn’t.” Most participants like DM open the windows/doors during the summer for air circulation. What they are not realizing is that, if the room temperature is cooler than outside temperature, then all the hot air is going to get inside. How do the participants know if their room temperature is less than the outside temperature? Using fans during summer might be a better option for the participants instead of opening all the door and windows. It also depends on factors. GM “Make an angular fan onto us. At night flowing at us during summer.” Fans may use energy, but it might be the better way to feel comfortable than opening windows.

**Fans are used during winter when it is hot! (My child uses fan during winter.)**

Two household participants mentioned that they use fans during winter when it is very warm. JF “The tower. Yes sometimes.” JM “Sometimes.” Researcher “Why would you use the tower sometimes?” JM “Because it’s too warm.” JM and JF live in the third floor, and they said the building is warm as they get heat from all sides. They live in an apartment unit. On the other hand, FF mentions that her son uses the fan during winter, she mentions that her first daughter did the same. FM “JJ like to use fan, we try to tell him that it’s not necessary because its already cold but why does he want to use it, we like to turn it off because there is no need.” FF “Older daughter was just like that too.” FF thinks the reason could be because the room overheats during winter. There is no heat leak in their room because it is compact and “the window is smaller.” Since her son is used to the comfort of a fan during winter, she is trying to break him of the habit.

**Blinds**

Blinds are highly used during summer than winter. *(In summer we leave the blinds closed everywhere to try and keep the heat out.)*

Most participants discussed the use of blinds during summer more than winter. There was only one person who spoke about drawing the windows during winter. Since Vancouver has eight months of cold to moderately cold weather and mostly has dark skies, people may
prefer to have more natural light. We did not specifically probe into individual blinds during the study, for that knowledge we may need to run another study. During winter, the blinds are drawn up when there is sunlight and closed during cold weather. During snowy times the windows are partially open to enjoy the view. During the summer most participants mentioned they lower the blinds to keep the building cool and also one participant mentioned that if the blinds are not drawn down, it becomes warm at night. One elderly participant mentioned that she operates the blinds based on the sun angles. PM loves plants, and it influences his interaction with blinds during winter or summer—his blinds are drawn up to accommodate for the plants’ need for sunlight. In summer he said the building becomes very hot. A few examples of quotes from participants are given below.

![Blinds Adaptations Diagram]

Figure 7.14: Blinds adaptations summary

1. Blinds are drawn up for clear sunlight and partially opened to enjoy the view during winter.

FM “When it’s clear we have sunlight I like to open the curtains so that sunlight enters and warms up the inside that’s what I usually like to do. But when it’s very cold and snowy then we try to close the curtains a little bit, but we also like to see the snow, so we open little bit and depending upon how the weather outside we like to keep warm.”
Yeah.” FM “The windows are closed but the curtains are open, so we like to see how the snowflakes go down.”

2. Blinds are closed to keep the building cool during summer

   GF “Close the curtains all day pretty much.” HF “In the summertime, we leave the blinds closed everywhere.” HF “to try and keep the heat out” HF that’s just the main ones. It heats up a lot and then when we are gone during the day for working then we leave all the windows and doors closed so then it gets super-hot by them time we get home.

3. Blinds are operated based on sun angles!

   IF Also usually in the mornings I draw the blinds, so it helps to keep the house cooler.
   IF And then when the sun moves from there to there, then I open that one. This one is closed and that one is open, and we will switch.

4. Plants influence the state of blinds!

   PM During the day, we usually leave the blinds up because of the plants.

5. Blinds are drawn down for privacy

   NM More for privacy. We open them. That’s actually a comfort we have at the house. I like once a week I like to see the green but my wife doesn’t like it when people see so I will like draw the blinds and shut them back

Windows/Doors

When buildings are overheated participants’ open windows/doors for fresh air

The natural tendency for most participants is to open windows when the building is overheated. It provides immediate comfort feedback. Most participants feel overheated at night; this is because of body temperature, it could also depend on the bed clothes and the building temperature. DM lives on the fourteenth floor. DM “Actually that often happens at night, and for me for example, once again the heater that we have. My impression is that it makes the air too dry and in this case, we just open the window let the fresh air go
in and so yeah.” **EM** and **EF** mention that they leave the windows open throughout the night during winter. They open the window in the kitchen and not in the bedroom or living room. **EF** “We mostly leave the window open.” **EM** “Which one?” **EF** “The kitchen, not the bedroom.” **EM** “It’s the kitchen one we leave it open a little bit.” **EF** “Like the opening is different like during the winter we leave it open a little bit just for fresh air.” **EF** “I would open the window.” They leave the windows open slightly. **GM** and **GF** live in the same apartment building as **EM** and **EF**. Similarly, they leave the kitchen window slightly open during the night. The unit plans are similar where one lives on the first floor and the other lives on the fourth floor.

![Windows/Doors Adaptations](image)

**Figure 7.15:** Windows/Doors adaptations summary

**LM** was actively trying to save the bills and be sustainable, but he said he stopped at a certain point because he was not sure whether his actions had an impact. **LM** “*Maybe we should strip that bedroom door, and you close it and because I sometimes wonder like just closing the door, would it do any good.*” The above statement confirms a need for more information. **PM** lives in a passive house, and all he needs to do when the building is hot or overheated is to use the HRV, but sometimes he leaves the window open after an activity. In a passive house, this may have less loss in energy usage. However, guess opening a window
gives immediate relief. **PM** “It’s easy to open up a window a crack.” **PM** talks about his experiences during an activity or after an activity. **PM** “I think it was because we were out exercising, and it was really hot ’cause you know if you got to bed, when you are cold you become warm and when we go to bed hot it’s hot all night. So, we open a window. Yeah.” He mentions he would use the HRV sometimes when the building is hot but while cooking, he will leave the windows open. **PM** “Like I wouldn’t want to open too major. Except that when I am cooking I often do crack that window a little bit or switch on the fan.” Now that the study shows that most participants leave the windows open while cooking, what will the designers do with such data? Will they redesign the space to it the new parameter? **FM** discusses the interaction with windows during rainy days. **FM** “Well it depends if it is with lot of moisture or it’s too cold, when it’s too cold, we try to close the windows so it will be warm, because with rain there will be 80 percent humidity, we like to open the windows for fresh air so it depends on the temperature of the rain, it can be cold or slightly wet but with moisture comes stuffiness So you need fresh air. So, you need to open the windows little bit.” He says that, if it is stuffy, he will open the windows for fresh air. **GM** gives a different perspective: he prefers to have the windows open with the fireplace on as well. **GM** “Turn on the gas fireplace, and then we crack open the windows for fresh air.” The comfort preference for this couple is slightly cold, and it influences their action. **GM** “It’s not so much of a hassle. It’s more cooler down. We often leave the window open. Our bedroom window is always open slightly, and our kitchen window is also open.”

**Most participants leave the window open while cooking**

Participant **DM** during the task completion said that he would open the window during cooking. **DF** affirms his statement, **DF** “The thing is usually when we cook no matter the temperature is, he would open the window just to get fresh air so that it would be the choice.” **DM** says he will also perform a combination of actions when cooking, he would open the doors or windows and will also change his clothing. **EM** and **EF** mentioned that they will leave the kitchen window open while cooking. It is open the entire day. They have a separate thermostat control for the kitchen. They said that during winter they will turn off the thermostat and open a window. **EF** says that they usually leave the kitchen
window open. **EF** “like the opening is different like during the winter we leave it open a little bit just for fresh air.” They leave the window open during summer as well. **GM** and **GF** do the same as **EM** and **EF** as their apartment plan is similar. **GM** “It’s not so much of a hassle. It’s cooler down. We often leave the window open. Our bedroom window is always open slightly, and our kitchen window is also open.” Comparing the actions of **DM** and **DF** with **EM** and **EF** (**GM** and **GF** as well), **DM** and **DF** will lose more heat because of the building plan. **PM** “like I wouldn’t want to open too major, except that when I am cooking I often do crack that window a little bit or switch on the fan (HRV).” People need instruction on how to use the buildings. Since **PM** is living in a passive house, he should be able to resolve the issues with switching on the HRV, but on the other hand, the building itself might be losing less heat with his actions because it is a passive house. However, how does the participant know the benefit of their interaction?

**Most participants open windows/doors during summer to cool the building**

Most participants leave the windows open, **OM** “Yeah, in the summer, it’s more the matter of opening doors or windows to cool off, so we don’t use any heating in the summer.” **KF** “Oh yeah we leave them open all the time except when we leave the house. (windows open during night time). **KF** leaves them open as well. The building may cool down or just increase the heat depending on the inside and outside temperature. The principle of heat transfer is if the room temperature is lower than the outside temperature the house will soon be filled with hot air. It is clear that most people are not aware of it. Few participants mentioned they would leave the windows open during the night time. That is the best way to cool the building during the summer. But the actions during the day matter. **DM** argues that even if they close the windows and the blinds, the building is hot. So he concludes that his interactions do not make a difference. **DM** “Actually the issue with the blinds is sometimes it’s a problem, why I am saying that is because we close the blinds and the windows because the heat comes from outside but it’s still hot inside so from that point of view it’s not super-efficient. There is no good solution.” **LM** and **LF**, share a similar experience as **DM**. **LF** “And it comes in. So, we are basically in here with this big window with the door closed baking in the sun. **LM**, “Yeah but I think it’s better. I don’t
know, it’s my thing but I like it in the morning and night, we open the doors as much as we can, we have the barbeque, the door can be sort of open. The screen shot. It will be cooler and, in the morning, when it gets hot out there, close those doors and also close the blinds because of the sun and it helps a lot but it does suck not to have the breeze. LM, LF and DM are aware of the interactions that help the building to be cool in summer, while one is not motivated because he is not aware of the impact his decisions make. The others simply express their displeasure of not having a breeze. DM complains about cross ventilation so he says for the summer scenario that he will open the windows and door on either side for cross ventilation but there is a conflict in their decisions. DM “Yeah but we definitely need some cross ventilation. So, we try to open window and door on different sides.” DF “I wouldn’t do that; I will just open the window side and not both.” DM “But after exercise, we feel hot but not for a long time.” DF “But then after exercise and if you open both then you will catch a cold.” DM “Yeah, DF will not do it, but I will do it, we will have to negotiate that.” Cross ventilation is a different problem for the inhabitants, how do they know that opening certain windows might have a better impact than the other. Lack of information discourages the participants from taking the right decisions and performing the most appropriate action.

7.2.3 Spatial Arrangement or control location

Location of feedback systems with the existing or familiar interaction location facilitates agency. “I would like to have the control close to the thermostat”

Most participants preferred the feedback system to be closer to the thermostat. HF “Right, I think it would be handy to have something like that next to wherever you do change the thermostat because then before you would adjust it, you could be like oh this is how I’m feeling what should I do properly to save money or whatever.” Proximity to daily activities is ideal for most people, for example, KF “Close to the lights.” Participants also wanted a voice recognition feedback system, as it is easy to converse. NM “Ok so that’s an interesting alternative user interface I would like it next to my thermostat. I think that will be a cool idea. Because you want to stop by and I say I feel warm I always assumed that the
thermostat is going to affect the behavior of your furnace. So, I mean if there was kind of a way to take your system to react that will be cool you kind of go I feel warm and it can go like you put on a sweater or I can take care of it for you.” Apart from it being “cool”, NM suggests locating the feedback system near the thermostat would make interactions very easy. NM also mentions “put one in every room,” So as he walks in it would respond to his queries. OM suggested a similar idea, for having a voice-activated system is easy to access from where ever he is. OM “I don’t know this is a chance I have to give you. Without having left with 3 or 4 different choices, one is I would like it voice activated so I can wherever I am and second is I want it wherever the thermostat is and 3rd I am not sure but no I don’t know.” Location of the feedback system with an advanced technology will improve the agency.

Easy access to the system will facilitate agency. (I don’t want to get up and go to the thermostat, alright I am not going to go up to the thermostat!)

Participants repeatedly mentioned that access plays a major role in using the system. DM states: “in the case the system suggests to you on what to do, then you don’t want to go there each time.” Participants thought that if LWLA was installed in the building and if they had to go to the system always then they would not use it. Their thought process was that if a system is fixed on the wall, they have to get to that specific location to interact. DM “If for example I choose the situation when it tells me when to do something and I need to go to remote position of my house every time then I will not be doing that.” EM “It depends on how it will be right, but if you say, for example, let’s assume ..hmm...for example, I think how easily I can access…. how easily I can see this? Using what?” EM highlights the technology available to us and how it will be useful in providing the feedback. He suggested that instead of having the feedback system near controls, it could be accessed through iPad or mobile phone. LM elucidates the issue of having multiple controls, “Recently it just starts becoming a hassle because there are so many of them, you have to run around and adjust them all.” LM narrates his current issue to emphasize the need for having a control on a mobile device with voice activation. LM “Or rather than expressing but it’s nice to have everything on your phone including the microphone and the speaker. Like if I was in
the bathroom and say the kitchen is too hot, kitchen too hot, I would not have to walk into
the kitchen and talk to the thing on the wall, I could just press it I kind of don’t have to get
my phone out and you know put somebody on hold and I would keep it in.” But his spouse
has a different view, she said she would like to have it as a part of the building. LF “Not
having it in the house. Like I am assuming it installed.” She was talking about having the
system in the living room, where she could just have a glance at it. The problem is people
would not like to go to the particular location to interact with the thermostat, like LM. A
mobile device is always nearer to them, so they prefer to have access from it. Mobile or
internet enablement offers remote access too. HF “like, just for my own sake of wanting
to conserve as much as energy as possible. So, having the building saying, 'yeah hey this
room is too hot or something.' Like you are wasting energy you have a window open and
its heating. Then do you want to do something better, like oh yes maybe the kids left it on
or something and yeah I want to fix that. And if you could fix that not even being home
will be awesome.” Remote access will help the inhabitants in checking on how the children
interact with the building and system as well. It also offers the ability to monitor energy
use and interactions performed by children or by other inhabitants.

![Diagram](image.png)

*Figure 7.16: Reasons for participants preferring phone for access*

Most participants preferred to have the system on their phone as it is easy
to monitor and access it anytime. *(I am watching TV, and I feel very cold then I don’t
have to get up if I have it on my phone.)*
Participants prefer the control of systems anytime and anywhere. Current technologies such as mobile, laptops or other electronic devices make this possible. For example, laptops have become a part of people’s work life, and they have prompts or notifications to access emails and other alerts quickly. EM prefers the phone because the interface is easy to use. EM “It’s easy to scroll it.” FF gives a different perspective, “I am watching TV, and I feel very cold then I don’t have to get up if I have it on my phone.” On the other hand, FM was talking about controlling it while watching TV. Participants would like to have the system control incorporated into electronic devices used in daily activities. HF talks about this from a different perspective. Today’s generation grows up with an iPad or mobile and use it in most of their activities. Parents extensively use such devices to entertain and educate their children. HF “People always have their iPad close by too so that would be an easy thing, you can even say to the kids hey can you check this and get them involved. Because they use the iPad all the time yeah.” People like comfort, if they are working, they do not want to move from their location. It can be inconvenient at that point. KF “On my phone. On all the electronic devices in the household, TV and then on the panel somewhere accessible maybe kitchen I guess cos we spend time here.””

LM prefers to have it as an app on his mobile so he could quickly access it. “Oh yeah then I want it on my phone, just like an app or something. A button that I can press to get it quickly.” However, his spouse had issues relating to its implementation. Her question was how will the data be collected? Though LM was trying to explain the technology she disagreed. LF “I don’t know I kind of disagree. Just because am not very good at using my phone.” Some people struggle with new technology. LM says his wife has difficulty installing even an app in her mobile because she forgets her password all the time. Advancement in technology has enabled us to have voice assistants and few participants prefer it. LM “Or rather than expressing but it’s nice to have everything on your phone including the microphone and the speaker. Like if I was in the bathroom and say the kitchen is too hot, kitchen too hot, I would not have to walk into the kitchen and talk to the thing on the wall, I could just press it I kind of don’t have to get my phone out and you know put somebody on hold and I would keep it in.” And most of all people prefer the feedback on
phone because its on them or they carry it around. **QF** “Probably on my phone. Everybody has a phone all the time.”

![Figure 7.17: System location choices by participants](image)

**Control system/location varies for different household based on their daily activities and building design**

The study showed most participants preferred the control locations to be available in all the rooms for easy access. The order of preference varied across different houses while some may have overlapped. The kitchen and living room played a major role for system location because people spent more time in these places. For some the kitchen was central
while for others it was the living room. Some people prefer the living room because they spent much time there or it was the building comfort, for example, LM/LL said they get a lot of sunlight during winter in the kitchen. So, they prefer staying in that room.

Figure 7.18: Preferred control locations by participants

For a few women, the kitchen was the nucleus, they would spend much time there and specifically, they preferred having it on the fridge. A refrigerator is a frequently used object in a house, and it sounds like an ideal place for installing the system. People complained about the temperature in the bathroom; “temperature matters while showering,” while another participant “feeling cold in the bathroom is bad.” Too much or too little heat matters. It was also convenient for participants to have the interface at the entrance/corridor as they can control or set it at the base of their comfort level. EM and EF had a different suggestion on where to have the system, it was more related to where they can experience
discomfort. For example, a corridor is a transitional space, so they are not going to feel the discomfort but once they are in the living room and watching movie then they are going to experience the temperature. So, they said they like to have the system located in the places where experience of comfort matters.

While people mentioned they would like to have the system mounted on the wall, QF mentions “not on the wall I think on the wall is very old fashioned.” DM suggests to a different level where the information could be projected on to the wall with time interval. DM “on the phone or project it on the wall from time to time.”

Different control settings spatially will solve age barriers.

FF discusses the problem of having a single thermostat control for multiple rooms. FF “But that problem sometimes happens in the kids’ room but not in our room. It is colder compared to the kids’, if I close the window and since we have one thermostat control, with the same thermostat level the kids room is warmer than my room.” She mentions that her room is smaller compared to the kids’ room. The kids’ room also has a small window, that helps in retaining the heat very well. So, in this scenario, having a separate control would be helpful for user comfort. GM and GF say they have different controls for the kitchen, bedroom and living room and they can vary the temperature in each. GF “We have them, and they all worked.” GM “We usually do that in our kitchen and bedroom.” GF “We use a different one in our kitchen. In the kitchen, we normally set at a particular temperature if it gets really really cold.”

It is a hassle to handle so many thermostats

What do participants feel about having multiple controls? Families with children prefer having different controls. Two factors influenced the decisions: age, and room location. Here LM talks about having many control and its hassle. However, previously we discussed people’s thoughts about having controls in every room. LM “I like the automated, programmable ones but when there’s 5 or 10 whatever it is, it kind of gets really bad and I am always dreaming of ways like home automation like I have a separate little thing where I can adjust every one of them, and I can fully control it.” Adjusting all the controls individually is a problem, LM “I find that annoying.” Having multiple controls in multiple locations
could be a hassle. A centrally designed control for the building may resolve the issue. Also providing individual overrides will enable the participants to have more control over the environment.

**Zones and control may resolve multiple comfort issues.**

Some participants find having multiple controls a hassle; others feel having zones will resolve individual comfort issues. **NM** lives in a big house and mentions having one thermostat to control over the whole building makes it difficult to set based on the indoor temperature of the different rooms. **NM** “Designed by zones. Like different zones turn off and turn on depending on the thermal inputs, that will be cool. You could basically have thermostats in every room and then it’s like this and you could have conversations with it as a system that will be cool.” **PM** lives in a passive house, that is a duplex and has one control at the entrance and the other at the living. However, **PM** does not have one in the bedroom. **PM** “Yeah. Then you can go say I feel, but I guess you need this in every zone. But these zones are the same. So, I think we need one for upstairs, one for downstairs and one in the office.” **PM**’s suggestion for his building is reasonable as the building is a duplex, and zoning would help to provide immediate comfort. **QF** and **GF** mention how they use different temperature settings for the different rooms based on occupancy and activity. **QF** “And so we have different zones. If I don’t heat the dining room until we use it, if I heat this area I can turn the basement off and I can turn the third floor off. So, I only heat the zones am using.”

**Proximity to heating vent affects comfort temperature**

How can heat vents be arranged in the houses? How can the arrangement be used to reduce overheating? **FF** discusses the spatial arrangement of the kids’ room. **FF** “and also the way the beds are in the kids’ room and one is closer to the heater, and the other is away, last year JJ was using the one that was closer to heater” **FF** “yeah it’s the heating vent, now the youngest kid is the one beside that, so I think he is fine” **FM** “I think he is comfortable” **FF** “Yeah, I think he is going to be fine”. Initially, she mentions the older boy was sleeping on the bed close to the vent, but he was always feeling hot and uses the fan. However, she later had to make the younger kid to sleep on the bed close to the vent, and
he is comfortable. However, she is not sure. The spatial arrangement of the bed near the vents will have an impact on the comfort.

7.2.4 Agency

Agency affects the comfort of the people and also influences adaptation in the building. DM and DF lived in a individual house before moving to an apartment. They narrate their experiences of having no control to adjust the thermostat. Their owner controls the heating. DM “We used to live in a single-family house and there especially in the wintertime, the person who is the owner, she actually didn’t put on the heater too much. It was really cold, for example in the kitchen, but what we like about this place is that even when we turn on a little bit it becomes warm and it’s a small place and its tight, I guess the building keeps the temperature, so we like that it is sufficiently efficient.” DM meant that, even in the kitchen, they felt cold. Indoor temperature varies between a single house and an apartment for various factors. An apartment is more compact in its arrangement and size in comparison to a detached house. They lived with their discomfort, and this issue was not probed more during the study. DM also discusses the make-up air unit in his apartment building. DM “Actually if you need from the perspective of energy use I have a couple of things the first thing that we have ventilation system for the building that goes in front of our door outside so in winter time when they put the ventilation on, it basically it pulls the chilly air to our unit which is not good. It’s not just us it’s the building and you cannot, I can show it to you after that, basically it’s a huge ventilation system for the building they need to make sure the air goes and gets fresh air and its cold in winter.” DM’s conversation shows that the makeup air unit did not have heating coils as he said the air was cold (perhaps the system was malfunctioning). For DM, the ventilation outlet was outside his apartment door. Occupants do not have control over the central ventilation. DM explains that his agency would be affected by proximity of the control, if he does not have the system nearby, he will not use it. DM “that makes sense in case you want to, in the case the system suggests what to do, then you don’t want to go there each time, if it’s the system that initiates the conversation then you don’t want to go to thermostat all
“the time then you probably want to have it.” EM and EF narrated their experience in their previous apartment. It was centrally heated, so they had no control over the setting. Both EM and EF recount that their previous apartment was centrally heated, so they had no control over the settings. Both EM and EF say in unison “But you have no control.” EF mentioned that they walk barefoot in the house during winter as it is very hot. EM “Yeah, there was one time like more than summer.” EM lived in X Apartment and it has central heat! EM “Yeah its central heat and floor heating” EF “here you have to wear slippers or socks, but in my previous apartment it was so warm that we walk on the warm floors, and usually you go to kitchen it’s warm, you go to the bathroom its warm.” Walking bare feet shows that the building is hot, and since they lived in the middle floors, their room might be collecting heat from all sides. Agency affects inhabitants’ adaptation in a building.

7.2.5 Design and construction

Building Insulation

Building insulation plays a major role in a sustainable building. Heat escapes during winter when the building is not insulated properly. Heat escape can happen when the building is not airtight, through windows that are not sustainably designed or when thermal windows blinds are not installed. During the study participants spoke about windows, both advantages and disadvantages. In the pre-questionnaire we asked the participants about the best and worst features. We discovered the following.

Windows: It is the best feature as it provides natural light and good view; it is annoying as it makes the building cold during the winter and reduces privacy.

Four households gave the similar responses. Their least annoying feature was windows. The reasons for their preferences among the homes varied. Here a simulated scenario: Researcher: what is the best feature in your building? Participant: “window”. Researcher: what is the annoying feature in your building? participant: “window”. We discuss these households and also enumerate the other issues consolidated from other participants. DM and DF live in a high-rise apartment. The apartment is surrounded by smaller buildings and has open space. DM “But what we like about this place is that even when we turn on
a little bit it becomes warm and it’s a small place and its tight, I guess the building keeps the temperature so we like that its sufficiently efficient, but from other point of view when it becomes really cold in winter time we have that glass wall when its -10 and because of that glass, the heater keeps going all the time and it doesn’t help.” In the above quote, DM elucidates the importance of small and tight space, as it retains heat. It is an important design consideration for sustainable buildings. What is more important here is that DM mentions heat escape through glazing. While DM was expressing his concern, DF “So, for me what I like about this place is that it has big glass windows, on one hand DM said sometimes it may become cold on the other hand you have a nice view and I just like the view that we have you can look outside, and it looks nice. Also, its higher floor, DM likes living in the higher floor because its less noisy and there are less exhaust fumes from the cars and you can see the view.” DF emphasizes her preference of the view and nature, a constant struggle for any person when it comes to saving energy. However, DF thought this issue could be resolved with double pane windows. DF “But on the other hand even if we have the same amount of glass if we have better insulation and double rows then it would.” DM cuts the conversation and says, “it’s double glass.” Double glass windows reduce heat escape, a general sustainable practice and DF says, “It’s still not sufficient.” Here’s the reason why the building is cold even after installing double pane window. They live in a high-rise building, and the wind speed will be higher at the top part of the building. The heat escape can be resolved by installing a thermal blind, but the occupant prefers the beautiful view. Hence a triple pane window could be the solution. However, also we do not know whether the building has a proper glass with higher R-value. KF lives on the mountain with a beautiful view. Her ceiling height was approximately 16 feet and the living room is fully glazed. KF “Yeah. Mostly in the winter, I think because this unit has very high ceilings and it becomes very difficult and expensive to keep it warm. So, winters for sure. And in the summer, there’s like this one week when it gets really hot and because it’s a greenhouse because of glass and we don’t have fans or air conditioners, so those are the two main seasons.” KF faces issues during winter as well as summer. KF does not have thermal blinds, in her case maybe even if they use partially closed blinds it could make a difference.
Their apartment building has a wonderful mountain view. It is a reason why KF finds it as the best feature. KF “Honestly it’s the windows. It solves the problem because it’s also the most fun.” KF is saying that the problem of the cold room offsets the beautiful view. As a designer, one could seek to incorporate the two things together. In KF’s case, because of the terrain, their apartment gets a high ceiling. It was merely a design constraint. LF explains an analogous situation, they live in a individual house, and they have a beautiful wooden patio, LF “and the heat comes in. So, we are basically in here with this big window with the door closed baking in the sun.” LF discusses the discomfort they face during summer. They love the glazing and its opening to the patio, but during summer it is unbearable as they get so much heat from the sun. In Vancouver, summer is for few days or few weeks, and people tend to adjust.

PM lives in a passive house, and he shares similar experiences as others, but his reasons vary slightly. PM “In terms of comfort, it could be in terms of view. I would say the best feature is all the windows.” PM talks about the south facing sunlight that keeps the building warm in the evening and also has a beautiful view into the garden. However, when questioned about the annoying feature, he mentions the windows as they reduce privacy. Similarly, other participants mention windows as the best feature but did not say as annoying. OM “forest and view and it’s basically a log house, a log home, and they are all machined cedar logs, it’s like walking into a cedar house.” OM’s house is on an island, and his house is not well insulated. On the other hand, IF mentions that her townhouse is better on heating bills compared to the previous house she lived in. Other participants liked the windows for good air circulation, for example, EF “and the windows, I love the windows in the kitchen, that’s the best. I like the air circulation; Yeah I like to keep it open while I cook or while we are all going out.” EF might prefer this feature because of the building plan, as it does not affect the other zones. On the other hand, LM argues that their building could have had more windows in the living room. It had one but seemed non-existent even during the study LM “Like in the living room you could easily have a window. The front part of the living room is an addition; I just figured that out recently because when you stand and look out the front door if you look to your left down the street,
it sticks out further than every other house the other ones are all at the same distance and our sticks out.” LM is not discussing the leaky building here, he is emphasizing on the bad building design for natural lighting.

Buildings are leaky as they are not well heated. (Yeah, it is leaky. These are all single paned!)

Most participants who lived in individual houses said they had single pane windows and it made the building colder. NM “Not really it’s just that some spaces turn naturally colder or warmer because we have a single-paned glass window, so you know you get cold air and it’s chilly.” Like NM, most people are aware that single-pane window makes the building cold, but what is stopping them from retrofitting the house? Maybe, if they could see the information on retrofitting costs with the cost of existing building condition, they might change their decisions. Another solution would be for the government to provide rebates. Similarly, QF is aware of her leaky house, but cost delays retrofitting. QF “what makes me concerned is No I just worry about the environment and this house is single-paned windows and not very insulated, so I know it’s a leaky house energy leaky and I don’t like to keep it too warm because I know the energy is going out. So, the only thing I did last year was I replaced the roof and I added a number of energy efficient windows upstairs and that made them a lot more energy efficient.” QF also explains how she knows that all the heat is going out because of them. QF “No, I know if I turn on the thermostat up the heat is still going outside.” A solution for leaky buildings can be for the government to give rewards or rebates for retrofitting a house. Another option would be for the system to project energy savings for retrofitted houses. Such a model would show investment cost with savings over time and how the inhabitants profit from the retrofit.

Cross ventilation

Participants DM and DF argue about opening doors and windows for cross ventilation. DM feels opening the main door and window will provide good air movement in the building. DM “So we try to open window and door on different sides.” The conversation arose during the summer scenario, where the participants feel hot after exercise. Though DM was discussing it in general, DF mentions, “I would not do that; I will just open the window
side and not both.” Her reasoning was it could cause health issues. **DF** “But then after exercise and if you open both then you will catch a cold.” Cold may depend on more than one factor, not just opening windows and doors on either side. Cross ventilation may work for an apartment unit, but the interaction may also be restricted because of privacy and security. In concluding their argument, **DM** “Yeah, **DF** will not do it but I will do it, we will have to negotiate that.” However, considering the situation how do they know if they are getting good air circulation? If what **DF** is saying possible, will it cause health issues? In another situation, **GM** and **GF** mention that they leave kitchen and bedroom windows open during winter for cross ventilation. **GF** “Often it is the kitchen windows and our room windows. We leave them open for cross ventilation.” One should consider how this action can be efficient in energy conservation. How could the participants resolve the issue efficiently? Installing an HRV will solve the problem of getting fresh air without heat loss. There should be a reward offered by the government to encourage the people to retrofit their houses.

**Insects and pests affect the use of building elements or system.**

Two participants explained about the problem of insects and mosquitoes and its influence on interaction. **DF** “Like I am not sure whether it is relevant or not, but we have moss and insects, so they are in the ventilation system and they come to the apartment constantly, and it is not fun.” **DF** explained with disgust about the unused ventilation system in their apartment and how the insects from it invade their apartment. It is not a pleasant experience for any occupants. Building managers should be able to help the participants to clear such issues. **KF** explains that the building is surrounded by plants; mosquitoes, and bugs come into their apartment when they leave the windows and doors open. **KF** “I find that the windows here don’t have a mesh. So, what’s happening here is when we leave the windows open for the air to come in for the air circulation, the mosquitoes come in. The building here, that’s the one thing that is annoying. Because there aren’t any fans. So, to think about the comfort for the residents, the air circulation, there should be a mesh on every window, is what I think you know.” Since most apartments in Vancouver do not have
a fan, it is annoying for the participants when they are not able to open the windows. The apartment owners should solve such issues. In this situation, the cost could be a hindrance.

**Mechanical ventilation**

**Participants lack understanding of system functions and design of building elements.**

When proper systems are not installed or if they malfunction, discomfort can result. **DM** explains how the vent outlet placed just outside his apartment unit causes discomfort because of the cold air during winter. **DM** “The first thing that we have ventilation system for the building that goes in front of our door outside, so in winter time when they put the ventilation on, it basically it pulls the cold air to our unit which is not good. It’s not just us it’s the building and you cannot, I can show it to you after that, basically, it’s a huge ventilation system for the building they need to make sure the air goes and gets fresh air and it’s cold in winter.” The issue could be resolved if the ventilation outlet was placed few feet apart from the opening of the apartment unit. **FF** comes from a warm country and mentions the lack of window in her bathroom. **FF** “Maybe there is no window in the bathroom, a little window.” They have an exhaust fan in their bathroom which solves the issue of the window. **FM** “but we have an exhaust system, the fan that automatically takes.” However, cultural lifestyle and lack of knowledge on the function of exhaust fans can be influencing her dissatisfaction in the system and building design. **GF** explained the process of make-up air unit and how it influences the heat in their room. **GF** “So in this building we have the air, I am not sure what we call it, makeup air unit, so it stabilizes the pressure the air pressure to up and down the building and supposedly that will also stabilize the temperature. Theoretically, it should. Now there’s a whole lot of things that could interfere with that. That I find as an interesting concept because theoretically someone could be heating their house to a huge amount if their makeup air unit does not work partly and that could be making it really really warm or their energy could be transferring it all the way to the bottom and it’s not actually heating their place up. There’s a suction tube running out to the basement, they were trying to explain to me in the board, sounds like an important piece of equipment to me.” A makeup air unit replaces the stale air and helps in the function of heating efficiency.
What happens if a makeup air unit is not working properly? More information about the functioning of building systems will help participants awareness and involvement toward a sustainable environment. GM also discusses the vent in their bedroom and how they use it to either pull the air in or to let the hot air out. GF “It’s small and open wide.” GM “We don’t readjust it during winter. It’s open as wide as possible.” They mention that they leave the vent open all the time even during winter. The function of the vent is to let the hot air out. Basic information on how functions of mechanical systems in the building affects the occupants’ comfort might help them in using the building better.

**Building orientation and placement**

**Placement and orientation of apartment unit or rooms in individual houses influences comfort and interaction**

DF needs information on how air could circulate in her in her apartment. DF “Also because it faces out one side, and not double side the air does not circulate, so it can become really hot.” Her misconception is that the building heats up a lot because of lack of air circulation during summer. The participant is not aware of the influence of the outside temperature on the inside temperature. So how do the occupants know if there is enough air circulation and how it gets heated up? FF mentions how her kids’ room gets overheated because they have only one thermostat control. “But that problem sometimes happens in the kids’ room but not in our room. It is colder compared to the kids’, if I close the window and since we have one thermostat control, with the same thermostat level the kid’s room is warmer than my room and also their window is smaller.” The reason is also due to other factors as the kids’ room is close to the furnace, smaller than the master bedroom and the window is small. This could be resolved with a separate thermostat control. Occupants need to know that many factors can influence the temperature of the room.

GM and GF mention that during summer, even though their building is not facing the sun, it is still hot. GM “In summer, it is hard to get the house cooler. Although the direction the house faces is cooler than the house previously rented. So, it is not bad.” How can they resolve the issue of heat during summer? GF “It’s not a sun-facing apartment. So, it’s not like we have sun pouring in here but... we still have an issue with that.” GM and GF
consistently said throughout the study that they like cooler temperatures, and also they leave the windows and doors open during summer. For IF and IM, the master bedroom gets much sunlight during the evening. So during summer, it gets very hot, but they have another room that is cooler during summer. IF “It becomes warm and our bedroom is at that end and that’s where we get the sun in the afternoons, but we can’t switch ’cause that bedroom is bigger than the master bedroom... the house we had before, but it doesn’t have any closets.” When questioned about changing rooms during summer, they mentioned that lack of closets in the room had stopped them from moving there during summer. JM and JF live in third floor, and they get heat from all sides, and the unit is warm. JM “Maybe it’s because we are in the middle of two other floors.” If their unit were in a corner of the building, they would have different temperatures. In a large building, the set temperature should vary across the apartment units because of their locations. KF gives an interesting perspective on how, when she enters her house, and it is warm in the passage and as she moves to the living room it becomes cold mainly because of large windows in her apartment. KF “Is interesting the way it’s set up. Like when we walk in, let’s say heating is on when one of us is home and we walk in, when we walk through that door that part it’s really warm and when we walk in to the unit, it’s all cold again. So it all settles there.” So, the warmest place in her house is entrance hallway. Since most participants have south facing windows, they mention they will close the blinds to block out the heat. Building orientation and unit placement influences comfort temperature and interaction. Design facilitates or hinders the interaction of the occupants with the building elements.

Black absorbs heat, a fact that is generally understood by most people. DM applies the same principle to the building. DM “Actually yes for the single-family house... it is the design, they had like a black roof and... had some layer in between, so bedroom was on the second floor.” DM felt that the attic was getting heated because of the black roof, but this is a misconception as heat is gained through the walls and rises. People need to understand buildings. NM shares his experience with optimizing the furnace. NM “We bought a high-energy furnace. We did like a high efficiency not a high energy, high efficiency. We are concerned about energy use in the sense that we think it’s good to try to use less. We had
for a while we got offered a program to check if you had leaks or something in your house, so we try to make your house more efficient. Whenever we replaced windows, but the house is built in the 50’s, and that is all single paned, it’s a pretty old schoolhouse so it will be pretty hard to replace all those stuff, so we had to optimize.” NM mentions that replacing the window material is hard. Cost is a hindrance here. However, he came up with the solution of upgrading the furnace. Is this the best decision an occupant can take? While NM talks about the system issues, DM compares individual houses with apartment units. DM “Actually in this apartment we are much happier with the temperatures compared to the previous place we lived, it doesn’t require so much heat in the winter and, it doesn’t get too too hot in the summer.” He felt the individual house was cold compared to apartment units. The individual house has different environmental parameters that affect its indoor temperature. DM also discusses stone floors and how they add comfort during different seasons. He mentioned that since the stone was cold, it was easier to handle the hot summer days. DM “But from other point of view, like in that individual house, on the first floor it was like a stone floor something so even in the hot day it was easier to be on the first floor. Design definitely matters for us. And DF we have lived in this house for 7 years?”

Lighting affects the participants’ moods and causes discomfort.

A few participants mentioned they like sunlight. EF mentions that she loves having a lot of light. EF “so we really don’t know how much we are using I love lots of light.” FM states that the building he lived in previously has many windows compared to his current house. He said that the light was good, but during summer it made it hot. FM “Yes, it is different from our previous home, we lived in X housing apartment, they have these big windows, in the LR house, the have these windows that you can capitalize the use of light, the windows here are not as big as the other one.” GM’s building does not get enough sunlight because of terrain and orientation of the building. GM “Lighting is poor. Generally, in this apartment, I like the main fireplace. Gas fireplace.” LM and LF discuss the lack of light in their apartment unit and how it makes them depressed. A sound design influences a healthy design. LF “the living room itself.” LM “It’s a bit dim and it is depressing!”.

149
were not using the place because of its awkwardness and spent time in another room that has a lot of light.

Lack of information on energy usage hinders the participant’s awareness and motivation to take sustainable action

People living in apartments have various levels of involvement in energy usage awareness. Some apartments come with electricity included in their rents. So, the occupants pay the rent without being aware of their consumption. EM “it comes with the rent but still.” EF So we really don’t know how much we are using. Not knowing the energy usage can demotivate participants from sustainable practices. KF explains he frustration of not having access to metering data. KF “We find it a bit small. I don’t know if this is going to be relevant, but we don’t have enough storage. And we find that we never get to see the meter for electricity. We don’t know what our usage is. And we don’t know how the strata divides its electricity bills among its residents.” BC strata should enable occupants to know how their unit performs with other units. KF’s unit usage is higher because of its design, and it consumes more energy compared to other apartments because of large window glasses.

Building material affects the indoor temperature

Not many participants speak about the building materials. Most of the participants’ houses were built in wood, apart from FM who mentions their townhouse had concrete walls which made their building cooler during summer as well as winter, but it was to their advantage during summer. FM “Here one section of the apartment has concrete walls, this one’s wall is different from the walls of other apartment it has different material which can get warmer during the summertime. But this one is cool, keeps it cool during summertime and we don’t get that much heat, so this is one of the preferences this wall has the concrete right, and others have different material that makes it warmer.” He explains how his neighbor mentioned that their building is hot. FM “We like to open as much as possible all the windows and bring the fans to the living room, to use light clothes, we open the doors sometimes too to allow the air to enter, again with concrete its cooler a little bit, this building has different kind of insulating material like wood or plywood can already get warm some people are complaining about the heat especially the people living upstairs (they
have wooden walls), and all the heat is trapped in.” Again, building material is not the only factor because their unit is the first floor and the neighbor’s house is on the second floor. **DM** also discussed stone floors in an individual house and how it made it cool during hot weather.

**Participants express their displeasure in not having to air-conditioning**

Most Vancouver buildings are free running: they have heat during winter and natural ventilation during summer. More new apartments are incorporating both heaters and air-conditioners. All participants’ building were free running. **EF** “We go out, it’s just unbearable and we don’t have air conditioning so and the room becomes very hot right?” **GM** talks about how they adapted in such situations. **GM** “We used to leave the door open as there would be a sort of air conditioning in the passage outside. It’s not proper air conditioning. So, we would keep it open. Or neighbors do the same thing. But our electricity bill was lesser that’s probably because we don’t use much heating and have better light because we are facing the sun more. Our electricity bill was less; And we had to deal with more heat. Here we deal with less heat.” **GM** is talking about the makeup air unit outlet in the passageway. They emphasize how their neighbors do the same thing. Privacy and security do not seem to be a problem to them.

**FM** discusses how the building gets heated slowly compared to their previous apartment. Slow heating could be due to various reasons, including the floor level, zoning, and the system itself. **FM** “Yeah usually here we in this building, the heater is not that high, the warming up here is slow, slower compared when we used to live in X apartment there it was high, here it takes time to warm up the home.” **FM**’s expression of concern shows that he would like to know the reasons for delayed heating.

**Baseboard heating is comfortable**

A few participants discussed baseboard heating and its coziness. **LF** mentions that their bathroom has baseboard and it feels comfortable. **LF** “We have baseboard heating.” **LM** “Yeah. So that one controls this one and there’s another one by the bathroom. The bathroom has a heated floor.” **LM** “Just in the bathroom.” **LF** “Just in the bathroom.” **LM** “So it’s nice. The thermostat controls it.” In fact, she mentions that she turns on
the shower and stays inside the bathroom longer because of the comfort of the heat. NM mentions the lack of baseboard heating in his house. NM “like my house right now does not have that ability. It doesn’t have baseboard heating. It did that will be cool. I have friends who have hot water on their floor.” He explains it from the experience from a friend’s house and sees it as more comfortable. OM also mentions the baseboards installed in his house.

Trees are a good buffer to block heat during summer

LM and LF live in a individual house surrounded by tall hedges; these help in blocking the sun. LM “So, in the summer, morning the sun is behind the hedge.” FF and FM also mention that they have a big tree and it blocks out the sun. FM “and it buffers the heat.” LM also talks about a monkey puzzle tree and how it does not play a role in blocking the sun but provides wind protection.

7.2.6 Social Context

Children

Parents are mostly concerned with children about turning lights off.

Participants with children are very concerned with them turning the lights off. EM and EF’s children are six years and less. EF “Oh yeah, I tell the boys to turn off their lights whenever they go out, it is not always happening.” Since they are young, they were allowed only to interact with the light switches and not with windows. They live on the fourth floor, so it is not safe for the children to interact with windows. FF says that her two young children are scared of the dark, and they always turn the light on while sleeping. FF “I like to see that, I say very concerned because I also keep checking if kids turn off the lights in the room, sometimes 3rd kid is scared of the dark so he wakes up and keeps turning on the light of the laundry room. He does not like to see that dark area, so we turn it on and also JJ we ask why did you turn that on. We say we are very concerned because I keep checking that the kids turn off the lights.” It is a conflict for the parents because of the child’s fear. The lights are on during nighttime in the laundry room to keep the child comfortable. However, GM has kids who are six and below and proudly says “Yes. To turn off the lights. They know it pretty well.” HF’s child is the same age as the above parents’ child, and she says
that she makes sure that her kids turn the lights off before they leave to school or when they go out. She also mentioned that she has been training them to turn the taps off while brushing their teeth. **HF** “Then you might leave a window open at night when you don’t know yeah, but when we leave to go to school every morning they are in charge of making sure they turn off the lights behind them. Because they tend to leave a lot of stuff, grab a sweater go get something from the other room, so then I always say did you turn the light off, so they do that. So, when we brush our teeth they are good for turning taps off, that sort of stuff yeah. So trying to teach them that.” Parents involved the children who are seven years and younger only with turning the lights off, mostly to keep them away from windows for safety reasons. The study did not have a large enough sample to understand how a child feels and interacts during uncomfortable room temperature but a few participants shared their stories. **GF** mentions that her six-year-old son and three-year old daughter know how to interact with the thermostat for the gas fireplace. **GF** “Yeah they do! In the wintertime, they know themselves when to put the fireplace on. They know themselves. We don’t put the heaters on in their bedroom. They know not to turn on the heaters in our bedroom, bathroom or in other places. They know we normally use the fireplaces and they know how to switch it on or off.” **GM** narrated his conflict of comfort experience with his three-year-old daughter. It just happened few hours before the study. **GM** turned the fireplace on because he felt cold and his daughter turned it off after few minutes. **GM** “I had it on little bit today and after a while, my three-year-old daughter got up and turned it off.” Children’s metabolisms are different compared to people who are older. Parents may end up trading their comfort for children. Similarly, **MM** says they use fans only when their son is around. **MM** “I mean the fan is used especially when my older son is now away. He uses it when he’s hot. When he’s warm so he’ll use the fan more in summer when he likes to sleep.” He says with the older son away to study no one uses the fan. Having children in the house affects the system interaction and energy usage. How is this parameter being considered in design? Or is it so small that it is negligible in design considerations?
Children might overreact to constant correction

EF talks about the difficulty in telling the children or making them do things regularly. EF “Yeah that’s especially so if you have young kids. You really can’t ... you can’t keep telling them every day don’t do that, they will run, they want to jump but we are highly concerned about overreacting like don’t do that for you always worry about your neighbors, so yeah that’s the big thing.” She talks about their tantrums and how the neighbors complain about the noise. So, this leads to considerations of how a system can involve the children in sustainable actions in a more pleasant manner.

Having babies affect the thermostat settings

We had only one participant who spoke about the need for different temperature settings when they had a baby. Most of the participants’ children were two years and above and also, we had a participant who was pregnant. EF “We never really use it unless it’s necessary. Like I remember I used it when my second boy was young when he was a baby, you know you want to control the temperature, but it’s manageable without the thermostat.” Even though she mentioned they had to change the temperature she concluded by saying it is manageable without changing the temperature.

Child lock is essential to ensure safety and control with LWLA or any system.

One participant was looking five years ahead and imagining that they have a system installed in the house. Any digital data with no proper security system poses a threat to the users. Moreover, today’s children grow up with technologies like iPad and mobile for entertainment and activities. EF “Child lock, password I don’t want someone else to walk in the house and change it. You know five years to come Kid 1 would be big enough to do whatever, security access like password, I think those are there right? Parents can have some keys to it, not only child lock but they will not play with it that will also not be too if you want to change or maybe someone changes everybody gets the message.” EF says that she would be liked to be informed if the child makes any changes to the system settings. She also further elaborates that you could also give them a call to inquire about the issue.
“Yeah something has been changed, and you go why did you change it and give them a call like you say what’s going on, the user can get the same information what has been changed.” FF is a sustainable enthusiast, she is an active participant in encouraging people to take sustainable decisions. FF “If it’s cold I would go check and see the thermostat, to see where the temperature is, if the temperature is very cold I just turn it on higher little bit and I also wear my sweater and ask the kids to wear sweaters and socks especially to keep them warm.” She suggests her children also to take similar actions as her. But when FF mentioned that she would suggest that the children to wear additional clothes, I asked her whether they would do it and she said yes. The children may learn by seeing the adaptions made by their parents and their involvement. In the previous section, EF mentioned how she was afraid of her children overreacting to corrections. Maybe the system can help in these decisions by prompting or sending messages for children, “Your parents wore another layer to keep themselves warm. What would you want to do?” and giving them few choices to choose their actions. Also, this idea would be limited to children who have access or permission to interact with the system. There could be different approaches for smaller kids.

Video games affect healthy habits

FF highlights an important factor that needs to be considered in design. “Especially for JJ I have to remind him to turn on the light because he is playing video games. He is in room that does not have a big window and it’s dark in there.” FF says that how she has to remind her son to turn the lights on as his concentration is only on the video games. Saving energy is one aspect but living healthy is important too.

“I feel” and “If buildings could talk” will help the children to learn.

In the post-questionnaire, the participants mentioned “I feel” and “If buildings could talk” would be more useful to the children as both are easy to use. They can also help in the learning process. FF “I like two options, “I feel” and “If buildings could talk”, I feel in this one “If buildings could talk” especially for children that are part of the family, this one will show them more, why, so they will understand why this option is better than the other. In I feel it gives less of that feedback, this “If buildings could talk” it’s the other way
here I am not thinking too much and options are already there.” FF prefers both expression modes as she concludes one will be easy to use and the other will help them in learning, since “If buildings could talk” send prompts to people based on the set parameters. The participant felt her children would learn why it needs to be changed or what affects the building comfort and energy usage. FF looks at the system as a learning tool for them.

HF has similar thought process as FF because the children use their iPad all the time, they can also be involved in LWLA if the system is available and easily accessible from different technologies. HF “it’s easy to use it. yeah definitely. It would be good if you are at home accessing it on your iPad. People always have their iPad close by too so that would be an easy thing. You can even say to the kids hey can you check this and get them involved. Because they use the iPad all the time yeah.” HF also talks about how the system will help her in reminding if a window is left open, HF “like just for my own sake of wanting to conserve as much as energy as possible. So, having the building saying yeah hey this room is too hot or something. Like you are wasting energy you have a window open and its heating. Then do you want to do something better, like oh yes maybe the kids left it on or something and yeah, I want to fix that. And if you could fix that not even being home will be awesome.” While some highlighted security and learning, HF spoke about reminders by the system, e.g., in case their children left the windows open.

Neighbors limit the interactions for assorted reasons like noise.

GM mentions that he leaves the extractor fan on to have air circulation in the building but also mentions that neighbors do not like the noise it creates, so they cannot leave it open throughout the night. GM “It’s generally cool. If it gets too warm in the nights, like I said, we put the fans, windows often open, fan in the kids’ room, angular on top at us. Sometimes, to also get airflow we put extractor fans on in the bathrooms. The neighbors upstairs say it makes too much noise. So, we can’t leave it on at night time. They say please don’t leave it at night. It makes noise.”

Conflicts in temperature across different age groups.

HF mentions they prefer wearing sweaters to turning on the gas fireplace during the daytime. HF “So we turn down the thermostat, we put on sweaters during the day and then
we wear slippers also because its concrete floor underneath us so your feet aren’t cold and then we don’t turn the fireplace on until the evening. Partially to save money but also partially, so the kids don’t touch it by accident….safety.” She mentions it not only to save money but also because their children are young, and they prefer the actions and setting for security reasons. While most parents were talking about their children’s comfort and interactions, HF was wondering about a situation when there are more kids over. HF “Your kids over because extra kids and they are running around, and you are cooking and the temperature because this is giving you live feedback from the thermometer right. They are not going to be cold.” Her concern was the children are not going to be cold, but the parents are going to be cold. So, in such case what would the system suggest?

NM elucidates the problem of conflict with the children in regard to comfortable temperature. NM “well see in the winter when it’s cold and rainy in Vancouver its really concerning I would say like a 7. I guess it is not life threatening but it’s still a lot. My daughter just likes to get in the bed and just cuddle in there.” He mentions that the children do not understand that the temperature is fine and there is no need to bump the temperature. NM “Not really no, we never feel like this place is too cold, and nobody seems to get it. We have arguments sometimes. The children get angry and go to bed to keep themselves warm.” The conflict is unresolved. Apart from switching the lights off, NM says that he often has to tell the children to shut the doors. They live in an individual house. NM “shut the doors. All the time.”

Collaborate or consult

We try to reach a compromise.

In the pre-questionnaire, we asked the participants what they would do when one feels warm, and the other feels cold. The most frequent response was that one of them has to compromise or they would suggest the other person feeling cold to wear something warm. DF “Yeah but for cold, we try to reach a compromise so than something that will be more comfortable for DM and something that will not be too hot for DM and something that would not be too cold for me. Maybe I will put on more clothes then it will be ok, so he is
in a tee shirt, and I am in a sweater.” DM further explains how it’s often a conflict during winter as DF is colder than her spouse DM. DM “I guess we have a disagreement about what cold means but we have an agreement about what hot means, my impression, basically above 25 is hot for both of us, is it correct DF?” So, they mention that the thermostat is turned up and down very often. The aspect of interaction with thermostat during a disagreement is discussed in the conflict section. FF considers her husband’s body temperature in her decisions. His body is colder type while she is warm. FF “If he is very cold for sure I go check the thermostat, if it’s below 15 or if the thermostat temperature is higher and the room is colder than I turn the thermostat little bit higher.” The most common response from the participants is for he one who is feeling colder to wear the sweater. KF “That happens very often. Well, the person that’s warm will tell the person who’s cold to wear a sweater.” GM and GF have different experiences as both of them have similar comfort preferences. GM “Some might say electricity bills are higher and some might say electricity was higher this month or while. Maybe we need to switch off the lights more or something. Because, that’s viable.” GF “And it’s good for me to know that so that I can take that into consideration.” They try to collaborate and ponder on the electricity bulls and where they had spent more energy. They say it helps in their actions for future. The system can easily provide such information to them for analysis. It’s not often that the one who feels colder needs to wear a sweater, few participants were willing to increase the thermostat. IF “Yeah, the warmer colors are warmer IM you can be in a cold room you change the thermostat, or you put on something a little warmer, you are going to feel more like that.” The participants who were willing to increase the thermostat were seniors. OM “No I mean it’s a very typical issue between husband and wife right or between one person and another who are living together, adjust the thermostat a little bit, if it is really quite cold we will put on an extra layer of clothing, we got a wonderfully warm thick sweater, I’ll put it on if it gets uncomfortably cold.” The younger people were generally suggesting the person who feels cold to wear the sweater. MM mentions that he and his wife have worked around a temperature that could work for the particular season. MM “We do for example when my father. In the case of MF and I the September chills we have now seems to work for both
of us and my son never complains. Typically, it is the guests that will cause for a change.”

The study concludes that younger generation uses the sweater as a compromise while seniors consider increasing the thermostat. Age plays a role in the level of collaboration.

LWLA helps in facilitating consultations

During the task completion, few participants started to consult with their partners on what solutions they would consider. Looking at the possibility of options helped trigger a conversation for solutions.

DM: “So DF, do you want to tell me what you would do in this case?”
DM: “Yeah what would be your suggestion.”
DF: “If it gets hot in the room and am cooking, if it gets hot what I will just reduce the heat.”
DM: “But you are wearing a heavy sweater.”
DM: “So in this case it’s fine, actually in this room I would probably take of the warm stuff. Do we agree with that?” DF: “The thing is usually when we cook no matter the temperature is he would open the window just to get fresh air so that it would be the choice”
DM: “F what would we do if were sitting on the couch? I would say we would put additional clothes on? No.”
DM: “It definitely makes sense to have hot drink and close the door. What would you say F? My first impression is often when we are cold during the rainy date we get hot tea or something.”
DF: “First thing would be to close the door or the window, the second one would be to put on some warm clothes and after that have something warm.”
DM: “What about hot drink? Do you want hot drink?”
DM: “I would open the windows and use electric fan and what about you?”

I just sat listening to their conversations. Similarly, EM wanted affirmation on his decisions. EM “I want to change activity but what would you do, I would drink something.”
Even GM and GF were consulting each other on their decisions. GM “What would you like
to do, open the kitchen window?” GF “I would like to open kitchen window, I don’t want to open the door.” GM “You want to put something warm on?” Participants considered their partner’s concerns.

Can the system replace professional or social consultation on system issues?

Most participants used the system as a consulting medium with their partners. IF throws a different light on consulting. IF “Well, here if it is like we have got it set at 20, it wouldn’t be warmer unless it gets up to 23 or 24. If it was going up that high, I would probably open the door and might even be tempted to call up somebody and say, why is this happening? Yeah” A participant expressing the need to know the cause of overheating shows that they need to identify the natural building cause for heating. Alternatively, does she need to consult someone to figure out the issue? Maybe LWLA can help in collaboration.

Conflict in comfort requirements

Conflict in comfort requirement is a constant battle for the inhabitants. (It is a constant battle!)

When the participants were questioned on what, they do when one feels warm, and the other feels cold, most of them laughed at the question and said, “it is a battle.” Here are the few responses, DM “actually it’s different for us.”, DF “it’s a constant battle.”, LM “Have a fight.” DM explains the reason it’s a constant battle is because they have different temperature requirements. DM “I guess it’s like two things, first of all, we have different temperatures of comfort DF likes warmer, and I like less warm and so basically I am turning off and she’s on and we find the balance in between.” Even during the study, the participants were conflicted in regard to their actions and choices. DM “Yeah but we definitely need some cross ventilation.” DM “So we try to open window and door on different sides.” DF “I wouldn’t do that; I will just open the window side and not both.” DM “But after exercise we feel hot but not for a long time.” DF “But then after exercise and if you open both then you will catch cold.” While one was feeling the building needs cross ventilation, the other was feeling they would get sick.
It was interesting during the study of EM and EF, because when the question was asked they narrated an event that happened few hours before the study.

EM: “So it was just an hour ago, we just had an issue with the thermostat, where I mean she thinks it was.”
EF: “too cold”
EM: “too cold, right, but I thought it wasn’t”
EM: “No to increase the temperature”
EF: “he did not”
EM: “but I did not”
EM: “I think this one is better actually, what do you think?”
EF: “No, actually this is very cold.”

This is a common struggle between partners. HF narrates an experience similar to that of the previous participants. HF “I would say I’m the one who drives it but then Jeff has a different temperature level than I do so he cranks the heat up more than I do. So, it’s a battle.” An elderly couple had a different experience where the wife narrated that she had to go to sleep feeling cold. IF “Because he’s usually warm. I am the one that’s always cold. And I just, as I have gotten older, I have switched to wearing woolens or an alpaca which is even warmer than wool.” IM “No” IF “Well, I have been too hot sometimes, I’ve gone to bed freezing and he says how can you be so cold when you woke up whole night feeling hot. The room had not changed my thermostat is sure” IM “It’s her thermostat.”

FF narrates an incident that brought conflict in their comfort temperature because they were doing different activities. FF “You know what he likes to do, he goes, like early in the morning like during the weekdays, I wake up and go to the kitchen to do breakfast, that’s why I get warmer because I do all these things mention but he wakes up and takes a very hot shower.” FF says that he opens the door later for cooling himself down. Activities affect the body core temperature, so people performing different activities will conflict in their comfort requirements. But there was one participant who mentioned that it’s not a
conflict. **OM** “I think this is not untypical, I often prefer it to be a little cooler than she does. But it isn’t like a constant turning up and turning down.”

DM and **DF** also said it was difficult to arrive at a comfortable sleeping temperature. **DF** “What he is comfortable for sleeping I am cold when I am comfortable he is hot. So one good thing was that we got a down blanket and then we can make the room temperature colder but still stay warm under the blanket.” They seemed to have resolved the issue with a blanket. Most participants mentioned that they are in constant battle, while some found solutions.

**Conflict with people living next door.** Neighbors thermostat set temperature heats the building above.

**IF** narrates an instant where she says an elderly woman lives in the house beneath theirs and she says that the heat from her house is adding to hers. **IF** “In fact sometimes, I wonder why it’s so warm when we’ve turned it down. But, we have an elderly lady living below us. So, it could be the heat in the other house yeah. It was always like. It wouldn’t be badgering the day but by evening, I couldn’t figure out why the whole house felt cold no matter what we did.” **IF** mentions she was not able to understand the issue. Heat gain happens from the house beneath theirs, but it can be gained through windows and walls as well. **IF** “light gives some heat. Today I was doing some baking and well as cooking cos it is Christmas season but even if I when am not doing that, I think some of it is because the lady below us is a lot older than us and they tend to need. She’s very tiny. So, I think she needs more heat and heat rises.” She further explains by saying that even when is not cooking, she feels the building is very hot. A participant explaining their need in understanding the situation shows the need for a system with such information.

**Conflict in self-decisions while considering others.**

**MM** narrates how he would adjust the temperature for his father who visits him occasionally. **MM** “I don’t. Well, I do now sometimes when we have guests, my father is in his 80s, MF’s parents are in their early 80s, and sometimes especially my dad feels a little cool we punch the heater one or 2 degrees when he comes. That is probably the only time that we adjust this.” They would usually override the thermostats for guests or relatives.
Moreover, also while doing the task with the LWLA system, he expressed the conflict in his decisions. MM “So I think the next thing I would do is am wearing a medium clothing. And this is what I would do in the answer to your question. I would do to keep myself or I would do for my family realistically?” The question that MM posed highly depends on the occupancy detail. The system can provide information based on multiple occupants present in the room or building.

* Negotiate

LWLA system helps in negotiation.

During the pre-questionnaire, participants were questioned how they negotiate or bring a solution to their conflict in comfort requirements. Most participants explained their struggles and compromises in such situations. However, during the study of the proposed LWLA system, DM and DF were looking at the several options the LWLA system provided. DF “We try to reach a temperature comfortable for both of us.” DM “So let me see what I am doing, I am using a lot of energy here, ok so my choices are not really efficient, so what about DF? Open (leaving windows open) not efficient. So, these two look to be better.” DM “Actually, you mentioned that negotiation, what to do? Actually this would help us to reach probably the collective agreement.” DM recollected the questions that was asked during the pre-questionnaire and said this tool would help them in negotiating to make a collective agreement.

7.3 Interaction Models

In this section, we discuss the findings on the proposed eco-dialogues “I feel,” “If buildings could talk,” and “What if?.” The eco-dialogues were slightly different from each other in their design constructs and data representations. So, in the General section I discuss the common concepts, understanding and issues across the three dialogues. Then I discuss each eco-dialogue individually based on the participants’ perceptions on what worked and did not work for them. I also discuss how the findings matched the proposed design constructs of the eco-dialogues and the gaps or factors that the participants found irrelevant, annoying
or needed. In model comparisons, we discuss why participants preferred one model over the other.

Figure 7.19: Eco-dialogue in order of preference. Out of 21 responses 11 chose “I feel.” Two participants chose “I feel” and “If buildings could talk” as first preferences

7.3.1 “I feel”

The design considerations for “I feel” were inhabitants’ expressing their sense of comfort in the building and providing them with all possible options they could take in a given situation. The possible options are displayed in terms of comfort and energy usage. In our study the energy usage displayed was related to only heating demand. Hence the main parameters are my sense of comfort, possible options and comfort/cost comparisons. In the post-questionnaire we asked the participants on which model they preferred. Most of them preferred the “I feel.” Why did the participants prefer this model?

My Sense of comfort (I feel)

Participants liked their current feeling or sense of comfort to be acknowledged as it responds to their immediate surroundings. *(It considers how I feel and that’s important!)*

Participants appreciated to emphasis on how they feel. DF mentions that her senses are important—that’s why she preferred this model. DF “For me the first one would be I feel, because I would go from my own sense of how I feel in the building right, so the actual temperature doesn’t matter that much if I like, it’s just my own senses are more important
I guess, so that would be my first option.” This shows how comfort takes precedence over other things. The “I feel” model evolved from how people express their comfort in their immediate surroundings and to people in the surroundings, for example, a person feeling cold in the room will mention to the other occupant “I am feeling cold, I am going to turn the thermostat up” or likewise. Participant IF noted exactly this kind of phrase by her husband “He is more likely to say, I am feeling hot! Turn the fan or whatever.” Another participant PM mentions “It is your response to the surroundings.” A very common phrase was NM “we can walk into the room and say I feel warm or I feel cold” or FF “On arriving, I feel warm and then I say I feel warm.” Expressing their discomfort allowed them to see the possible actions they can take to feel comfortable. These expressions also conclude that acknowledging the inhabitants’ perception of comfort is important and easy to express to the system.

Participant QF passionately explained the need to acknowledge how people feel in the building. QF is a sustainability enthusiast. During the demo of “I feel” model she mentioned “I think humans like to tell the systems how they feel. I think people like that. To feel very attached to how they feel” she continues to say “It taps into human psychology. We don’t care how the building feels. We just don’t care about it. We just slam the door and we turn around and say sorry I banged the door. But if we slammed the door on a friend, you turn around and say sorry I hurt you, are you ok? So, I think that one to me is psychologically more powerful. I think it’s the human need to be heard to say how I feel.” This participant highlights the psychological need the humans addressed. And the “I feel” model addresses such issues. GM mentions how they would use this model for their personal use “If I am using this for my personal use, I would see what is relevant to my situation.” “I feel” addresses the comfort in the immediate surroundings.

Participants believe “I feel” addresses their present discomfort (It’s now!)

The concept of the “I feel” model addresses the immediate discomfort. I did not expect the participants to specifically mention that they preferred the model because it addresses their present discomfort. Participant IM “Probably because you are feeling that” and JF “because its more present I feel cold and the information comes to you.” Addressing their
immediate discomfort is an important criterion. During the demo when I was describing “I feel” model OM said, “I like that” he also said the reason he likes the model is “I feel is I feel now” This concludes that addressing the immediate discomfort or issues is important to inhabitants.

Participants wanted voice recognition (or assistance) in the system. (I would like to voice my comfort feelings to the system!)

When the model was being presented to the participants they were excited about the fact that they can simply say I feel warm. But they were a little disappointed that they had to select a widget to express how they feel. In initial design I had thought about voice recognition but did not incorporate it reducing the scope of the project. But a most interesting part during the study was when participants heard about the “I feel” model, they started voicing it with modulation. They had a doubt whether they had to voice it or select it! LF “So we would indicate how we feel and then the building can hear what we are saying? We will say it aloud?” I had to mention to the participants that they need to select their feeling of discomfort in the system and in the next stage of the interaction design we would incorporate voice recognition. During I feel task FF mentioned “Yeah you can check the options and say you can turn the thermostat off.” Having voice recognition would make the system more relatable, IF “Probably a good idea especially in this digital age, where people could come in, just walk in and say, “I feel cold in here” and then say “warm it up.” I don’t need to go turn it.” This reduces their interaction physically with the system. Here’s another example, OM “You have a little lever and you can walk over and do a voice recognition and you say I feel cold.” FM was concerned “what about blind people and deaf people, you might need a voice.” NM “I think I feel is neat because it is more differential. It is sort of like you walk into the room and go I feel cold. Okay here are some things you can do. Kind of makes you think in terms of energy.” The voice assistant was not restricted to “I feel” model but it is applicable for the “If buildings could talk” and “What if?” model. In “If buildings could talk”, people mentioned that the system could state a prompt or voice the situation. EM “Hey your room is cold,” it was funny because the participant was imitating in a digital voice. LM was mentioning “It would
be nice to have a speaker and a microphone on the wall, so it is the house that talks “Are you feeling cold?” Oh really am I cold.” It was interesting because that was the intention of the build talk was to have a conversation. LF mentioned it could simply be an alert through sound “Yeah If I was prompted by a sound I can say I feel warm and the house could like, automatically should decrease the thermostat.” NM was comparing about this system design and how it could be incorporated with the Amazon Alexa, “I mean I am just thinking in terms of user interface you keep walking in the room and it goes I know I can sense is really cold would you like me to do something about it?” NM posited that advanced technologies and integrating comfort and energy with the existing voice assistant would help in easy interaction. Most of the participants spoke about the voice recognition or assistant during “I feel” or “If buildings could talk,” but this could be adapted for what if as well. KF mentioned “My schedule is pretty much set. Every Sunday morning, I would clean right. It would be cool if I can just go to the thermostat and say ‘cleaning’.” This relates to the individual inquiry concept of the “What if?” model. All these inferences from the participants mention that a voice assistant would make for easier interaction.

Multiple options and cost comparison

Participants liked to express how they felt in the room and see the possible options with cost comparisons. (I can say how I feel, and it will show the possible options.)

For example, participant FF was reenacting or voicing the scenario as expressing their feeling at the moment or how they feel at that moment. FF “So right now I say I feel and then it is going to show me all the options.” They were mentioning that they can express how they are feeling at the current moment and seeing the possible options. This shows that the system helps in their choices. JM and JF were a couple who mentioned that they have more options to choose from and are able to compare the options for their choices. JM “Yeah you have more options to choose from!” JF “And you can compare, go and click in there and see.” This shows how the participants like to see the options as it gave them feasibility in their choice of actions. Participants felt that it would be tedious or intuitive
to go and check individual actions and their effects, but they preferred the system to show the options. For example, LM “Yeah, just choose from comparative ones.” LM “I think I like “I feel” is the best because the whole point of doors, windows, insulations, sweaters and thermostats is all of us feeling comfortable. So, if I am not comfortable that’s really what matters.”

While doing the study, the visualization display took two steps. Participants could see the comfort levels and make their choices, or they can click on the charts to see how the energy consumption affects each action. Here’s a conversation that happened with a couple when they were asked to make choices. During the pre-questionnaire when we asked them what choices they would make if they felt hot in the room. The husband would always mention opening the windows. The task completion was for winter scenario, where the participants assume they are cooking, wearing a sweater and feeling hot. In that context what are the actions they would perform? The system shows the possible options with the current thermostat setting and also by lowering the thermostat by 2 degrees. DF and DM initially make their choices, but they are doing it with the current thermostat setting because DF mentioned that she prefers not to change the thermostat setting during the winter. DM thinks about what he usually does and still chooses to open doors. See figure 7.20 for narration.

7.3.2 If buildings could talk!

Reminder of Building state and user actions

Participants liked to be reminded when there’s a change in room comfort at a particular time interval or when it differs from norms. (I prefer this model when I am not thinking about anything or too tired to think.)

Participants preferred to be notified when the building comfort was changing, for example, LM mentions the importance of being reminded of how the other rooms are performing with respect to comfort and energy consumption. LM “Although I am just sitting in some other room where I am not, and if the attic is getting cold or something we could probably close the window. I think that is really important. They all have their pros and cons..”
Drake and Gabby are performing the task completion for “I feel” model. They are working on the cooking scenario during winter. Once they express their discomfort “very warm” in this case, the system displays the information. But Drake answers the scenario with the actions he usually performs and is surprised by its influence in energy consumption.

If I am feeling warm and cooking. For me I would probably change the heating
Yeah, I will lower thermostat and remove clothing
Yeah probably change the clothing and open doors maybe

Drake continues ...
If I have to keep cooking, then open doors and remove clothing

Open doors?
So, if you actually select that, if you want to select the “doors open”, you can click on the interface.

Drake and Gabby checked the energy use for lowering thermostat and opening doors as it gives them the desired comfort but when they saw the energy data...

Participants see the comfort options first and energy as second step to give freedom of choice.

Drake and Gabby preferred to see the energy consumption data at the initial stage and did not prefer it at two steps. The option was provided for people who prefer comfort over energy but during the study most of them preferred to see both the data at same time.

Figure 7.20: A narrative of cost and comfort comparison and its influence on inhabitants. The narration is from the study and the names are not real.

LM had issues with heat escape through the attic as their building was not zoned properly. He had tried to resolve the issue by blocking the opening to the attic. Because of the heat leakage to the attic, the building lost considerable heating energy. Hence, he highlights

169
the need to be reminded on what’s happening in the other rooms in regard to comfort and energy usage. **HF** “So that part is getting cold air, and in the other room you don’t realize it, and it says it is starting to get cold, then you left your heat on something?” Here **HF** is narrating similar instance of the temperature control of empty spaces as LM. The inhabitants are comfortable in the occupied room, and they are often not aware of the empty room where it could be getting overheated or cold. This issue affects the energy usage in the buildings. People like to be informed of what’s happening to the building in regard to energy and comfort. **EF** “Yeah that’s the one that will send you messages that something is on I prefer that one better?” **EF** is a stay at home mother of two, and she mentions that she prefers to be reminded that something is on as there are too many things to be handled.

Participants with family liked to be notified of the states of windows or door to further inquire about “who did it.” (I would like to be reminded if the door or windows is left open, so I can check if the kids left it open.)

During the demo of the “If buildings could talk” dialogue, participants asked questions about its function. “What about the people, when something like the door is open, and somebody forgot to close it, will the system sense that?” This showed that the participants would like to know what others do to the buildings. **HF** “Like just for my sake of wanting to conserve as much energy as possible. So, having the building saying yeah hey this room is too hot or something. Like you are wasting energy you have a window open and its heating. Then do you want to do something better, like oh yes maybe the kids left it on or something and yeah, I want to fix that, and if you could fix that not even being home will be awesome.” Here, **HF** mentions the need to be notified of energy conservation, as children could leave the window open and not know the consequences of their action on energy savings.

**Reminder of user action**

**Sometimes default recommendations suffice.** (I don’t want to determine what’s happening to the building just let me know what to do)

Sometimes participants mentioned that they would not be assessing the tool to find out what’s better. Participants preferred less interaction with the system when they are sick or
stressed. And they preferred to be notified. DM “The first one, I want to plan everything, the second one if I don’t want to think about that, it can remind me when I need to do something.” Here DM was mentioning that, after he assesses the different comfort options and their effect on energy consumption, he would not like to interact with the system. Rather he would like the system to notify him about the changes. FM preferred this option, as it would help inhabitants in making decisions when they are sick or overwhelmed. There is a lack of motivation for interaction in such instances. FM “When the computer tells you what to do! Sometimes you are at home, you are overwhelmed and stressed, so you will hesitate to do it by yourself so in real like for people who work and people who are at home might want to interact more, so if it says you can do these then you make the selection” FM mentioned the difficulty in reasoning during stressful times, and this option would be helpful during those times in taking appropriate decisions. OM “But wouldn’t you get a lot of energy saving like having kind of a default temperature up or down? Waking/Sleeping because some people might turn it too high and forget to turn it down?” OM is a senior, even as he discussed the programmable thermostat he highlighted that people might forget their actions. Here the system can take the initiative by itself to either increase or lower the thermostat, but it would not give the inhabitants’ the learning experience or control over the system. Hence it notifies inhabitants.

User Preferences

Most participants wanted the system to prioritize the options based on their comfort preferences. (I want to personalize the system to my comfort priorities.)

In the study, most of the couple had different comfort preferences where one preferred cold while other preferred warm, for example, DF preferred being warm and DM cold. Here’s what DM says “Actually, I am also thinking that from the point of view of the building talking, if the building becomes hot then probably it makes sense to suggest the person because he will feel soon that it is hot. It is becoming cold, and you don’t feel it may be better to wait if the person does not feel cold why you should remind him that he is cold, he is actually not. It makes me incentive to create and put thermostat on, so it is
not symmetric in a sense.” Here **DM** talks about his sensitivity towards being warm versus cold. If the temperature is becoming cold, he may not be bothered as he is comfortable, so the system suggesting the building is becoming cold could influence his comfort decision to actually turn the thermostat on. **GF** talks about similar experiences; if you are cold, then the system can show you the warm options alone. For this study, we included all possible options, so inhabitants can see the difference. But as **GF** mentioned the options could be customized to the discomfort expressed. **GF** “Or if something had to pop up, if it is cold, here are your options that this is how you can warm yourself up. Or the reverse if I was sitting on the computer and it is too hot. The house is hotter; there are the options you can take to cool yourself down.”

**Participants preferred the system to sort the options based on comfort, electricity or based on history of actions.** *(I would like the system to sort the options based on my past actions, comfort or energy).*

Participants prefer an intelligent system that would learn from their preferences and choices. **JM** mentioned that the system can sort the data based on thermal comfort actions they have been taking and then suggest the data based on it. **JM** “Maybe you can sort it based on the thermal comfort on more I used to do it.” **GM** also shares similar ideas in system prioritizing the options based on your interactions. **GM** “I prefer to take action, but it will be interesting to learn from you over time, so it is suggesting your preferred action or may be put your preferred action on your list. Out of ten times, this scenario has happened you have chosen eight times this, so your preference gets on top of the list.” On the other hand, participants preferred simple sorting from hottest to coolest or in order of preference. **EM** “So would it pull out these things or would it be saying do you want to do 1, 2, 3, 4.” Here’s what **GM** mentions: . “But you can show the hottest to lowest”

**Participants suggested having a threshold where they could define energy usage in terms of money.** *(I would like the system to notify when I exceed a threshold of energy use)*

One participant preferred to put their budget in the system and then be notified if they were nearing or over the budget line. **KF** “Yeah, so is it like one could even look at the
system and say that “hey my budget for electricity is too high bucks.” So, then you can sort of like do a graph that says, “How much is above or below?” Or like if you know how you sometimes like when you are looking at your cellular data you would go like “oh my god I have one gig left.” Maybe we could do something like that with electricity. Like you have this much of your budget left to use. So, you better reduce your comfort.” KF continues “Here I want it to be an option. I think this is cool in the sense that it shows me ok you know how much energy am using or saving but in addition to this effect it could also have something to look at so that I know that ok I am reaching that limit so energy usage or for a dollar value more people would want to see.”

Participant asked for examples to guide their actions.

HF suggested including guidance or examples in the system design as people may not be aware of the implications of their actions. HF “You have to be like, ok if I turn these off maybe it would be better or not. So yeah there is no real guidance.” Having guidance or examples may help the participants learn and have impact on their choices.

7.3.3 “What if?” Model

The core design of “What if?” model aimed to probe, through play or exploration in order, to learn or plan. We observed that the inhabitants used the “What if?” model to play or explore, plan as designed, and we discovered other possibilities and limitations.

Play or explore

Participants liked to make inquiries about their daily activities.

During task completion, many participants wanted to enquire of the “What if?” model about their regular or day-to-day operations. Though we had different scenarios during the system evaluation, we hoped that the participants would explore or play with it. Participant EF was a quiet observer while her husband was inquiring about exercise during winter. She asked, “What about cleaning the house?.” I told her she could check it in the system. Another participant GM was more curious to know how clothing affects the comfort. GM “Do you think blanket affects? The warmer cloth?”. One other participant
wanted to check their regular activities like “I work in my kitchen or cleaning the office.” It seemed more like testing and checking if the system and their sense of comfort matched. **QF** “Let’s just see. I’ll probably put my computer in the kitchen I often do that.” **QF** “Yeah, I am cleaning office let’s see what happens, Yeah, I am hot. Yeah, I can feel the temperature cranked up working hard.” Participants compared the comfort difference with the current building settings and their preferences.

**Participants explored the choices they knew and then were limited in furthering the actions.** (*I will explore all the possible options I know and then what.*)

Participants tried to solve problems with the options of which they were aware, and when the problem persisted they were limited in their thinking process. The couple **DM & DF** explored the possible actions they perform in the winter scenario: they lowered the temperature and changed clothing, but the room temperature was still slightly cold. “It is slightly cold, does that mean **DF**, what would be your suggestion? We lowered the thermostat, changed how we dressed and if we want to go to neutral should we make the thermostat go higher or something?” The inhabitants were trying to bring the temperature to neutral as **DF** prefers warm and the **DM** prefers slightly cold. After they had tried regular actions, they were concerned about getting the temperature neutral and were contemplating on further choices. Noticing their discomfort, I mentioned to them that sometimes slightly cold is an acceptable temperature and we moved ahead. Since the activity was exercising for the summer scenario, it affected personal comfort to a high degree. To get immediate comfort participants needed to take more actions than just opening windows or doors during summer. **JM** during the summer scenario task “**I don’t know. We open the doors. You open all the windows, or do you want to open this more?**” **JF** “Windows.” The participants chose the regular interactions. Opening the windows and doors may be efficient at certain time of the day and it also depends on the building orientation or it will only add to the heat in the building.

**Participants find the model is fun to play and explore.** (*It’s fun, I would like to play around*)
The post-questionnaire revealed that the participants found the “What if?” model as fun to explore and play. DF “What if, is more like play around, that would be a fun thing to do so, I wish I could have that functionality to play around.” Participant HF found that, instead of looking for possible options, it would be fun to try the different scenarios and figure out the actions. HF “And that would be fun as like just not to make it gimmicky use the right word but to see different scenarios as opposed to I’m going to do this and then wait and then see what the results are but yeah you should play with it to figure it”. Participant KF was mentioning that she would not use the model on a regular basis, but she would use it to have fun and to play around. KF “Probably I will not use it on a daily basis. But I would do it to have fun and to play around.” A few participants mentioned it was fun for learning through exploration and play, but a few participants felt it was a lot of work and would restrict it to occasional use.

Planning

Participants like to plan

During the task completion, participants planned their actions in relation to their daily habits. DM “So, the room is warm, what I would do is first I would put something light, that’s for sure and then if I am cooking, I think, we need to open windows. What do you think?” DF “If it is still hot then yes.” Here the participants planned before referring to the system and then they applied their decision to the system. This particular scenario was during winter and opening the window was not a sustainable action. “What if?” was limited as it provided only the comfort differences and not the energy difference. But when participants were informed how that choice would affect the energy usage, it made them think. While one participant was working on another model, they mentioned that they usually turn off their thermostat before opening the window. FF “Ok let’s say this is the kid’s room and they are sleeping.” FF was talking about the issue they have in the kid’s room as it always gets very warm leading to sleep discomfort. She wanted to plan the scenario in the “What if?” model, it would have helped the planning process to be more fruitful if the mock model was their house. HF “Yes so if I was like now say I start cooking later in the day
with a different outside sort of temperature affecting would I be cooler at that time or would I be hotter at that time.” Participant HF mentioned that it would be good to look ahead on their activities to see how it affects the comfort. LF had a behaviorist background and found that what if model would be helpful in making smart decisions. LF “Yeah, because that’s perspective. That helps residents in a home to make smart decisions about what they are going to do next. For me, that’s going to be the most informative one.” Other participants just liked to know what happened when they performed certain actions. DM “It allows me to plan what’s going to happen, I like that, it tells if you do this, this happens.” Participant IF “I like the idea of knowing what happens if I do this.” The idea of people wanting to know what happens when they are doing an action tells us that they like to look ahead and plan.

Others

During Post questionnaire, we found other possibilities and limitations in this model.

“What if?” scaffolds tacit learning. (I will use it to learn initially and then will not use it!)

One or two participants mentioned that they would use the model initially to learn and experiment and then they would not use it. LM “Yeah if we moved into a place that has this, I would probably be experimenting all the time.” LF “Yeah he would,” LM “For a while then I would never use it again.” DM “First, I want to plan everything, second, if I don’t want to think about that, it can remind me when I need to do something.” DM mentioned in their conversation that they like to use the model for planning initially and then they would have no use for it and mentioned they could use the other dialogues where the system alerts them based on their preferences.

“What if?” scaffolds explicit learning, that is, mental model construction. (I like to test and weigh my decisions) LM “I enjoy experiments like I said I will be like testing it sooner or later, so I can play with it and you can learn more about the house and get a more objective sense of things you can do to change things because some of the
people really don’t know. All they know is to turn thermostat up or down or open and close window. This will help people learn where the options are.”

7.3.4 General

Multiple occupant comparison

Participants needed to see collective information on other inhabitants’ comfort needs to make decisions. (My decision(action) will impact others)

Most of the participants wanted to see the other inhabitants’ comfort needs; for example, couples wanted to know how the other person felt or in a large group they wanted to know how comfortable the people were? JF “I would say the number of people in the rooms, that would be nice to see, say ten people.” Participant QF discusses this issue in the context of the various comfort needs in a large family. QF “So my view on this would be, suppose if I had a family and we all had this right. Say 7 of us, so A is hot, B is cool, and I am in the middle. Would be interesting if the last person in could take it and see that information. I think you need to see what other people want.” Here QF, explains from the perspective of a person acting if two people have already made their thermostat level choices when the third person makes the decision to change that setting, that person needs to be aware of the previous changes made by other inhabitants. Participant FM “The model approaches can be categorized according to the people in the family, right? You can have a single system for an individual, and the couple can have a separate one.” The above quote shows the participants’ need for individual and collective decision-making controls in the system.

LF would like to group the information between generally cold or warm people. She mentions such information could help in adjusting their decision. LF “Some people are cold or warm, it would be neat if there would be some way for you to capture. Sort of aggregate individual level data within a building and use that to calibrate you know, ‘cause then you would know all right it is a little bit cold, but these people tend to be warmer, so they might be experiencing it as not as cold as somebody.” MF mentions the other inhabitants’ comfort needs will affect his choice of action than being energy conscious. MM “The difference would be I would probably put on more clothing, but if there were others in the house,
I would probably increase the thermostat.” MM further explains what happens, “In a scenario like that it might become a conversation, cause if I were to say I am in the kitchen. I am hot. I am energy conscious. I would want to reduce the thermostat, but if MF is upstairs she does not want to feel cold then she will say don’t turn down the thermostat. Just take off your sweater and open a window.” The participant highlights the importance of other people affecting their choices as it will impact them. MM “Sure. Well, that is nothing in there that kind of factors on the other people in the house. If you are simulating either the behavior or the thought process, it gets more complex that’s reality, but how that is already is, I am not making the choices. My decision will impact others. That is the point. So that is one that is missing.” He further explains how time plays an importance too. “We cannot really play with the time element. However, I can see that being important. If I am cold for 15 mins, that is one thing if I am cold for 3 hours does not matter. It is a level of discomfort I am willing to tolerate for a short period that I would not tolerate for a long period.” The level of discomfort inhabitants can tolerate considering the comfort needs of other is a research by itself. People often wonder what others feel in the house, QF “I always wonder when guests come. I think are they too hot? Are they too cold? It’s not like they say, are you too hot, do you want to fire up the heat? I do not know that, but it is the biggest thing if a guest could say I am sorry you want me out? Here, push the button, and the system would do whatever you like the last person in decides. But then my next guest come turn it.” Participant QF mentioned about the CIRS thermostat control system—how the last person gets to see other inhabitants’ choices before setting the thermostat. The important part she discusses here is that she does not know how the guests feel. Maybe here the system can help in communicating their needs.

Participants like to be aware of social norms in similar environmental situations. (What are my neighbors doing?)

Two participants in particular mentioned that they would like to know the decisions made by others either between two houses or two different groups of people. LF “Yeah between two different people or houses or something. Do you know what am saying?” MM “What are the options to compare my home to the neighboring homes.” Though
many people did not speak about this, literature study shows social norms may influence inhabitants’ choices.

Participants need to know what to do when there is a big gap in comfort needs. *(What do I do when kids are over for a party? They are active! or What happens to people who are going through menopause?)*

A typical scenario would be comparing two age groups: children versus adults. People generate heat and if there are more people it adds to the heat. Activity and comfort requirements vary vastly between children and adults. **HF** “*If you are having a party and there are lots of people that creates heat and not that you can be like oh get rid of the guests.*”

Moreover, she talks about kids and their energy levels. **HF** “*Your kids over because extra kids and they are running around, you are cooking and the temperature.*” Her underlying thoughts were all these add up to the room’s heat. Moreover, her question was would the system help in processing live feedback on such data? Variations in comfort needs can be due to age groups or health reasons. **LF** talks about variations in body temperature, where a person can dress warmly, but their hands might be cold. **LF** “*Some people wear sweaters, but their hands are always cold. Some people are like that. Some people are hot all the time, like when women go through menopause.*” She further explains how an inhabitant’s health issue can affect the body temperature. System needs to address these special issues.

Decision-making

Participants are willing to change their choices/decisions after seeing possible actions with energy consumption data. *(After seeing energy data, I will change my decisions.)*

During the task completion, participants initially saw the possible options for the situation from a comfort perspective, and then they were able to see the comfort data along with energy consumption. For this study, heating demand stood for energy usage. Choices of participants varied when they made decisions only with comfort data and when they made decisions with comfort and energy use data. Participants mentioned that seeing the energy consumption data will affect their choices. **DM** “*There is a chance that how much*
it consumes I will go back to change my decision.” When participants saw the options with comfort and energy consumption data, most of them wanted it as first step and not as two-step process. **EF** “After we see the energy data, yes, I would go for the lesser one.” Participant **HF** explains how this might affect their decisions. **HF** “It is out there, and then you will be like oh geez look at the money I am wasting so I should go and turn off my heat or close the door or something.” She further explains that looking at this information helps in the decision process. During the rainy scenario, Participant **HF** mentions “I think to look at this; it is sort of in your brain logical like close the door.” A participant mentions during the “I feel” model, that it would be good to see **GM** “What charging this to the heater instead of turning on the heat.”

**LF** is a behaviorist by background. During the “What if?” model task, she mentioned how this could leverage behavior. She felt it was necessary for the inhabitants to explore the “What if?” model and try the choices before concluding as it will provide a good learning curve for the inhabitants on comfort and energy usage. **LF** “For the behavioral one, do you mean that people would think about ways that they are going to change their behavior that would then impact their comfort level or the way they are feeling? Alternatively, they are thinking about the behavior they are going to engage in and then that is the basis, that is the foundation of which they decide to manipulate the other?.” She further explains that “What if?” does not constrain their actions, but it would facilitate the behavioral decisions. **LF** “And so are we supposed then if we want to open the doors or open windows we can do that. So basically it’s various behavioral decisions that we can make.” **LF** and **LM** spoke a lot about the issue of leaving windows open in the bedroom and the heat on in the living room. Initially, they lowered the thermostat and opened the windows during night time and turned up the thermostat in the morning. However, they lacked the motivation to continue these actions in order to have a comfortable temperature, so they left the thermostat up. They were not sure how the action affected their comfort. **LM** “But then it would create an interesting thing where you know it is like right now in that absence of that information, all we know is that it makes us have a better sleep.” They conclude by saying that lack of information about energy usage is helping them in getting better sleep.
Scenario: My choices are not efficient!

Drake and Gabby are performing the task completion for “If buildings could talk” model. They are working on the rainy scenario during winter. They are discussing and evaluating their choices with comfort and cost. Drake mentions Lwla will help them in negotiation. In this narration we can observe that Lwla helps them in making efficient choices.

I would do these three first and then in case it is still cold than only after that I will increase the temperature.

So let me see what I am doing, I am using a lot of energy here, ok so my choices are not really efficient, so what about F? Wearing a sweater with window open is not efficient. So these two looks to be better.

So what’s going on? So the most efficient is Gabby’s 1st choice, hmmm..... I have always chosen inefficient options. So these are the reasonable one so I would like to finalize on that.

Actually you mentioned that negotiation, what to do? Actually this would help us to reach probably the collective agreement

So the most efficient is Gabby’s 1st choice, hmmm..... I have always chosen inefficient options. So these are the reasonable one so I would like to finalize on that.

The reason behind the possible options was to help the inhabitants make choices that would use less energy and assist them in it taking personal actions like wearing a sweater. During the post questionnaire, a participant remembered what was mentioned and agreed to it.
“That is a cool idea. I think it is like you are right it might leverage in the behavior than like always turning the thermostat.”

During the task completion, a couple was mentioning how their choices were not efficient. The figure 7.21 shows the task scenario of My choices were not efficient. HF concludes how people will learn to use their energy better by seeing this data. HF “Yes if people are just using this, then how can I better use energy but also to become more sustainable like you are doing these positive things for the environment because you changed your behavior whatever. People like those little things.” Providing possible options with energy usage data helps the participants to narrow their choices.

Providing motivating factors or immediate feedback with gratification will help in a participant’s selection of actions. (Money is not the only big motivator.)

One of the key design decisions was to provide energy usage data for the different options to encourage decisions that could save energy. Though most people found money a big motivator, there were other factors like carbon footprint, immediate gratification or rebates that could help in decision making. KF “Money is a big motivator.” As explained in the previous use scenario, money plays a role in decision making. However, couple LM and LF discussed how money might not be the only motivator. LM “Some people are self-motivated so saving money is all they care about and people who do not care about money, they will spend as much as they want and don’t care about the environment at all so that they may be more motivated. Moreover, another thing I wanted to say is that it does not have to be a number, it can be a bar graph or one of these graphs where you can see that this is more than this.” LM explained motivating factors that could help save energy. Separate research is needed to understand what motivates a person in taking energy conscious decisions.

QF recalls her experience in energy decisions, “I lived in a building in England for a while, and there you had to put money in the heater if you want it to run. So, in my bedroom, if you wanted heat then you put money, and it was fascinating because you have to decide whether you wanted the money or the heat every minute. We were all poor students, so we had to look at our money and decide whether we wanted the money, or we wanted to warm up.” She mentions “So that is a very immediate feedback, right?” She also continues
to express the need for knowing who is spending that energy. QF “It would be easy for my
daughter to turn the temperature because she does not care. However, your mother knows
you are turning it up, and you are the one that’s spending the 10 dollars and not your
mother, then it comes to the place where she might think do I value the 10 dollars.” She
emphasizes the need for the children to learn about energy usage and cost. Providing a
numerical value will help in the process of saving energy.

Participants felt they would use “What if?” model mostly for buying deci-
sions on sustainable materials. (How much energy will I save if I change it to thermal
blinds?)

Decision making was evident in “I feel” and “If buildings could talk” models. Probably
it was due to the energy usage being displayed along with it. The “What if?” model was
less used in decision making, probably because participants had to make individual inquiries
and the model lacked energy usage data. However, a few participants mentioned it would be
good to use this model for replacing existing material with sustainable materials to forecast
how that change will affect energy saving and costs. KF “I would use that for these sorts of
things. Buying decisions.” KF was talking about replacing the blinds with thermal blinds,
and she was asking about this during “What if?” Another participant, GM, mentions light
bulbs and their cost. GM “Something we can add is, one of the things we have done, as
light bulbs burn out, we put energy efficient bulbs because the efficiency is higher. We bought
a whole bunch in the US; it is cheaper there and subsidized by the company, the Costco ones,
a whole lot of them. Another thing is my parents paid for the new carpet, when we bought
the carpet we chose lighter color because if it is darker, we need more lighting because we
are not facing the sun.” They also discuss visual comfort and its influence. Many people
remembered individual elements and their implementation during “What if?” model study.
One participant mentioned that if wearing a sweater would save money in the long run,
then they would not mind investing in it. The participant discussed this during the “I feel”
model.
7.3.5 System suggestions

Participants would like to have controlled automation and intelligence in the designed system. *(It would be cool if the system learned your preferences.)*

During the study, participants suggested the incorporation of controlled automation and artificial intelligence or machine learning in the system. GM states that *“It would be cool if the building learned your preferences.”* GM was open to the option where the system could suggest options based on their preferences or actions. Similarly, KF wanted the system to know the person who is interacting and to *“Remember the person keying in.”* KF uses technology a lot as she says, *“I love automation”* and prefers to interact with the system less. KF *“It would be nice to preset settings because, for people like me, we have very fixed sort of lifestyle so yeah, I want to preset. I want the house to do stuff by itself without me touching the system.”* While these two participants talked about the system collecting the history of actions and suggesting options based on it, NM discussed the room sensing the person and suggesting options. NM *“I mean if there was kind of a way to take your system to react that will be cool, you kind of go I feel warm, and it can go like you put on a sweater, or I can take care of it for you.”* DM also shared similar thoughts, *“I mean also you can have once the system recognizes your presence and determines all the stuff in the radar which would lower the thermostat automatically.”* Participants are willing to involve automation with restrictions.

**Custom** *(if possible to have an option like custom to make it your own scenario.)*

Participants like to customize the system for additional criteria they would like to consider. EF *“I was wondering like, if it’s possible to have one like custom like make it your own, make it custom according to how you feel that will be nice, after all the options, if there nothing that works for you, what do I do? You want to do a custom one. You know what I still have heavy clothing and I am still feeling this way probably you are sick so yeah.”* FM discussed how having an indicator or threshold to define energy usage would help them to understand about their performance. FM *“An indicator telling me whether or not my setting is working and when it is exceeding over time for the given threshold, above or below the threshold, that will help you keep in shape. Keep in check basically.”* Having a threshold
will help the participants keep track of their energy consumption. While discussing customization, QF suggest an option where you can toggle the preferences between two people. She explained it with cars as an example. “That’s interesting, I just noticed the cars they have two heat settings, two seats can have different settings, toggle it off.”

7.3.6 Appliances and its influences

Peoples’ needs are complex, and they have varying comfort needs.

The study brought to light adaptations the participants make to mitigate their discomfort. GM discussed his actions during summer. “So, I would drink a glass of water and run the tap till the water comes cool. That will be one of the actions.” As Vancouver does not have very hot summers, this problem would only occur for a short period. Participants want to see the changes in the building gradually as they take action. For example, when opening windows or blinds, they wanted to see the changes inside the room as they gradually open the windows. HF pondered many questions like “Whether it actually would matter people who have houses have wood-burning fireplaces.” Though she felt that using wood could cause air pollution, but the activity of collecting wood itself will make the person feel warm. She also had questions HF “What about if you have like an oven fan and a bathroom fan running if that would affect the temperature because it pulls the air out because I know when I’m cleaning I have all my fans going because of the smell and stuff to get rid of it but then I find that.” She wanted to know how it affects the building when they perform this action. She also had related questions on multi-operational use and its effect, like turning lights on. HF “So then if you are in the kitchen then you have all the lights on it gets hot in there so just even from the lights.” Appliances add heat. Her suggestion was “turn some more lights off to help cool or something that works.” Since HF was living in an apartment, she felt it “all adds to the heat in the building” and mentioned she would like to see it in the system. KF “I always wonder stuff like how much electricity it will consume if I put my hot cycle in my washing machine. Like you know.” KF said she was sure “it doesn’t affect the bill” but she is curious about it. KF also mentioned that her bills are huge during
the winter, so she might be trying to wonder about the details of energy consumption from appliances.

### 7.3.7 Mode comparisons

Mode comparison summarizes the reasons on why participants choose a particular model in comparison to other models. Figure 7.22 shows that “I feel” model was highly preferred because it acknowledges their sense of comfort in the building and also provides various options for the environmental situation based on comfort and cost. There was one participant who was profoundly influenced by advanced technologies. The participant mentioned that they would use these two models “I feel” and “If buildings could talk” on a daily basis. She also mentions that she would use the “What if?” model, for fun, play, and for making informed decisions like replacing existing blinds with thermal blinds. She concluded by saying that the “What if?” model could be more useful for retrofitting with life cycle cost. For “What if?” model, three participants mentioned they would like to initiate/explore or learn about buildings. These participants liked to plan everything. One participant felt she is the best judge of the economic constraints in their household hence preferred “What if?” model over other models. Figure 7.23 shows the participants quoted and reasons for preferring different model over other models.
**Figure 7.22: Model preference and comparisons**

<table>
<thead>
<tr>
<th>Participants ID</th>
<th>&quot;I feel&quot;</th>
<th>&quot;If buildings could talk&quot;</th>
<th>&quot;What if&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>DF</td>
<td>My own sense of feeling is important.</td>
<td>It's interesting as well because it updates on what’s happening to the buildings.</td>
<td>Play around its fun.</td>
</tr>
<tr>
<td>LM</td>
<td>If I am not comfortable that’s really what matters.</td>
<td>If it’s cold I already know. But if another room like attic is cold then its useful.</td>
<td>No preference</td>
</tr>
<tr>
<td>NM</td>
<td>You can actually do that! gives you option with cost.</td>
<td>It’s cool.</td>
<td>I know what to do, I am not going to look at various options and weigh them.</td>
</tr>
<tr>
<td>PM</td>
<td>Because I am the one initiating it.</td>
<td>You don’t want the system to say “Alert” stop what you are doing.</td>
<td>No preference</td>
</tr>
<tr>
<td>OF</td>
<td>I think it taps into human psychology.</td>
<td>No preference</td>
<td>No preference</td>
</tr>
<tr>
<td>EM</td>
<td>Building talking is scary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>QF</td>
<td>No preference</td>
<td>No preference</td>
<td>No preference</td>
</tr>
<tr>
<td></td>
<td>If the system says here are the options and optimizes energy versus comfort, people will use it.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Model Preference Order**

1 2 3

<table>
<thead>
<tr>
<th>Model Type</th>
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<tbody>
<tr>
<td>1</td>
</tr>
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<td>2</td>
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<tr>
<td>3</td>
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</tbody>
</table>
### Figure 7.23: Model preference and comparisons

<table>
<thead>
<tr>
<th>Participants ID</th>
<th>“I feel”</th>
<th>“If buildings could talk”</th>
<th>“What if”</th>
</tr>
</thead>
<tbody>
<tr>
<td>GM</td>
<td>Choices and it helps me weigh.</td>
<td>Don’t want it to be annoying like if it happens every time like every 5 mins.</td>
<td>No preference</td>
</tr>
<tr>
<td>KF</td>
<td>Use it on a daily basis.</td>
<td>Use it on a daily basis.</td>
<td>Not use it on a daily basis. Use it for fun and play. Use it for making informed decisions like purchasing nice curtains.</td>
</tr>
<tr>
<td>DM</td>
<td>No preference</td>
<td>If I don’t want to think about that it can remind me when I need to do something.</td>
<td>I want to plan everything.</td>
</tr>
<tr>
<td>IF</td>
<td>I can change the feeling but doesn’t solve the economic problem.</td>
<td>No preference</td>
<td>I like the idea of knowing what happens if I do this. I tend to know what’s the best option.</td>
</tr>
<tr>
<td>LF</td>
<td>I feel would be last because it’s already subsumed within the other two.</td>
<td></td>
<td>Favourite one. Impacts behavioural choice.</td>
</tr>
<tr>
<td>MM</td>
<td>I already know the options. I don’t need the building to say it.</td>
<td>Prompting can be annoying.</td>
<td>Just to understand that I am making mental thought for what I do.</td>
</tr>
</tbody>
</table>

### 7.3.8 Suggestion to improve system data and visualization

Participants suggested improvements to the system design data representation and visualization. The suggestions are grouped into four categories based on the feedback: Data representation, interaction design, categorizing multiple options, and timeline. Data representation covers general data display and feedback issues. Interaction design refers to spatial
display with menus, highlights on mouseover and other interaction techniques. Categorizing multiple options shows how multiple options can be categorized to reduce difficulty in readability and data management. Finally, timeline covers the hours to be displayed and histories.

Participants expressed or suggested simple summative terminologies that correspond to their action. *(How not to be so warm?)*

During the study, participants expressed multiple options in simple terms. **HF** “Ok interesting so it will give me some hints on how to not be so warm.” **FF** suggested a more simple expression to write as a header “This one I can use to cool down.” Simple terms like “Cool down” or “Not be warm” will easily relate to the inhabitants.

Pie donut chart for the cost to vary in color, size and the representation to have an effective impact on the decisions.
Since the cost was represented in a green color, the participants related to sustainable practices and found it ineffective for decision-making. FF “If I am consuming more energy maybe red.” FF suggested a red color while LM and LF suggested purple color as it was not related or tied to environmental decisions. LF “If you use purple then you would not have the issue with the whole environmental like people.” LM argues “Purple is fine as long as we make it clear that the intensity of the purple breaks with the intensity of the energy usage. You know you make it as light as possible as purple is bad.” Another participant OM suggested grey or reddish purple. Participants LM and LF also suggested varying the size of the pie chart based on the intensity (see figure 7.25) or overlap the donut chart with a line graph. LF “But another idea is that instead of using different gradations of colors, different intensity of purple, I wonder if there would be someway maybe also for the middle circle for the energy usage. If the energy usage is either thinner or fatter and rather than the shade if you have kept it as one color because it would sort of like reduce the cognitive complexity.” LF concluded saying that it will reduce cognitive load. LM “Like a line. This will be like a red line or black line and the yellow donut is just a reference from inside has no energy and outside maximum.” While LM and LF discussed the visual representation, HF suggested having a numerical value to the visualization will be effective. HF “I think numbers make sense and yeah you see the colors and you can kind of understand it, 100 this is 50, and you will be oh ok.” While some participants prefer visualization, there are others who prefer visualization with numerical values for decision making.

Figure 7.25: Visualization suggestions
Feedback to be artistic, motivational and summative

LM and LF suggested representing the cost as dollars or in counts of carbon dioxide. LM “Especially if you could just be more green. If you could add a number there in terms of dollars or counts of carbon dioxide or something like that, dollars would be, but carbon dioxide is purely environmental.” However, LF argued stating “I do not think counts of carbon dioxide will have effect, it is subjective.” LM had other suggestions of representations like “well you could even tell that you are burning half a liter of gasoline or something like that.” LF also spoke about the motivation for taking sustainable choices; she suggests adding themes that would be meaningful for the individual in taking sustainable actions. LF “But it also would be cool, and you know if that’s not going to be motivational for everyone it would be neat if people could decide like, what are the graphics that are more meaningful to them like dollar signs in terms of how much money they would be saving on their energy bills or is it the number or leaves in terms of how green the place is. They are just the inverse of one another right. they are like greater leaves is fewer dollars signs.” Adapting to meaningful representations for saving energy is a good suggestion. While LF and LM spoke about artistic representations, KF highlight summative feedback. KF “It would be nice to see a graph of where I am for the month. Like month to date. So that we can then, we know what the bill would be.” She said having the overall graph of energy usage in the building will make them aware of “when it is at the max” and “when it is the least.” These discussions concluded that artistic, motivational and summative feedback would facilitate decision making.

Summation of short-term and long-term implications of actions will impact behavioral changes.

One participant discussed the short-term and long-term implication of an action. MM, “First thing that pops into my mind is these were kind of short term behavior changes, clothing, close the door, change the thermostat. The first thing that comes to my mind is a forecast which says ok this is what you choose to do now and if you choose to do this regularly, here are the implications for a longer period of time.” The idea is great as the
people will be able to see the impact of their actions in the longer term. It may influence their choice of actions.

**Interaction design suggestions**

- Highlights the active room area
- Pop up menu as mouse hovers over the location
- Connect activities to location
- Background or floor area of the room to be represented as comfort
- Horizontal display of multiple actions
- Move timeline indicator

![Figure 7.26: Visualization suggestions](image)

Participant had various suggestions to improve their interactive experience with LWLA. **OM** was an experienced interaction designer. He suggested to “**highlight this particular square footage**” in the plan. **OM** also said to get rid of all the icons in the individual rooms. **OM** “**You do not need them. As soon as I hover anywhere in here,**” the icons could “**pop up.**” **OM** “**I would not separate these areas by the label, and I would just have one set of icons for the whole thing.**” **OM**’s suggestion will reduce visual clutter and needs to be considered. **OM** also suggested that, as a person living in the house, he would perform routine tasks in similar locations. **OM** “**Because if I am cooking than you know you are not going to be here and if I am reading am going to be there.**” When the system is implemented in the real world, the above suggestion would help in more effective choice of actions considering energy and comfort data. **OM** “**One thing it would be maybe interesting to experiment with is to represent the level of comfort or temperature whatever it is we decide to represent as a background colour of the areas in question and get this down is completely that’s colour whatever time it’s right no that’s represented there, and over here is a big 24 hour lead and as I run it up and down I go from midnight and these colour changes.**” The idea was
already explored at the initial stage of the design but had design constraint. To reduce the visual color load, the data was simplified to donut charts. While OM was giving insight on interactive display, KF explained her difficulty in scrolling over large data (multiple options). She preferred to view all the options display in horizontal position as it is easy to compare and decide. KF “Let's make it horizontal, it makes sense that way.” The system provided the option of expanding the dialog box to a horizontal position but to make it easy for comparing a large set of data, other techniques should be considered. HF had an interesting question on the timeline indicator. HF “Can you change the time or is it stuck there?” The systems timeline indicator is fixed but can be made interactive. HF wanted to move the timeline indicator to a particular hour and input the activity and see its influence as well on the comfort and energy consumption. These suggestions are considered for future design.

Categories (Categorize based on participants interaction in buildings.)

Multiple options or various choices of possible actions is an important design consideration for LWLA. Since the multiple options were large data sets, participants suggested categorizing the data according to thermal comfort or their actions, separating current or actual thermostat from increasing or lowering thermostat, and finally considering decision trees in displaying the data (See figure 7.27)
“This model approaches can be categorized according to the people in the family, right? You can have a single system for one person, and a couple can have a separate one.” Here what FM mentions is parameter settings for different individuals in the house like children, teens, elderly persons or couples. JF says “Maybe you can order the options.” and is continued by JM “You can sort it based on the thermal comfort on more I used to do it.” JM would like his preferences to be considered by the system and have it order the data accordingly. LF explains the need for distinct separation between the current or actual thermostat with the forecast of lowering or increasing the thermostat. LF “I think it would be good if there were some way to easily differentiate the actual thermostat role from the increase thermostat role. Almost you know ‘cause it is in some sense it’s kind of a decision tree, you know you could even just have it so that the actual thermostat once could have one color that encircles these and the increased ones can have probably something visually.” LF has experience in behavioral study, and her suggestions were tuned more to influence people. LF “I am wondering if there are other sorts of decision trees. You know but then at the same time either you do not want to force people into making a one or other decision without seeing the implication of the decisions. Then it would maybe impose a decision structure on them that doesn’t actually exist.” LF mentioned that, when the participants choose actions with the actual thermostat, the system could show other persons actions. LF says that might influence the choice of actions.

Timeline (I do not need to see before because before is not relevant. You have already used that energy you know.)

Most participants liked to see the day for the entire day, but a few participants suggested that timeline hours could be separated as waking/sleeping hours. JM “or maybe you can have another control to say AM or PM, and you can stop whatever the time of day it is. And you can swap whatever time of the day you want, and you have the clock for 12 hours.” Four participants suggested displaying the data as 12 hours instead of 24 hours. OM mentioned that a system needs to consider not only “24 hours but 365.” Another participant GM mentioned that they like the 24 hours “So a lot of decision I am making is the current time. Maybe you can block your current time because I am looking at that piece.”
The LWLA study focused more on the proposed model type, and less design thought was implemented for timeline data display. Moreover, also to convey an appropriate simulation easy, 24 hours or that day is shown. However, LF highlights “I do not need to see before because before is not relevant. you have already used that energy you know.” These were good and reasonable suggestion for improving the LWLA visualization and has been further explained in discussion chapter.

Timeline suggestions

- History versus whole day
- block or highlight current time
- 12 hours to 365 days
- waking/sleeping hours or am/pm or day/night time
- Data before the current time is not needed

Figure 7.28: Timeline suggestions

**Participants thoughts on building operations and its influence on energy usage**

The study brought to light the adaptations that participants make when experiencing discomfort. GM discusses his action during summer “so I would drink a glass of water and run the tap till the water comes cool. That will be one of the actions.” As Vancouver does not have very hot summers, this problem would be only for a brief period. Participants want to see the changes in the building gradually as they take action—for example, opening windows or blinds. During the study participants spoke about how long the windows will be open and also how they would like to gradually open the windows. EM emphasizes “how long will you open the windows and also how wide will you open the windows.” It was a constant topic that arose during the study. LM also wonders about the opening and its effects. LM was talking about many factors in his room, how much air leakage is going to happen with space beneath the door and asked if that is important to consider. PM
shared a similar experience and said, “I will be hesitant to open that much.” PM lived in the house modeled for the project.

**Operation use and its influence**
- Drinking a glass of water but run the tap till water is cool
- Wash my face with cold water
- As I open the windows I want to see the changes
- Operating blinds partially
- Accumulation of appliances heat
- Steamy hot shower and turning fan on
- Hot cycle in washing machine does it use more energy
- Why I use this particular material because it drives my comfort

**Hindrance**
- Technology drives me crazy
- Noise issues with neighbor

Figure 7.29: Operation use and its influences

**HF** pondered many questions like “Whether it actually would matter whether people who have houses have a wood burning fireplace.” She felt that using wood causes air pollution, but the act of collecting wood itself will make the person warm. She also had questions on “What about if you have like an oven fan and a bathroom fan running that would affect the temperature because it pulls the air out because I know when I am cleaning I have all my fans going because of the smell and stuff to get rid of it, but then I find that changes temperature. I do not know if it would or not.” She wanted to know how it affects the building when they perform this action. She also had related questions on multi operational use and its effect, like turning lights on. **HF** “So then if you are in the kitchen then you have all the lights on, it gets hot in there so just even from the lights” Appliances cause radiant heating, her suggestion was “turn some more lights off to help cool or something that works.” **HF** felt it “all adds to the heat in the building” and mentioned she would like to see it in the
system. KF “I always wonder stuff like how much electricity it will consume if I put hot cycle in my washing machine. Yeah, some clothes you wash is hot and am sure it does not affect the bill, but it is more my curiosity to know.” Hot water affects energy usage. KF also mentioned that the bills are huge during the winter so that she might be wondering about the details of energy consumption from the appliances. Figure 7.29) provides a summary of operation use, and its influence on questions or actions performed that were narrated during the study.

Assumptions that need to be considered in the system design based on participant’s feedback

- Action/location
- Outside/inside conditions for facilitating actions
- Details on thermostat increase or decrease in degrees
- Set point versus current point
- I would like to know the actual assumption details on clothing

Figure 7.30: Assumptions to be considered

- Summer, eat late nine or ten pm
- Eat salads and not cook during summer
- Cook late during summer
- Set schedules like cleaning weekends
- Set tolerance for comfort and energy usage
- Adaptation in using the technology will vary

Figure 7.31: Assumptions to be considered
7.3.9 Controlled Automation

Participants would like to have controlled automation and intelligence in the designed system. *(It would be cool if the system learned your preferences.)*

During the study, participants suggested the incorporation of controlled automation and intelligence in the system. GM states that “it would be cool if the building learned your preferences” GM was open to the option where the system could suggest options based on their preferences or actions. Similarly, KF wanted the system to know the person who is interacting and to “remember the person keying in.” KF uses technology frequently as she says “I love automation,” and prefers to interact with the system less. KF “It would be nice to preset settings because, for people like me, we have very fixed sort of lifestyle so yeah I want to preset. I want the house to do stuff by itself without me touching the system.”

While the participants talked about the system collecting the history of actions and options suggested based on it, NM discussed the room sensing the person and suggesting options. NM “I mean if there was kind of a way to take your system to react that will be cool, you kind of go I feel warm, and it can go like you put on a sweater, or I can take care of it for you.” DM also shares similar thoughts, “I mean also you can have once the system recognizes your presence and determining all the stuff in the radar which would lower the thermostat automatically.”
During the study, participants discussed their daily activities. Based on their opinions, the system could incorporate these scenarios as well. FF narrated what she does every morning. She has three children and making breakfast is a routine. The system should have the option “taking the dog out for a walk,” FF described her comfort and how she feels in the building after the activity. For example, FF “if we are taking the dog out for a walk. Then we come back home, and we find it’s warm in here, open the windows because we feel warm.” Most newer buildings do not have natural wood burning fireplaces to heat the building. HF “so if you had to go and carry the wood if you had to chop up kindling then you bring that back in and in Ontario too we had a wood burning fireplace so then you the fireplace will create heat cost minimal but then that action itself.” HF describes an important activity that increases your metabolism, but the use of natural firewood will cause air pollution. However, the system could suggest activities to improve the metabolism of people. Finally, “Away” should be an option in the system as well. IF narrates her experience when they travel away from home for a brief time, and the discomfort it causes when they return back. IF “We went to Whistler for three days on a retreat or when I go away I turn the thermostat’s down. Like I am just going to the town for shopping, I am out for the day, I don’t change the thermostat. But if am going away for a week, several days or a week longer, I turn the thermostat down. But then when you get home, the weather has really dropped, the house is going to be cold, I would turn the fireplace on to warm the house quicker and
wait till the thermostat has gone up to there and turn it off. Or it’s like we turn it on just for the ambiance. No priority. Not very often. We use it just to warm the house.” So the system could have an ‘away’ option to help the people define the time they are leaving and arriving from vacation.

7.4 Interface Design

7.4.1 Annoyance

Annoyance discusses issues in the system that are quickly resolved. Annoyance has two parts: general and data representations. Firstly, in general, overall annoyances like feedback delay, interaction issues, and icon representations are discussed. Secondly, the issues in data representations cover color, terminologies and the donut chart. Each section is explained with participant quotes. Figure 7.34 summarizes the general issues, and Figure 7.35 summarizes the issues in data representations.

Annoyance general issues

System feedback delay

Delay in simulation feedback causes annoyance and trust issues with the system. (Process is slow!)

Running large data for simulation causes delays in feedback. The issue lies in data sending and receiving, as running parallel simulation takes a few seconds only. Participants were asked to ignore this issue during the study, but still a few participants expressed their annoyance. JF “Process is slow,” Similarly, LM commented “Simulations are not faster. The calculations.” Also, FF said that “If it is going to take time to get the data,” she will not be able to trust and use the system. The issue could be resolved as we have advanced technology and fast computers to run parallel simulations with large data. The system used had lower compatibility and also since it was a low-level prototype I discount these issues.


Interaction issues

Participants had issues with where to click in the system

During the study, when participants made mistakes in the selection of elements and systems, it was difficult to cancel the process as the data are simultaneously updated. Data processing was not an issue for the “What if?” model as the volume of data sent was less, but for the other models (“I feel” and “If buildings could talk”) it takes few seconds. Cancelling or reselecting the actions will not be a problem with a high-end computer system. The interface consists of the building plan and, to make interaction elements clear, operable systems like doors and windows were represented in green. However, a few participants needed more clarification. **HF** “Can you click on here to change the doors and stuff?” A video demo on the system interaction will resolve the problem or also there could be highlights to indicate the location of interaction. Moreover, also once participants use it more than once, it will be clearer for them. Participants also had issues in knowing where to click once they made decisions. “So, I do that here?” Providing a demo on in interactions with examples may resolve the problem as may other design interventions.

Icons
A few participants had issues in understanding icons and needed more clarity.

(So, this is closed or open, it says it is closed right?)

A few participants had issues in understanding the state of door and window icons. GM “This door is closed?” Participant GF mentioned that it would be good to have a legend of the icons for people without architectural backgrounds. GF “This is a very small thing. For someone who does not have an architectural background, even though I am aware of architectural lines, where the doors were and knew what they looked like, but I did not know where the blinds were.” She also says providing “slight key” could be helpful while clicking. The participants had issues in understanding the windows icon. Legend and demo will resolve this issue as well. The other issue that came up was the icons being displayed during different seasons, EM “Usually during the summer we do not run any thermostat.” The thermostat settings considered were zero for summer, but the presence of the icon was confusing for few participants. Hence in the next iteration, the thermostat setting can be hidden for this season.

Annoyance in data representations

Green was annoying for representing cost as people relate it to green actions.

The heating cost was represented in green as comfort scale was represented in blue and red color ranges. Most participants found it confusing as the design represented more energy usage as dark green and less energy usage as light green. People who were environmentally or sustainably involved found it confusing as they related darker green for saving energy. Even if the color were inverted, it could have been clearer. The intensity of the color was depicted for the intensity of energy usage. LM “Can I point out something else, I just know that most people know that green normally falls between yellow and blue on this scale. So, to me plus you had yellow. Yellow is this colour.”

One participant had issues in understanding the changes in color. (Can you explain why the outer ring is blue and saying it’s cold.)

One participant needed more explanation on why the color changed to blue to state it is cold. She did not relate it to the action she made. Maybe a summation or a question mark
for a further query will allow the participants to understand the parameters that cause the effect. The query or summation will help in clarifying the results.

Diverging colors are an issue to the thought process and decision making. Most participants did not have issues with color gradation for warm colors. However, one couple mentioned that the color for warm colors is varying between red and orange and suggested to use one color gradation. LM “I just noticed that on the cold side these are all just different shades of blue, aren’t they? However, on the warm side, you are changing the color to go from red to orange” The other issue faced in color was if the participants choice
was wearing a sweater than it assumed that the action was for 24 hours, it was a similar issue for activities, but opening doors or windows change the room temperature, and hence the data varies over the 24-hour cycle. **LM** “Okay how come it is the same color all way around? Whereas this one has gone lighter here.” Initially, the system considered schedules for activities, and due to delay in data processing the option was removed. These issues will be resolved in next iteration.

**Terminologies**

Abbreviations like AT (actual thermostat), naming conventions and representation were not clear for the participants. *(What is AT sitting?)*

Most participants had issues with the abbreviations for actual thermostat (AT) or lower thermostat (LT) on the multiple option data. **GM** “So LT AT?” Though the abbreviation was provided on the first pie, participants missed it or found it hard to read and correlate it with other options. Having a clearer interface design for the two data sets, actual versus predicted, will give more clarity and increase readability. A few participants had issues with naming conventions as they were not easily able to relate to them. In the multiple options, clothing was represented as high, medium and low. Participants found it hard to relate to the terminology. Even though the data was present on this, they asked about sweater which was represented as heavy clothing. **DF** “Yeah and what about wearing the sweater and not wearing the sweater?” The terminologies or naming conventions could be solved in the next iteration by providing a question mark query, or the terminology could be modified based on the seasons. Some icons like clothing need more descriptions as the prototype uses only light, medium and heavy. **LM** “Just for the information of what the three things are about.” One participant needed a clearer statement on what it is updating. **MM** “When you say updates, what is it updating? Is it updating energy consumption or comfort level?” The update dialog box was added to have control over the data being sent, as constant changes may crash the prototype system. When implementing a real system, this option will be removed. **OM** also argued the importance of highlighting icons with text descriptions as it will increase readability. **OM** “And I would say if you are talking about heating on or off, I
would say that here.” Combining text and icons will give more clear readability and should be considered in design.

**Donut chart**

**Participants preferred similar representations for all the three proposed models.**

In the three models, the outer and inner circle data were similar for the “I feel” and the “If buildings could talk” model. The outer circle represents comfort, and the inner circle represents the cost. However, the “What if?” model represents comfort data for the inner as well as the outer ring. The inner showed the current comfort level, and the outer showed the predicted comfort changes with the action they choose. **LM** “But it’s not the same. Do we also have the green circles on your previous one? Is it not the same green circle?” **OM** “because I know this is a little thinner. The inner energy is a little bit thinner, the delta R here is a little less than the delta R there. But it is still it is so much the same that I need to sort of focus too much cognitive energy on separating the two and it maybe after a few minutes it will not matter but it’s so nice to represent this by the thermometer, but that would not give you the temporal change.” **OM** Talks about cognitive overload with a lot of data. While other participants discussed the size of the donut chart, **DM** asked “So, I guess the inner circle is how you feel, and the outer circle is what’s in the building?” The inner and outer circle representation could be resolved with mouseover text descriptions. Participants also wanted to define the schedule. **MM,** “well the scenario sounds like it’s winter. I am cooking and am feeling something probably I will choose very warm and then what would I do? I would not do that for 24 hours. So that would probably happen in the early evening.” A detailed schedule can be incorporated for future design.
7.4.2 Barriers

![Logic or reasoning barrier in data changes](image)

**Logic or reasoning barrier in data changes.** *(It came from blue to yellow, what does that mean!)*

A few participants were not able to understand why the data changed from cold to warm. DM *“It came from blue to yellow, what does that mean?”* DM asked about the color changes during the demo of what if model. The *“What if?”* model allows the participants to interact with individual building elements, systems, and activities. When the participant changed the activity, the data changed because of the increase in metabolism, so I had to explain the underlying reasons for the change in data. FM *“Why it’s warmer, this is living room?”* FM’s questions may resonate with others. The building model in the prototype was a passive house, and due to south glazing, the living room is hot during summer. FM did not understand the heat gain occurs through the glazing and other activities like cooking. Participants tried to understand the changes in comfort and its logic. Participants were trying to understand why personal changes were not affecting energy the energy usage. KF *“So why would having a cold drink use more energy.”* In the rainy scenario, the door is left open partially, and the participants were asked to select the choice of actions from the options provided. KF chose to drink something warm, but the door was still open, and hence it did not increase the heating demand, so her choice was not sustainable. So, the reason behind the no change in cost was explained as drinking something cool is a personal
change and does not reduce the energy usage. HF “Oh ok why would it be less here,” HF had a similar question between the actual thermostat and lowering thermostat in combination with personnel changes. When a person wants to cool themselves and chooses to remove a sweater, it does not affect in cost, but if a person is planning to lower the thermostat, it will. Reducing thermostat by 2 degrees will save a considerable amount of energy. Hence the system should explain further participant queries.

**Too many steps in interaction will hinder the use of the system.** *(Look! I don’t want anything which is seen before)*

In the proposed three models, both “I feel” and “If buildings could talk” display comfort and cost options as two steps. The design was done as a two-step so that if there are people who want to make the choices purely on comfort, then they will not be hindered. NM and DF are interaction design experts and advocate showing the data as one step. NM “Look, I don’t want anything which is seen before. If you need to have it on your computer or an app, it might be a little easy. Maybe that will work, but if you have it on your computer and your app and you have to operate it, then it will be too many steps.” the suggestion was for multiple options for interaction, but KF stated that getting too many questions prompts in “If buildings could talk” model would be annoying. KF “Yeah, you know Netflix has done this recently. I don’t know if you know this, they have too many buttons to click. I just got the Apple TV. They ask if you want to watch this show. If you click yes, it will go to the show. Then it will say ‘Do you want to start?’ and I don’t know, it has too many clickings.” She explains about Apple TV notifications and finds it annoying to have too many prompts. “If buildings could talk” model, need to eliminate unnecessary steps in interaction.

**No rewards are detrimental to actions.**

People expect a reward for actions they make. In the LWLA system, multiple options were included making personal changes like changing clothes, activity or eating and lowering or increasing thermostat. Making personal changes did not influence energy consumption. Participants knew that making changes to their clothes is sustainable and when they acted, they expected the cost to change. DF “I am not actually seeing any change for removing clothes.” During the study, participants questioned why personal adaptations were ineffi-
DM “Why is it inefficient to have a drink?” While DM was questioning on drinking something EM had a similar question as DF, EM “What is the source of energy for light clothing than?” Also, in the post-questionnaire, EM explains, that he would use a system that helps him save energy. The “What if?” model did not have cost incorporated in it as the data was complex. EM “I mean the interest in this is for me is how much can I save the energy.” He says to include energy cost in the “What if?” model. EM “Yeah not just for the last one(“What if?” model) at least it should include energy right” The “What if?” model needs to consider how to incorporate cost and the entire system needs to consider rewards for personal adaptations.

Learning new technology poses a threat to system use.

Two or three participants mentioned that technology is difficult for them. IM and IF are an elderly couple, while IF was tech-savvy, her husband was not. IM “Well am not a computer person.” IM mentioned he prefers old-school methods and his spouse IF narrates that “It took him six months to learn how to send an email through his iPad to the computer. So, he hasn’t got to the computer yet!” It is not the elderly people who have issues with technology. LM also said that “LF does not know how to install apps on the iPhone.” Learning technology poses a threat. Hence the system should be easy and straightforward to use.

Complex data hinders the selection of appropriate choices in the system.

One of the LWLA core ideas is to provide possible options for resolving discomfort in the built environment. The possible options show advantages and disadvantages of the combination of actions. A few participants found it hard to make decisions while others wanted to see all the choices to make their selection. DF “My only concern is that or the actual options like opening the windows, putting on clothes, right now you have quite a lot of circles and if the amount of activities get bigger it could be hard to read. Right now, it was not that many right?” For this study, apart from blinds, most of the building system worked. The clothing-type considerations were reduced to three types: light, medium and heavy. Activities considered were more related to residential use. Complex data is hard to read. GM “This is quite a lot. So, like if you look at your actual thermostat in lot of these scenarios
you are not touching the thermostat, but you are doing a lot of actions right?” GM has a point. He suggests a clear demarcation between the changes in thermostat and personal adaptations. The core idea of the system is to encourage participants to change their habits, and hence personal adaptations are incorporated in the possible options. GF “Even though personally I like a lot of data, thinking at the moment going over all the data might be.” GF expresses similar concerns as GM and DF. Reducing the data to view or incorporating highlights for appropriate choices or ordering the data based on comfort and energy usage can reduce this issue.

**Next set of actions is a constraint when participants knowledge and information is limited.** *(I have done this what do I do next.)*

In the three proposed models, the “I feel” and “If buildings could talk” models suggested possible action and inhabitants can take in the given situation. However, the “What if?” model exits to help the participants make their own decisions. “It is slightly cold, does that mean DF, what would your suggestion, we lowered the thermostat, and we changed how we dressed, if we want to go to neutral should we actually make the thermostat go higher or something.” In this situation, DM tried a few options to bring the comfort to neutral and got stuck with the next step of actions. MM had the same issue, after a set of actions in the “What if?” model, he asked “Is there anything else I can do?” This situation was observed among a few participants where they were wondering on what action to do next. This issue was not limited to the “What if?” model, FF “For example, I want to wear socks, I feel cold and then what do I do?” FF narrated her issues about feeling cold even after wearing the socks and wanted to know the next set of actions she can take if the issue persisted.

### 7.4.3 Trust

In the post-questionnaire, participants answered about trust. Figure 7.37 summarizes three questions; Firstly, why do participants trust LWLA system? Secondly, what will make the participants trust the system? Lastly, what hinders their trust?
The most common response from the participants was that the data make sense. GF “I did not see any other graphs or anything obvious that makes me go hmmm I don’t agree with that. The participant felt that the system was showing information in the direction they expect. JF says that she was able to relate to the data easily, “It’s like really clear. So, I don’t need to what’s in there and kind of look around and go like I can understand” Understanding the data easily is a parameter that helps participants trust the system. JM “Yeah you can understand easily like colors tell you what they mean. If it’s cold its cold and if it’s slightly cold it’s slightly cold, you can relate to it very easily.” JM discussed how the legend the data displayed correlates and that helps him to trust the system. MM narrates his experience with the system, “On face value I mean if it is just a scenario that the results were directionally correct when I close the door temperature was up, so I trust that from the data.” Participants correlated their experiences with actions in the past and since the data related to the action and its experience they were able to trust it. OM “Ok it is updated all right, so that’s good. It changed certainly in the direction that I would think.” OM expressed his satisfaction in data display during the study. The other criteria that helps participants to trust are because the decision is theirs. JF “Because you get me importance or decisions.” and JM “Because you can change, and you see the changes.” Participants having control over the data being the initiator of the decisions helps them to trust the system. However, only one couple spoke about this criterion.
Secondly, what will make the participants trust the system? There were two responses: (1) the system learning about their choices and testing and (2) comparing the data with comfort experiences. The latter was the most common response. Only one participant mentioned that using advanced technologies to learn about their choices and predicting the data based on it will help them trust it. KF “If the tool had a built-in system where like some TV acts now have the base tool. They sort of figure you out as a person an individual right? Then I would trust it.” The participant expressed that they would trust the system when it displays the data based on their habits. The most common response as mentioned earlier is trusting and comparing the data. Here are few quotes to support the statement.

DM “I think for example what you have done I trust it, but for me actually, I would like to test it with actually what I feel, and the system shows me, like do some calibration of the system or something like that.”

HF “Well I would have to be able to test it out first to really know if I could trust it. So, this is what my thermostat says the temperature is that’s matching that. If i’m feeling hot and its saying oh cool cool in here right now and you are like. I have my warm coat on with my thermostat, and I am lying down what do you mean I am cold.”

LM “Yeah that’s true. I think I would still have some skepticism cause if I put on heavy clothing, what does it mean to have a hot drink if I could just do this. I just had hot drink. How can I not feel warmer yet? you know!”

Most people expressed that they would like to test the system data with what they feel and that will help them in trusting the data. LM highlights a crucial point by having a hot drink, a person may become warmer but other factors like body type, health issues may pose a problem, hence this recommendation may be detrimental in trusting the system.

Thirdly, we discuss what hinders the participants from trusting the system, largely privacy and security of the data. One couple spoke about this issue and mentioned, GM “Also what I would like is personally I don’t know if the system would report back to a central database. I don’t like that.” GM expresses his problem in others having access to his data, one for security and two he does not want to be penalized for the actions he is not performing. GM “Yeah like I don’t like it. Like I was looking at some security cams. All the data are
centrally stored online. What if someone is collecting data, I don’t like that. I don’t know who is on the other side. Anyone can hack. If there is a way you chose not to upload live data or not to be connected to internet, it can be internal, or someone could hack into your place and heat it up.” GM has reasonable thoughts on threats that are posed due to remote access to the system. The system could always have a manual mode that could disconnect remote aces to ensure safety. FF “if there is any sort of ID, I don’t want anyone to know how personally I run my apartment.” and GM continues “Start penalizing, BC hydro is collecting data.” This is an important criterion that system needs to address. Finally, there was one issue mentioned by OM who stated that if the color displayed does not match with the color legend, then the system would be seen as broken. During the study, the system showed a very dark blue that was not in the legend for cold room temperature. It happens occasionally and can be easily fixed by programming.

7.4.4 Control

Participants expressed control in different perspectives. In the post-questionnaire participants were asked if they felt they were in control of the decisions they make, and we identified five types of control. Most of the participants felt they were in control of the system. The four main reason were:

(a) The participants felt they were the one who was initializing the system;

(b) The system suggests options but does not make decisions;

(c) The participants still make the final decisions;

(d) Participants can still override the data.

Secondly, participants spoke about the need for partial control in the LWLA system. “If buildings could talk” is a partial control where participants can define the criteria or prompt the discomfort. A few participants mentioned that they would not mind if the system learned about their preferences and suggested options. At the study stage, this was not incorporated. These participants either wanted the system to suggest based on their actions or behavior or have the system respond based on their criteria or preferences.
Two mothers, GF and EF, both have two children of similar ages, and they prefer to have total control of the system for security reasons and personal reasons. GM said that he felt “If buildings could talk” is like a guided control and was not sure if he wanted that kind of control. He still wanted to be in charge or be in control of all decisions and actions. Finally, NM spoke about advanced zone controls where the system could recognize the presence of the participants and voice activate the suggestions.
Chapter 8

Discussion

The Findings chapter, documents and explains each code to understand the wide range of influences on energy usage and comfort. In this chapter, I narrow the findings into three categories: the need for LWLA, inhabitants’ adaptation using LWLA and redesigning LWLA.

8.1 The Need for LWLA

This section consolidates the need for a system like LWLA from Inhabitant’s profile (see section 7.1), and Adaptations made (see section 7.2) from the findings. The need for LWLA finds support in the following categories: people and their needs are complicated; adaptations differ in context, technology, and design; interaction factors that influence energy consumption; and a brief description of what LWLA design considers and ignores.

8.1.1 People and their needs are complicated.

Recently, researchers have focused on how people use buildings. The main reason is that building simulation tools assume simplified models (almost caricatures) of inhabitants and it is increasingly understood that performance is sensitive to behaviour not captured in these models. Also, researchers found that adaptations vary even in similar dwelling units. People and their behaviors differ widely. People adapt, that is, they change their behaviour, due to building type, layout and technology; personal needs; preferences; and interaction with
other household members. Simulation tools largely ignore the social context in buildings. Conflicts around comfort preferences can, in fact, have substantial energy and (of course) comfort effects. Simulation tools mostly consider and analyze the data from a building perspective, for example, insulation and external sources of heat gain and loss. They largely ignore the response of the inhabitants to that design. For example, overheating may have many causes, yet inhabitants may seek to lower temperatures in ways that fight against an actual cause (if a thermostat is set high, an inhabitant may open a window to achieve comfort). PMV, the most widely used model, aggregates data for a large number of people in similar conditions. However, in an individual household, the inhabitants’ conditions are not similar: one may be wearing a sweater while the other may be in a tee-shirt. The PMV model works well for individual people, similar parameters and a closed environment. However, the context within the household varies for inhabitants, and each has their preferences and habits.

Agent-based simulation techniques attempt to capture complex inhabitant behaviour but are seldom validated. They may help in understanding inhabitants’ context and use. There is no guarantee the inhabitants will perform the actions predicted by a simulation. An individual placed in a different type of building may respond and adjust to the surroundings in different ways, due to social context, purpose of being in the building, building design, construction, location, available controls and operating features. All these aspects may affect comfort and energy use. Further, an inhabitant cannot consider all these implications to achieve comfort. Their knowledge and awareness of building function limit their adaptations.

In the Findings chapter, inhabitants profile (see section 7.1) and adaptations made (see Section 7.2) reveal various approaches and perceptions of the inhabitants to achieve comfort. These approaches and perceptions are sometimes effective in saving energy or may simply waste energy. Inhabitants’ profiles show that comfort preferences and actions vary based on people’s body temperature, income, building type, social interaction with others, knowledge of sustainability and lifestyle (7.1). Throughout, people displayed imperfect knowledge of how comfort and energy “work” in buildings, particularly how changes made now may only
have effects much later. Such human complexity was a major part of the motivation for the LWLA design, and the three LWLA questions aimed to help inhabitants understand and control the effects of their actions. If anything, the study findings have shown the situation to be even more complex than I anticipated. A future LWLA system should likely support even more rich interactions.

**People’s needs are contextual and unique to each house.**

When a person relocates from a tropical country to arctic chills of Canada, their body acclimatizes over a period. The person relocating comes with habits, beliefs, and practices from their region. Years of living in a region have influenced their lifestyle, habits, and adaptations in the building to a certain degree. In a tropical country, heating the building is not a typical practice or a necessity. However, using air-conditioning is a common practice. The weather and adaptations vary between countries, within countries, and within states. A participant who moved from Ontario to Vancouver expressed his difficulty in adjusting to Vancouver’s weather. Ontario is cold, but a dry region compared to Vancouver. Also, Vancouver has many microclimates because of the sea breezes. Vancouver weather is mild in winter compared to other Canadian cities. It is wet, and the weather keeps changing because of the sea breezes. Hence it feels colder compared to Ontario weather. This participant felt colder in Vancouver than in Ontario, and his reason was Ontario weather is dry. The participant mentioned that he took long hot baths to regulate his body temperature. It took a year for him to adjust to the temperature. As mentioned earlier, cultural practices of a region influence habits and adjustments in a building. Two couples who moved from Mexico (and other warm countries) to cold Vancouver revealed that cultural practices prevail. During cold winter they said they would wear sweaters. One of the reason was back home in their country they do not have a heater. So, whenever they felt cold, they would wear a sweater. It is a good sustainability practice. On the other hand, a participant narrated how her friend wears light clothes and flip-flops during winter. She cranks her thermostat to be comfortable. This person is from the Philippines and is used to wearing light clothes. She feels comfortable in them. Here energy is being wasted. Cultural practices can facilitate or
hinder sustainability-related actions. When relocating from one country to another country, a person needs to consider the local climate, practices, and beliefs.

A person needs to unlearn to relearn local practices. As much as inhabitants need to adjust when relocating between countries, they need to adjust while relocating from one building to another. Each building is unique and has its own attributes to be considered. Building type, its insulations, local climate, available controls, orientation, all play a role in comfortable living space. The LWLA study shows that inhabitants’ practices in apartments have similar goals but adaptations vary. For example, apartment units have shared walls, and the heat can be lost to the adjacent units or gained from them. In an detached house, the heat is lost or gained to its surroundings. The LWLA study also shows that the room comfort level for an apartment compared to a detached house varies significantly. For example, a few participants in individual apartments were comfortable with 15-degree Celsius, while individual house participants mentioned they would be cold in that setting. Hence LWLA should be personalized for different households.

A system like LWLA needs to personalize the settings for different regions, building type and attitudes of people.

**The type of building impacts the operation of controls.**

Controls in building refer to anything that is operable (like thermostat and windows) to achieve the perceived comfort. The study covered on four types of houses: detached, townhouses, apartment units and a passive house. The goals for comfort were mostly similar in all the houses, and the adaptations vary based on the context. During the study, a common issue for apartment units, townhouses and the passive house was overheating. Most or all of them left the windows open to cool the building. However, the most important factor was their response to the thermostat control. A participant living in the apartment mentioned that they do not turn their heat up, as the unit gains heat from the neighboring units. They operate the thermostat only in the evenings. The participant living in the passive house mentioned that he would not lower the thermostat as it takes time to heat the building. Similarly, in the townhouse, the participants struggled to understand the overheating in
their units. This couple lives on the first floor. One of the reason could be stack effect, but it could also be that the building has no room to breathe. Overheating was not an issue in the detached house. Detached houses for the study were not compact and varied from three to five bedrooms. Participants living in apartment units were satisfied at 15-degrees Celsius, and for an individual house 20 - 25-degrees Celsius seems nominal. The setting that is comfortable for one type of the building is cold for another.

**Both comfort and energy preferences regulate inhabitants’ actions.**

An effective design approach for the future is to consider both the parameters: comfort and energy use. One cannot be separated from the other. Most participants preferred one over the other, and few people gave equal preferences for both the parameters. The reason is an individual who prefers comfort may trade on actions that might save energy. Comfort will be their priority, for example, a couple mentioned they like the building to be slightly cool, and hence they leave the doors open during winter. This couple also mentioned that they do not care about energy use. Their reason was gas is cheap. If each couple responded similarly then as a city or a region, we would be spending more energy than necessary. Likewise, people who have an economic constraint or if they are a sustainability enthusiasts might trade comfortable temperature. These may not be the healthiest interactions. It is easier to approach and present solutions for an individual as compared to couples. Comparing the preferences of comfort and energy concerns for couples reveal they are mostly conflicting. One member of the couple prefers comfort highly than the other and likewise for energy concerns.

Participants need to understand that both comfort and energy use play an important role. An efficient design approach for the future is to give equal importance to comfort and energy concerns. The study did not include children, teens or youths. Their responsibility may vary at different stages of life. The inhabitants’ socio-economic condition plays a role as well. A system may help by motivating the inhabitants to balance their choice by making it available to them.
Conflict arises from differences in perceived temperature.

People struggle with controls because of conflict in comfort preferences. Couples struggle to maintain a balance of comfort between themselves. A typical resolving method for couples is to regulate the thermostat to their preferred settings. Couples often identified one person’s body temperature as warmer and the other person as colder. The comfort needs of the person who feels warmer or colder vary leading to conflicts in interaction. For most couples it was a battle; they either lowered or increased the thermostat with or without the other perso’s knowledge. Personal comfort matters. People are willing to compromise thermostat settings when guests, seniors, and children are present. However, with their spouse, there is often a dispute. Aggregating comfort data for residential building use is futile as individual preferences dominate. Due to lack of knowledge of other strategies, couples typically resolve with the thermostat. Making the inhabitants aware of other strategies is where LWLA can help.

Conflict does not exist among couples alone but also with children. In the study, there was not much discussion about the conflict between adults and seniors. The seniors were living by themselves and not in a large family, so there was not much information regarding them. Couples living with children have conflicts as comfort levels vary between adults and children, and activity and response to the environment differ as well. Children are most active and energetic, and their metabolism is high most of the time. This naturally affects how they feel inside the building. In contrast, adults are often not as active as children. They may feel slightly cold, cold or neutral compared to children who feel warm. Thermal comfort is subjective to either of them. One participant said he increased the thermostat because the room was cold. However, within five minutes his daughter lowered the thermostat. In this specific scenario, the thermostat was lowered before the interaction could take effect. The discomfort is at different levels; one feels cold, the other hot. The study showed it was a challenge to meet the gap between adults’ and childrens’ preference on comfort. One participant mentioned the issue and asked how to address this comfort gap. She observed that the problem exists when inviting children over to a party or to play. Children are at one end of the room, while seniors are at the other end. The presence
of seniors often leads to raising the thermostat to make them feel comfortable. Hence a system can help in suggesting strategies to bridge the gap in preferences. A few people compromised their comfort but were unhappy with their decisions. They often mention that they must always adjust and the expression on their faces during the study showed that they do not feel this is fair. Relationship dynamics impact their response to conflict and willingness to compromise in a household.

*Inhabitants compromise on actions with personal conflicts.* The study shows that a person who is colder in the room is the one who compromises on adaptation. For example, their partner will be wearing a tee while they must wear a sweater. People were unhappy with the trade-offs. Still, they compromised with their personal preference because they felt they had no other choice. At the same time, a few people were not willing to compromise on their actions. They are in a *constant battle* over thermostat settings for the desired comfort levels. Inhabitants need to understand that increasing and lowering the thermostat alternately affects energy loads. LWLA currently displays current thermostat levels when lowering thermostat or increasing the thermostat, but it can further show the effect of energy loads while lowering or increasing the thermostat on a frequent basis.

A system can help the inhabitants to negotiate their actions. LWLA needs to display information that will enable the inhabitants to agree on interaction decisions collectively and satisfy personal needs as well.

**Life upsets energy plans**

Inhabitant’s lifestyles, health, personal interest, hobbies and cultural experiences affect adaptations and energy use. A participant mentioned that he was cold most of the time because of health issues. He had to adjust the thermostat to keep the room comfortable for him compared to other household members. His spouse said that she has to keep him in mind while regulating the thermostat; otherwise, it causes discomfort for him. In this case, the spouse said she often increased thermostat instead of lowering it. However, she always had conflicts in setting the thermostat higher, because she was warmer compared to him. Health conditions affect interaction habits and energy use. The health condition
for this person is long-term, a factor to be considered in the design. However, another participant who was pregnant during the study mentioned how her comfort preferences varied on different days. Pregnancy is a short-term influence on the inhabitant’s body. However, these factors influence the interactions and energy use in the buildings. While health conditions influence adaptations, so do hobbies and personal interests. For example, one participant was passionate about growing indoor plants. Indoor plants need sunlight, and this affected the inhabitants’ interaction with the blinds. The blind states influence either the heat gain or heat loss in the room. The participant mentioned that he would not operate the blinds as the plants need sunlight. In this case, the inhabitant’s interaction with blinds is constant or passive because he always leaves it open. During different times of the days and months, the action affects the heat gain and loss in the building. Inhabitants’ hobbies or personal interests are important. Even these interests can fall into long-term or short-term interests. So, this affects interaction habits and energy use. Children cannot be ignored in this context for their activities change as they grow. For example, one parent was concerned that her son was very passive to his surroundings while playing games. He would not turn the lights on while playing. She was concerned about his habit as it may affect his eyes. Children at different ages exhibit different interests and behavior. Thus, leading us to discuss on stages of life and its influence on the interactions and energy use. Life influences and affects energy plans.

The stages of life within a family present hard constraints.

Hobbies and practices interfere with energy control, but the stages of life within a family completely disrupt a control design. People exhibit different characteristics through different stages of life. The responsibility for living increases as they grow. At different stages of life, a person’s comfort will vary, life varies, hobbies and interest vary, responsibility and knowledge vary. There might be many factors, but a few related to energy usage and comfort are highlighted here. Stages of life need to be part of the design because people change over time. Similarly, buildings age as well. A building may not function the same way as it did when new. An inhabitant’s stages of life are not linear—they keep changing
over time—whereas building performance is linear and predictable. However, a building is a habitat for the people, and hence it is not linear in use. The challenge here is to consider both the building’s age and the inhabitants’ stages of life. Considering all this information in simulation tools is complex. LWLA can fill this role by helping inhabitants to adjust at different stages of life. The concept of stages of life and their relation to energy use was inspired by the participants’ feedback on how they respond in comparison to their children. Designers need to understand that inhabitants are not linear in their living practices. A household comprises people at different stages of life. Finding a balance to meet the dynamism in the household is a challenge.

Further research can be conducted to categorize stages of life and their variables. This factor increases complexity in interactions, and the needs of people. Further, a personal preference changes at different stages of the inhabitant’s life. Also, not only do people age but buildings age too. All these factors influence comfort levels, interactions/adaptations, and energy use in the buildings.

Summary

This section gives an overview of complexity at different levels: personal and social implications; macro- to micro-climate; harmonizing comfort and energy use; and stages of life and their significance in building use. Context varies based on the region, building type, comfort conflicts, personal interest or habits, health conditions and stages of life. The study shows that conditions vary for each household as people and their way of life are different. Hence LWLA needs to be unique for each house. The advanced algorithm or AI can be used to consider the issues in a broader context and meet individual needs. The literature on energy-efficient building shows that inhabitants are one of the causes for energy use. The simulation community discusses the uncertainties of inhabitants’ building use. However, giving people instructions on how to use the buildings through a system like LWLA will influence their choice of actions and habit. This system may resolve the uncertainties in building use.
8.1.2 Adaptations differ with context, technology, and design

As discussed in the previous section, the needs of the people are complicated because of location, cultural practices, preferences, building type, and social dynamics. However, the LWLA study gave strong feedback on how people adapt to the buildings. The adaptations discussed here are related to Vancouver weather. Vancouver weather is mild and damp compared to Toronto or other cold places. Also, adaptations vary for a warm climate. Likewise, the study covers only a few building types in Vancouver. So, there might be variables that this study did not capture.

Inhabitants are passive, selective or actively engaged in adapting.

Passive engagement. The study showed that a few participants are passively engaged in adaptations. Passive engagement can portray an inhabitant who is not making a sustainably conscious decision, ignorant of the actions to be taken, unaware of their surroundings. For example, toddlers do not take any actions, nor do they contribute to energy saving. A better example would be a teen who is engrossed in video game ignores or is inactive to his surroundings. Similarly, the study revealed inhabitants who are lazy to make appropriate action. For example, a participant mentioned that when she is resting she does not like to get up to change the settings. She would ask someone else to act, and it is never carried through. Children are not responsible for energy bills, and their actions are not energy conscious. Sometimes, or most of the time, their actions are not sustainability-related. This engagement was most common. Participants often took actions that do not save energy.

Selective engagement. Selective engagement is where the inhabitants can control certain aspects of the building. For example, some participants mentioned that children six years and younger could operate the lights but not the windows. This attribute is mostly related to children, as they can interact with specific systems for safety, privacy, and experience. It would also relate to buildings that do not give full control to the inhabitants—for example, a centrally heated apartment building, or individual houses that are sublet giving less control for interaction.
Active engagement. In active engagement, inhabitants are actively involved in interactions that provide comfort and saves energy. For example, the inhabitants consciously evaluate the action they are taking and see if it trumps energy savings. A very few inhabitants in the study was actively engaged. The goal of a system like LWLA is to help the inhabitants become actively engaged in interactions or adaptations.

Personal adaptations were performed more out of necessity or need than for sustainability reasons.

Personal adaptations or changes the inhabitants make have no impact on energy use. Personal adaptations are sustainability-related action. Very few participants said they would wear a sweater to save energy. Personal adaptations like wearing a sweater or covering themselves with a blanket during a cold day are taken to resolve conflicts among household members. Participants wear the sweater because they need to, not because they prefer it. It is mainly an element of compromise for inhabitants. A participant mentioned he would often shower to regulate his body temperature. Water is another resource to save; researchers have studied how much water a person uses for a bath. One person is in a tee while the other person wears a sweater because body temperature varies. People learned to adapt, but the adaptation does not meet their preferences. Participants expressed their displeasure in adjusting because there was no other option. The study revealed participants were unhappy about the trade-offs. They had to compromise on their comfort for others. Encouraging inhabitants to wear a sweater to save energy can be one of the system motivations. However, personal preferences matter.

Spatial relocation is not a common practice.

In summer people go out to the mall or the beach because the heat in the building is unbearable. It is a prevalent practice in Vancouver. Spatial relocation is changing positions in a room or between rooms to feel comfortable. Except for two or three participants, no one else spoke about spatial relocation. Heat levels or room temperature in the room vary based on the location. For example, a person sitting close to the window during winter may
feel cold if the weather is cloudy or rainy. However, if they get sunlight then they will feel the heat from the sun, it may or may not be pleasant depending on the people. The person may close the blinds to keep the heat out resulting in turning the lights on, or they can move to another place in the room that does not have direct sunlight which still allows the natural light into the building. Inhabitants are used to their daily activities in each room and use regular spots for certain activities. Locations becomes part of the inhabitants’ lives, and they do not think that moving their location spot can change how they feel. A person who likes to work by the window and likes natural light will choose that spot irrespective of the comfort issues it presents. This is a personal preference. Maybe the system can show inhabitants the temperature level within the rooms. While cooking, the kitchen will be warm because of the heat gained from the appliances and the activity itself. Similarly, the proximity to heating vents affects the room temperature. Only one couple mentioned about changing rooms during the summer season to avoid the heat. Their master bedroom was facing south and gets much heat during summer, making it unbearable. Hence, they decide to move to another room, but they did not move. They found it challenging to move necessities like a wardrobe as they were elderly. Another participant spoke about moving to another location when there is a conflict in comfort with his spouse. One of the participants mentioned that her sons share a room. The older son was feeling hot always and ended up using the fan during winter. She explained to him that this was not necessary. However, she said that her older son’s bed was close to the heating vent, and swapping the locations of the two children’s beds resolved the issues. The solution was not found immediately; it took time for her to figure it out. Especially in large individual homes, temperature will vary based on the orientation of the room and the people can take advantage of that.

A system like LWLA can simulate the scenarios of spatial arrangement based on the inhabitants’ comfort preferences.

**Activities and body’s core temperature amplifies interactions**

Inhabitants’ activity is one of the core principles in an energy comfort model. Standard and scheduled assumptions are used for these models. Activity affects the metabolism
of the body: being inactive or sitting in a constant position for a long time will affect
the body’s core temperature. Participants mention that if they are doing an activity and
feeling cold, they will increase the thermostat. A few participants mentioned if they are
working (like sewing or working on the laptop) and feeling cold they will increase the
thermostat. According to Fanger’s PMV model, if a person is working, then they are at
specific temperature, and it is constant. However, the study shows that participants doing
the work feel cold after some time. The PMV model considers the activity input as an
immediate effect, but for most people, it is a gradual increase.

A system can show the cause-effect of the actions.

**Inhabitants’ mental models of possible actions are limited based on awareness,
knowledge of the building, memory, and comprehension of buildings**

Technology and built environment (see section 7.2.2) in the findings cover various issues in
adaptation with controls like thermostat, blinds, doors or windows. The study shows three
kinds of interaction with the thermostat. First, *active interaction with the thermostat*,
meaning participants frequently interact with the thermostat to adjust the temperature.
This is the primary solution for discomfort. There are other options they could perform
instead of increasing the thermostat. Participants need to change their habits as there
might be other options. Mental models of possible actions are limited based on awareness
and knowledge of building, memory, and comprehension of the effects of actions. Secondly,
*adjusting the thermostat in extreme discomfort*. Here participants prefer the temperature
at certain levels and change it only at a colder temperature or other causes. Lastly, *I do
not like to interact with thermostat often*. The reason is that people find it difficult to
use the technology or the person is passive in interacting. A thermostat is also increased
for the following reasons: to reduce moisture or to avoid mold growth; conflict in comfort
requirements; the building is cold, the presence of a baby, children, seniors or guests; people’s
sensitivity to cold; and finally, if the inhabitant is doing an activity and is feeling cold.
Participants need to understand the moisture increase in the building can be caused by
poor insulation, cooking, showering or other factors that increase moisture. Increasing the
thermostat is one option to resolve the issues, but there are other solutions like increasing the window insulation, ventilating the building sufficiently or use the extractor fans. Awareness of possibilities and understand building functions will affect their choice of actions. Most participants mentioned in the social context (See section 7.2.6) that it is a constant battle during conflicts in comfort issues. They often interact with the thermostat by raising or lowering it. Cranking the thermostat is not the practical choice. Hence, it leads to the question of how to use the thermostat efficiently to save energy. LWLA can demonstrate the possible criteria mentioned above as the current system only considers few variables. LWLA does not provide building function solutions yet. Any system should consider the context to help inhabitants make a sustainability-related action. Blinds were operated based on building orientation towards the sun. They were lowered because of privacy issue, or they were left open for the plants that needed sunlight. The state of the blind affected the heat gain or loss during different seasons. LWLA can help the inhabitants in weighing the action and making meaningful interactions. In conclusion, the needs of the inhabitants and interactions cannot be approached separately. They need to be approached holistically based on inhabitants’ knowledge, awareness, and comprehension.

Cultural practice and knowledge affects understanding and interactions

Another lifestyle issue was mentioned by one participant, who stated that her friend who grew up in the Philippines was comfortable wearing light clothes and flip-flops during winter. She always cranked her thermostat up (because habit influences adaptation). This increases energy use. Inhabitants need to adapt environmentally to save energy. One cannot be forced to do a particular action, but the consequences of that action can be made clear to them. Another participant mentioned the absence of windows in her bathrooms, and because of the lack of that feature she felt the design was not efficient. She comes from a warm country where openings in the bathroom are a common practice for ventilation. In colder countries, the exhaust fan fills that role. However, here the lack of knowledge of design elements causes displeasure with design. LWLA can resolve this barrier by suggesting solutions to people who are migrating from a different culture and climatic zones.
A system can help in understanding the underlying building functions, systems and elements for efficient interactions.

**Technology aids or obstructs interactions**

Technology influences the daily practices of inhabitants. Understanding the function and use of the technology aids or facilitates interactions. People need an easy interface with which to interact. People do not understand how a thermostat influences the room temperature. For example, participants found it difficult to understand why the room was cold or hot after increasing or lowering the thermostat. Various factors may influence room temperature, and the inhabitants need to evaluate the causes to make appropriate changes to the building elements and controls. Two participants mentioned that it took them a few weeks to months to figure out that the issue was with the system. However, this is more of a mechanical problem—the real issue lies with the interface design of control system, for example, the thermostat. Participants mentioned that they would not change the programmable thermostat setting, as it is complicated to do so. Literature shows that interface or interaction design for smart thermostats is being addressed by researchers to make it easy and efficient.

Technology is ingrained in an inhabitant’s life. Current tools learn about your preference and choices and display information related to personal interests. For example, Netflix learns the choice of your movies and shows and suggests movies based on your interactions. Similarly, participants preferred the system to learn their interaction choices and display information based on it. Alexa and Siri are becoming part of daily life. Participants mentioned that they like to have a voice-assist system to increase ease of use and access. Here technology aids interactions. The current generation is growing with technology and appreciates its use and incorporation. However, some people who are not tech savvy and old school may prefer to make their choices.
Summary

Adaptations and the needs of the people are interlaced and interdependent. This adds more to the complexity of interactions in the buildings. There can be no “one size fits all” in LWLA. Any successful LWLA system will be specific to the context. As mentioned earlier the system is unique to each house.

8.1.3 Interaction factors that influence energy consumption

In the Findings chapter, each topic explains the issues in detail as this is relevant for the design community to understand and perceive inhabitants’ interactions. However, looking at the two sections; Inhabitant’s profile and adaptations made, new themes emerged relating to inhabitant’s action and energy use. Many participant actions are combinational—for example, wearing a sweater and leaving the windows open, or increasing the thermostat and wearing a sweater. Most of the adaptations were not sustainability-related and used more energy than necessary. This section covers the issues that increase or wastes energy. These criteria play an essential role in the inhabitants’ interactions in the buildings.

Without knowledge, comfort trumps energy

It is easy and fast to open a window; harder to turn down a thermostat and wait for the temperature to fall. For example, people use fans during winter when the room is overheated. Here the participants mention that lowering the thermostat before sleeping causes discomfort when waking up. Implementing a programmable thermostat will quickly resolve these issues. However, the study shows that easy user interface affects the interaction. Lowering a thermostat may or may not resolve the issue because sometimes could be based on building design. Especially for apartments, heat is gained through stack effect and from shared walls. Investors in the building decide the materials or method of construction. Making the building airtight solves the heat loss but causes discomfort by overheating. The building needs to breathe. This shows that participants will adopt other methods to achieve thermal comfort. Another example involves opening windows during winter for air circulation. Of course, installing an HRV (Heat recovery ventilation) will balance the overheating
issue. However, the main issue is participants’ need for immediate satisfaction. Lowering the thermostat will take time to affect the current room temperature, while opening the window gives immediate satisfaction. That is their reason for choosing the non-sustainable action. The study included only one house with HRV installed, so the response of participants to its use is unknown. The study observed that most participants leave windows open while cooking; this was noticed in a passive house as well. The person living in the passive house mentioned they turn on the HRV but still leave the windows open while cooking. The interaction does not balance the function, but it apparently explains that people will adapt by any means to achieve their comfort. These actions are not efficient if they become a regular habit, as they affect the energy use substantially.

*Overlapping changes of clothing and interaction with windows or doors and the thermostat was not efficient most of the time.* A couple mentions that they like wearing long sweaters during winter. The action seems very sustainable at the beginning, but looking at their lifestyle in more depth showed it is not sustainable. They prefer the house to be slightly cold and hence wear a sweater, with the thermostat at a particular set point, and they leave the windows or living doors slightly open for a cool room. The interaction is inefficient apart from giving comfort. This habit was seen for other couples too. They crank the thermostat to keep themselves warm and leave the windows open for fresh air and to avoid overheating. Well, researchers and designers may argue the implementation of mechanical strategies like HRV will resolve these issues. However, the literature highlights the uncertainties of the building use in so-called sustainably designed buildings. They are still uncertain about how people interact in the buildings because predicted and actual energy use differs. Installing an HRV system may improve the building design, but the study here did not cover sufficient houses with HRV. So, it will be good to study how people adapt to the presence of HRV. As mentioned earlier, the study conducted in one passive house with HRV installed showed that people still chose inefficient actions. The participant mentioned the HRV helps in air-circulation, but while cooking, he will still leave the windows open for fresh air. The heat gain from the appliance and activity adds to the existing heat. Designers need to rethink the design for the kitchen. Currently, comfort models do not
calculate the heat gained from the appliances. The comfort models need to support these factors for useful assumptions and evaluation of building use. LWLA needs to incorporate the mechanical systems used in different individual houses to show benefit and on how to balance the built environment.

*Understanding cross-ventilation in the building will affect interaction.* Participants’ actions on opening windows were mainly for cross ventilation. Their actions affected the comfort levels but ignored influence on energy consumption. If inhabitants do not understand how cross-ventilation works, they are unlikely to use it to control comfort efficiently. The participants mention they leave the windows open in the kitchen and bedrooms or living rooms for cross ventilation. A few mentioned they leave the windows open throughout the night with thermostat up. These interactions break the function of the thermostat and cause more load on it than needed. The designers and simulation modelers need to consider activity related interactions. For example, what interactions are likely to help inhabitants sleep comfortably, or while cooking what actions do they perform to keep themselves at comfortable room temperature.

A system can illustrate how such strategies affect both comfort and energy use for the current hour and future effects. Currently, LWLA aids the participants by showing the comfort temperature and energy use over time, this enables the participant to change the action or interactions with the built environment. It also considers activities and its effect over time but does not cover interactions related to cross ventilation.

**Family and extended relations can dominate comfort decisions.**

*People lead socially complex lives.* The study identifies three factors – conflict, negotiation, and compromise – that typically influence comfort decisions. Any LWLA must support these inevitable social interactions.

*Presence of children/seniors affect interactions and energy use.* Aggregating the comfort levels for inhabitants in a household is not adequate. The study shows that individual and collective satisfaction both matter. Perceptions of the value of comfort increase when seniors and children are present. In these situations, inhabitants often choose actions that involve
raising the thermostat. Some reasons are unavoidable, and this is one of them. Guests are another factor to be considered. Participants mentioned that they are not aware of guests’ comfort, so they increase the thermostat. It is also a social norm to keep guests comfortable and cared. Being socially conscious leads to the compromises inhabitants make for others to be comfortable.

Neighbors’ actions affect my room temperature. A frequent topic that arose in the study was the heat gained through shared walls in apartments and townhouses. For example, one inhabitant mentioned that their building was very hot because of seniors living on the lower floor. The heat could merely be due to stack effect or other issues. Another participant mentioned that their building is hot most of the time and that they gain the heat from the neighboring apartments. In fact, she stated that she never turns the heat. This action equates to stealing energy from the neighboring house; consequently, it is not efficient for the neighboring house. LWLA can suggest and help to communicate in a social context, which varies for apartments and detached houses. Also, individual houses are sublet, and people have private spaces and shared spaces in which interaction varies.

A system needs to consider the possibilities of building use and provide information that aids in efficient interaction. People’s natures and adaptions vary for different households. It is a challenge to find a parameter that satisfies everyone. Artificial intelligence might help in refining the data or provide possible suggestions considering the various factors.

Design really does matter

Design and construction (see figure 7.2.5) of the building affects both comfort energy usage. Insulation materials for the windows cause heat leakage in most buildings, especially detached homes. Retrofitting of building is often deferred for cost reasons. Detached homes are often leaky because of window insulation and installations. Old buildings need to be retrofitted for better energy performance. In the longer run, the investment helps in energy savings but does not give an immediate return for the expenditure. Government policy on funding or rebates can influence people to retrofit their homes. Also, LWLA could project the savings of installing well-insulated windows to current expenditure. Considering the
remuneration for the owners when they install energy efficient material is important. If the owner is not getting any benefit from the modification, then they will not be encouraged to retrofit their homes.

*Complex controls create barriers to use.* During the study participants mentioned that they do not change the control settings of the programmable thermostat because it is difficult to use. Understanding the interface and use of control devices affects interactions. Designers need to consider these parameters for effective interaction in the buildings.

*Controls need to be ready to hand.* Familiar locations and proximity to control devices affect interactions. Most of the participants mentioned that they would not go to another place to control the thermostat settings and preferred to have it their mobiles. Control settings for the different rooms are necessary to meet different age comfort requirements. Placement and orientation of apartment unit or rooms in individual houses influence comfort and interaction as well. The existence of too many controls presents a hassle for inhabitants to operate. There needs to a balance in considering controls and zoning where too little or more might be an issue.

*Passive house and strategies reduce energy bills.* New buildings in Vancouver are incorporating passive design strategies. The core issue of the adaptation was people trying to adjust the windows for fresh air and overheating. The designer needs to consider the occupants’ comfort. An airtight building prevents heat leakage but causes discomfort. Building managers and owners insulate the building and do not consider systems for air-circulation. A participant mentioned that they like to have good air circulation in the building and they do not like the suffocated feeling. Such discomfort only leads to adaptation that is not sustainably efficient. In other words, if the participant is not comfortable with the existing design, they are going to adapt the building to their desired comfort. Moreover, the adaptation may be efficient or not efficient. These apartment units have make-up air unit but not HRV. This system will help the building to breathe but whether the inhabitant will be comfortable after its installation needs further research.

*Proximity to the heating vent affects comfort and settings.* Placement of beds or seats must be considered in design as this influences interaction with thermostat and other ele-
ments in the building to achieve comfort. One of the participants mentioned that her two boys share a room; one was closer to the vent and felt the room was always hot. He often used the fan to cool himself as lowering the thermostat affects the comfort temperature for his brother.

Design really matters. A system like LWLA can be efficient with well-designed passive houses or green buildings. On the other hand, LWLA can predict the efficiency of retrofitting a house.

**Agency affects adaptation**

*Agency must align with effect for a control system to have an impact.* For example, if an inhabitant has no access to mechanical system controls, (s)he will resort to actions that yield comfort but may increase energy consumption. In a centrally heated apartment, the inhabitants have less control to operate for comfort. A couple mentioned that their building was too hot, and they had no control to change the settings. Instead, they adapted by wearing light clothes and walking barefoot in the apartment. No control leads to unwanted energy use.

In an individual house that is sublet, the owner has more control over the thermostat setting than the tenants. A participant mentioned they were cold during winter and could not adjust the thermostat setting—so they therefore very uncomfortable. The participant also highlighted that the kitchen was cold as well. The owner preferred a different setting. Lack of agency disrupts life.

**Knowledge affects adaptation**

Most of the interactions performed by the inhabitants were energy consuming, and even during the task completion participants needed an explanation for specific actions.

*People can and will use qualitative performance explanations.* Most of the participants left all the windows and doors open during the summer. This will only increase the heat in the building, but at a particular time of the day and orientation of the building, operating windows or doors can be helpful for ventilation. The knowledge gap between system use and
function affects interactions. For example, understanding the function of the thermostat, windows and blinds will affect the way the inhabitants are interacting with them.

*Lack of information on energy usage is frustrating.* Lack of information about energy usage hinders the participant’s awareness and motivation to take sustainable action. LM mentioned he would like to know the effect of his action on energy usage and savings. LM, who was taking actions to save energy, became demotivated because he was not able to see its effect on cost. LWLA helps in this respect. The participant mentioned that he wished he could see the data for his house after seeing the effect of different interactions in LWLA.

KF mentions many times that the bills were high and she did not know the reason for the cost. She also wanted to compare the energy usage of her building with other apartment units to understand the performance of their house. Participants need to see the meter data or usage, but while there are monitoring systems for large buildings this is not a typical practice for residential buildings. BC strata provide the energy usage for the individual unit but do not give aggregate information for the apartment building (like the performance of their unit compared to the neighbors) or micro details on their energy loss. LWLA needs to address the knowledge gaps at different levels for different users.

*Trade-offs are another issue to consider.* While comfort was the most prominent influencer, aesthetics of the surrounding environment influenced as well. Here a system can collect data from different units on their comfort and provide a setting that is suitable for the apartment.

**Time latency affects adaptation**

People do not understand time latency. Frequently changing the thermostat setting is not effective. Here a few actions that participants perform related to the thermostat:

* A few participants mentioned that raising the thermostat does not have an immediate effect on the room temperature. Hence, they hesitate to lower the thermostat and made adaptations to themselves like wearing a sweater or covering themselves with a blanket. Participants often look for immediate comfort relief rather than a long-term influence on
their actions and comfort. The time latency is dependent on the presence of inhabitants in the building.

*Short-term/long-term presence or absence in building affects interaction.* Participants operate on the duration of presence or absence in the buildings. For example, if the participant is going out for shopping, they do not lower the thermostat as it takes time to warm the building on their return. One participant mentioned that they turn off the thermostat only when they are traveling on a long vacation. In fact, this particular participant had a programmable thermostat that could easily resolve their issue, but was not using it due to a difficult interface. One participant stated that he would simply like to express to the programmable system lower it for two hours.

*Certain activities and interactions in time affect adaptation.* Similarly, some activities take effect in the future and not at the current state. For example, initially, when the inhabitant is reading a book, they are at comfortable room temperature. However, when some time has passed, they are going to feel cold because the metabolism level becomes low. Hence, they are going to feel cold. Participants need to understand the cause-and-effect of interactions and activity in the buildings.

**The contextual location of technologies like LWLA may affect its use**

Greenberg et al. (see section 3.3.4) summarize the importance of the contextual location of technologies in a home. During the study participants suggested locations for installing the tool about their daily activities and use. As explained by Greenberg et al., these locations become a “strong shared language in the home.” LWLA affirms these factors as participants choose objects or appliances related to daily activities like the refrigerator or mobile phone. Another critical factor is the proximity to these locations, as participants mention they will not use the system if it is not readily accessible. People choose the places and activities that become contextual locations in Greenberg et al.’s terms. Thus, LWLA should, by design, be able to be sited in a variety of locations and be embedded in a variety of activities. Any LWLA system needs to remain open to such adaptation.
8.1.4 What LWLA considers and does not considers in its design?

Currently, LWLA considers lowering and raising the thermostat with the combination of other actions. For example, in the study we often notice participants mentioning that they would raise the thermostat and leave the windows open. LWLA shows the impact of that particular action and its influence on energy usage and comfort. Lowering the thermostat and wearing a sweater will give the same comfort as the current thermostat setting. Participants were able to see combinations of actions with systems and building elements. Multiple occupant comparisons were not considered in LWLA as it adds to the complexity of interface design. Data considered were internal to that specific building and did not consider the neighboring homes or units in the apartment. LWLA was designed for an existing building because designing for different units is complicated and time-consuming. LWLA covers the typical issues mentioned in the pre-questionnaire and task completions except for multiple occupants, children, the lifestyle of people like video gamer, party person, cultural influences and hobbies like indoor plants. I discuss this in detail in the following section, adaptations using LWLA.

8.2 Adaptations using LWLA

In this section, I explain how the LWLA system helps in adaptation. Design affirmation and issues of each interaction models (“I feel”, “If buildings could talk”, “What if?”) are discussed.

8.2.1 Adaptions using “I feel” interaction model

Participants affirmed the expression “I feel” and how it acknowledges their sense of comfort in the building. They also said that it responds to their surroundings and is easy to express. The response that was not foreseen during the study was “I feel” acknowledges the present discomfort, and it was important to the participants. Multiple options help them to weigh their choices. Participants mentioned that they would use the model on a personal level and see its relevance to their situation. LWLA allows the participants to express the feeling
of discomfort by interacting with the button on the dashboard, but the study concluded it would be best to incorporate it through voice recognition. They merely wanted to voice their expression to the system. “I feel” was most preferred in comparison to other models as the interaction is initiated by the inhabitants and provides them with possible comfort options and its energy usage.

8.2.2 Adaptations using “If buildings could talk” interaction model

The core design of this interaction was to remind the inhabitants of the state of the building elements and systems and to remind the user of actions to be taken. The core idea was to help the inhabitants define their preferences. The study confirmed the main concepts and suggested other considerations. Participants with children explained the need for “If buildings could talk”. They like to be aware of the window states or doors to check if the kids left it open. The participant mentioned that if the system prompts them, they could then call the children and ask the reason for leaving the windows open. The other reason inhabitants preferred “If buildings could talk” was when they had no motivation or energy to contemplate their actions. They expected the system to take the initiative—for example when they are sick or if they forget to act. “If buildings could talk” was most preferred for user preferences. Participants said they would like to personalize the comfort according to their preferences. They also mentioned that the system could refine and present the data based on their comfort preferences, energy consumption, or based on their history of interactions. The data were not categorized or organized based on the above suggestions. LWLA can incorporate this suggestion for future implementations. Participants preferred the use of “If buildings could talk” when they do not want to plan anything or to be aware of the performance of rooms that are not in use. Participants suggested that the system should incorporate a threshold for energy usage and inform them when they exceed the threshold. All these confirm the need for AI and control over energy and comfort in buildings. The other suggestion by participants was to provide examples to guide their actions. Also a few participants said constant alert or information would be annoying. However, participants
can configure the system to inform based on their input, and frequency in updating can be
defined based on the deviation in their comfort preferences.

8.2.3 Adaptations using “What if?” interaction model

“What if?” model was the least preferred but helps the different types of inquiries like daily
activities. “What if?” helps in planning and exploring actions. Participants found it fun
to play and explore. The drawback of this interaction model is that once the participants
explored the choices they were aware of, it limited further action. Very few participants said
that they like to test and weigh the decisions. On the other hand, most participants said
they are not going to be weighing their choices. One participant mentioned that she would
use this model for buying decisions like changing the current blinds to thermal blinds. They
suggested that the system can show them how this affects the energy usage and investment.
“What if?” is still a potential interaction model as it caters to different types of people. It
can be more useful in providing information for retrofitting the house.

8.2.4 Overall influence of the system on adaptations

During the study the LWLA helped the participants in the following:

Decision-making

Possible options and energy data helped them to weigh the options and choose the action.
During the pre-questionnaire, participants initial interaction was to increase the thermostat
when the building was cold and leave the windows open for fresh air. However, on seeing
the information, they understood its impact and changed their choices. They were willing
to make combinational actions like lowering thermostat and wearing a sweater. Lowering
the thermostat was not a standard response to the pre-questionnaire, but during the task
completion, when participants saw the comparative data, they said they would choose to
lower thermostat if it saves some cost.
Learning

During the study, participants learned the effect of their actions on why one choice was efficient than the other. For example, instead of increasing the thermostat, a participant chooses to wear a sweater. This action brought them to a comfortable room temperature. But they also noticed that lowering the thermostat by 2 degrees and wearing a sweater causes low energy usage and gives the same comfort. There were questions about personal changes like wearing a sweater and its effect on energy usage. The sweater does not affect the energy usage but is a sustainable action. They wondered why lowering the thermostat reduces the cost and the sustainable action of wearing a sweater does not. Here participants need to see the effect of their actions. So, seeing the options helped them in narrowing their choice. Also, one of the participants mentioned that “I feel” and “If buildings could talk” will help their children to learn why one option is better than the other. The participants say that while “I feel” is easy to express, the “If buildings could talk” responds to the deviation in comfort or threshold.

Couples negotiate or consult using LWLA

Most of the couples mention during the pre-questionnaire that differing comfort requirements created a “constant battle” or that one needs to compromise when different comfort requirements are present. While conducting the task completion, I noticed that the participants started consulting with each other on the options and what choice they would like to make. They discussed and weighed the options and came to a conclusion. In fact, one of the participants stated that LWLA or a system like this would help them in negotiation.

The user is the primary decision maker

Users mention that they trusted the system because they are in control of the decision they make. Across the three interaction models, they are the ones initiating the action and deciding the choice. The system only provides or suggests the possible options as to comfort and energy use. Participants trusted the system because the decision was initiated and concluded by them. A few participants suggested partial automation and system intelligence
to learn their preferences, but expressed they would still like to be in control. In LWLA, the inhabitant controls and initiates the actions.

8.2.5 Gaps in the interaction models

Comparison of multiple inhabitants

Participants expressed the need to see how the other members felt and whether the system could refine and suggest the data considering both their needs.

Social norms

Participants liked to know how their neighbors were adapting to similar issues. The suggestion depends on the community in sharing the data, as most participants asked who is going to access the data and did not want to be compromised.

Short-term/long-term implications of actions

LWLA displayed the effect of actions for comfort on energy and comfort for a 24-hour timeline. However, participants suggested incorporating the effect of their action (behavior) over the short term or long term. For example, they wanted to see what happens on opening windows while the heat is on and how this would impact energy consumption in the long run if they continue the same action. One participant said comparing the inefficient interaction and efficient interaction over a more extended period will help in influencing the interaction choices.

Appliances and their influence on comfort

The most critical aspect of the study was participants asking about the radiant heating from appliances and how it accumulates in the overall heat. Only one or two participants spoke about this issue and were interested in knowing the difference. Adding the operation hours of the appliances will also help in calculating the radiant heat from the appliances.
Motivational feedback and immediate gratification

Data on energy usage helps in decision making, but few participants suggested including motivational feedback. Motivational feedback may vary for different users: while one may be motivated by dollars they are saving, the other may purely be motivated by saving nature (for example, how many trees they are saving?)

Summative information

Participants needed to see summative information along with visualization. They mentioned that it helps them in understanding the data.

Controlled Automation and intelligence

Participants also like to set up their scenario (based on their habits and routines) to calculate comfort. Participants expressed the need for controlled automation, ?If buildings could talk? precisely meets this criterion but they concluded system could use intelligence on their lifestyle to suggest information. They mentioned they would like to be in control of decisions.

8.3 Design and improvement

In this section, I present ideas for restructuring LWLA in the light of the needs and suggestions of the participants from the study. The explanation starts from the design of the data visualization and proceeds to the overall interface.

8.3.1 Reconstructing donut pie chart

Participants faced specific issues and suggested improvement on the donut pie-chart. I present the following suggestions.

Display data for day/night or a.m./p.m. or sleep-awake hours.

The donut pie chart shows the timeline for 24 hours. Participants revealed the need for clear identification of day and night hours. On questioning on how many hours they would like
to see in the timeline, they quoted that they liked to see the 24 hours but needed more clear demarcation. The figure 8.1 shows the demarcation on the boundary with the intensity of color. The color is light gray to dark gray.

**Figure 8.1: Donut chart showing day/night or a.m./p.m. or sleep/awake**

**Highlight the current time**

LWLA shows the current time with a dot, but participants required a more explicit identification as the dot was tiny. The solution can be to increase the size of the dot, or design an arrowhead pointer, or highlight the slice, so it pops out from the other slices. See figure 8.2

**Figure 8.2: Highlighting current hours in the Donut Pie Chart**
Integrating energy usage to donut pie-chart

Figure 8.3: Comparing the Donut Pie Chart for (a) “I feel” “If buildings could talk” and (b) “What if?”

LWLA displayed the comfort and energy data in two-layer visualization. Figure 8.3 (a) shows the representations used in the “If buildings could talk” and “I feel” model. It became complex for “What if?” model as it shows the comfort levels for existing building conditions with the interaction made by the inhabitants. See figure 8.3 (b). It becomes four circles, and it causes spatial integration issues and adds cognitive load for the user. Participants expressed the need for similar design across all three interaction models. The new design suggestion is to continue the use of pie to represent comfort level and the pie height for energy consumption (See figure 8.4). The reconstructed pie chart allows the users to see both the energy and comfort information for “What if?” model, which was missing in the initial design. Multiple options can use the same design for consistency.
**Icons to describe the multiple options**

One of the suggestions of participants is to include icons in the center of the donut to replace the text headings. They found it hard to read the text. Integrating the icons for combinational actions can be overloading and crowded. Showing a single action is easy but showing combinational actions is difficult. The design options can be explored in the future. The figure shows the solutions but needs usability test to analyze its acceptance. Icons should be designed universally for people from all backgrounds and ethnicity to understand. See figure 8.4.
8.3.2 Improving multiple options

“I feel” and “If buildings could talk” gives wide possibilities of actions with the building systems and options. I suggest the following based on the participants feedback.

Filter by comfort or energy used

LWLA needs to refine or filter the display of options based on inhabitants’ preferences. In Section 8.1.1, I classify three types of people in comparing energy and comfort: comfort is highly preferred, same preferences for comfort and energy, and energy is highly preferred. The study revealed the inhabitants who prioritize energy would make trade-offs with comfort. LWLA should refine the options based on the inhabitants’ preferences, but LWLA needs to encourage sustainably responsible actions. For example, when the participant is selecting an option that is not contributing to energy savings, then the system can summarize its implication for a longer duration.

Categorizing the multiple option data by thermostat settings (Current versus suggestive)

Multiple options have two layers of information. One layers consists of possible interactions with current thermostat settings. The other layer consists of possible interactions with lower or raised thermostat settings. The interaction systems differ seasonally; it can be fan or air conditioning during summer. However, during the study participants voiced the need to see a clear boundary between the two, for example, how lowering or raising the thermostat affects the cost. The figure 8.3 shows the existing design and figure 8.6 show the new suggestions of incorporating color intensity to separate the two data.
Summative data for efficient inhabitant performance

LWLA shows multiple options for comfort and energy usage by color representations. The comfort color ranges from red for very warm to blue for very cold. The energy consumption was represented by the intensity of color green with light green representing less energy used and darker green representing more energy consumption. The visualization helped in refining the choices, but participants felt it was not giving them a strong impact to make a decision. For example, summative feedback in dollars will have a greater impact than mere color representation for more energy consumption. So, users want to integrate color with values. Users suggested the summation should vary, as different people require different motivations. For example, the dollars may work for one person while for the other person it could be how many trees he saves. LWLA’s motivation is to encourage participants to save energy. Presenting summative data of energy consumption in dollars may or may not have an impact. In the study, a participant said spending few extra dollars is fine for them as far as they are comfortable. Another participant said they do not mind opening doors and leave the fireplace on as gas is not expensive. In this context, once the user selects the option the system will show cumulative data for a year if the action behavior persists.
For example, if the participants decide to leave the window open during winter, how will it impact monthly to yearly?

8.3.3 Incorporating multiple inhabitant comparisons

A common suggestion during the study was to incorporate multiple inhabitant comparisons. The suggestions highlight the complexity and conflicts the inhabitants face as they try to meet the needs of other household members along with their personal needs. Participants needed to see information about other inhabitants’ comfort needs to make decisions. QF?

“So my view on this would be, suppose if I had a family and we all had this right. Say 7 of us, so A is hot, B is cool, and I am in the middle. Would be interesting if the last person in could take it and see that information. I think you need to see what other people want.”

Participants need to know what to do when there is a big gap in comfort needs, for example, seniors versus children. LM highlights the need to consider inhabitants with health issues as they might have different comfort requirements. LF “Some people wear sweaters, but their hands are always cold. Some people are like that. Some people are hot all the time, like when women go through menopause.” LWLA helps the inhabitants in negotiation and consultation to agree on mutual actions. Current technologies with the use of AI will be able to refine and suggest data that consider collective inhabitants’ needs and preferences. Representing the data becomes a challenge. It is quickly resolved if the household members are couples, but more than two people add many layers to the data. Participants expressed the need to see how the other person felt. The following suggestions need further study to understand the preferences of inhabitants.
Figure 8.7: Representing multiple inhabitants through circular line chart

Figure 8.7 shows an overlapping donut chart with line chart will help in incorporating multiple options. The base chart segmentation represents the different hours, but this solution can increase clutter and cognitive loads. A horizontal line chart may be more evident, but may hard to define spatially in the building plan representation. The base bar represents the comfort values and the height represents energy consumption. The base bar shows the data for current thermostat settings, and it considers the existing thermostat levels, states of windows or doors, inhabitants' clothing type as medium and activity as sitting. The line chart figure 8.8 with nodes can represent multiple inhabitants. The line height represents the energy used, and nodes represent the comfort level.
LWLA visualization aims to integrate the design spatially; line charts give options to integrate multiple inhabitants they may not be able to incorporate it spatially. The data can be tied to the location of rooms but this may be overloading. User studies will help in evaluating the design suggestions. I have developed a very different consideration for incorporating multiple inhabitants; it may have to be constrained to incorporate the different interaction models. Figure 8.9 shows the spatial view of the rooms in the building and a layer for defining inhabitants’ parameters. The circles are represented over time. The color of the circle represents comfort, and the size of the circle represents energy used. Since participants wanted to see the data of the other members, this design will resolve the issue.
8.3.4 Overall design suggestions for LWLA

Integrating the interaction models

The three models were separated for the participants to explore interaction through different expressions. One model allowed self-exploration, in another model user expresses their discomfort and the system suggests the action, and the third model allows the inhabitants to let the buildings remind them of actions and states of the building. The study shows integrating the models will facilitate interactions. LWLA will retain the three interaction models to cater to a wide range of inhabitants but integrating the three models may guide the inhabitants. In the “What if?” model, after the participants explored the possible actions they were hindered in furthering the actions. Hence LWLA could integrate “If buildings could talk” to “What if?” model to enable and guide the inhabitants to explore further.

In “I feel” the system responds to the inhabitants’ expressions and displays multiple options. For example, based on the options, if the inhabitants choose to open the windows
during winter, with the help of “If buildings could talk” they can set a reminder for closing the windows after a particular time. Likewise, they can set a reminder when there is a major deviation in comfort on energy levels.

**Defining thresholds for comfort and energy usage**

One crucial feedback was to define the threshold for energy and comfort. “If buildings could talk” revolves around this suggestion but for the study, the participants were not given a threshold to define, but when they selected the icon, it suggested the options based on the existing settings. Participants wanted to be notified when they exceeded the energy use for that week in monetary definitions.

**Information of their action and energy usage over a period.**

For example, if participants choose to open windows while having the heater on, the system will show how much it will cost them over a year. Likewise, if they perform an action that saves energy and continue the habit, the system shows how much energy they will save.

**Integrate other comfort issues**

The system could integrate comfort issues like noise, smoke, visual comfort, lighting and heat from appliances to LWLA. Since the model uses simulation at the backend, it was reduced to thermal comfort.

**Controlled automation and intelligence in the designed system.**

Participants felt it would be cool if the building learnt their preferences. Though inhabitants preferred the system to learn about their actions they said they would still like to be in control. Controlled automation and intelligence will help the system to suggest interactions based on their comfort, actions, and choices.
Incorporate voice assistant in the system.

When the model was presented to the participants, they were excited about the fact that they can just say “I feel warm.” However, they were a little disappointed that they had to select a widget to express how they feel. In the initial design we had thought about voice recognition but did not incorporate it, to reduce the scope of the project. During the “I feel” task FF mentioned “Yeah you can check the options and say you can turn the thermostat off.” LWLA needs to consider this in future design.

Providing motivating factors or immediate feedback with gratification

Motivational factors and immediate returns will help in participant’s selection of actions. One participant expresses the need for knowing who is spending that energy. She wanted her child to know that her actions are observed by others and if they perform a sustainability related action then they can be rewarded. She emphasizes the need for the children to learn about energy usage and cost. Providing a numerical value may help in the process of saving energy.

HE et al. (2010) apply the transtheoretical model (TTM) to survey a range of existing sustainability systems and to develop an initial set of design guidelines for such systems. LWLA can be viewed as responding to or supporting all of the stages of the TTM, but in varying ways and strengths.

The first stage of the TTM is “precontemplation” where inhabitants acknowledge their “problematic unsustainable behavior.” LWLA displays possible choices of actions with energy usage, and it helps the inhabitants to identify the cause of the problem with their interactions. In other sense, it “plants the seed” to acknowledge their behavioral issue. The design implementation for LWLA needs to incorporate personalized messages recommended by the framework to cater to individual needs. One of their design rationales at this stage is to provide the pros and cons of “individual’s current sustainable behavior.” LWLA meets this rationale by combining personal changes with building system interactions. It provides them with its effect on energy use. Based on the context the information displayed should be adapted. For example, one of the participants mentioned that they would leave the
windows open with heat on as gas is cheap. As recommended by the model, showing social norms may help the inhabitants behavior. LWLA’s “I feel” and “If buildings could talk” modes both support precontemplation by revealing information about comfort and building performance with minimal inhabitant action.

Stage 2 of the framework is Contemplation, “Tip the balance in favor of change”. Lack of motivational feedback impacts sustainable actions in the building. During the study, a participant expressed that since he was not able to see the effectiveness of his actions hence, he discontinued. A system like LWLA can show or reward the inhabitants for any sustainable actions taken. The “What if?” model helps in evaluating individual queries and helps them to evaluate the pros and cons of the action by providing comparative data of current action with future implications. In contrast, “I feel” enables contemplation and exploration based solely on self-perception of comfort, again providing useful information with low barriers to access.

Stage 3 of the framework is Preparation. “Develop a plan that is acceptable, accessible and effective.” “If buildings could talk” model may help at this stage of behavior change. “If buildings could talk” model alerts or prompts or reminds the inhabitants to take action related to comfort and energy use. It helps the inhabitants to customize their tool. “If buildings could talk” can incorporate small to large energy goal setting for inhabitants based on their current sustainable behavior. As recommended by the framework, the system can provide expert advice (engineers or architects) for that context or connect to the community to see what other people do. “What if?” enables inquiry into how the building as a system “works.” Thus, it may be useful to people developing awareness and understanding of the system and preparing themselves for future action.

Stage 4 is action, “Positively reinforce sustainable energy actions” and “develop intrinsic motivation.” The framework suggests reinforcing the constructive behavior by providing for interactive exploration, customization, and annotation. “What if?” model allows the inhabitants to explore individual actions and “If buildings could talk” helps the inhabitants to customize, but they do not provide annotations to motivate the people to continue the sustainable behavior. The three models “I feel” “If buildings could talk” and “What if?”
model allows the inhabitants to explore the data in different ways, and the study shows “I feel” model was highly preferred as it was easy to expresses. In the future, LWLA can incorporate annotations or summation to encourage sustainable actions.

Stage 5 is maintenance, “maintain durable sustainable energy behavior.” The framework has three recommendations, First, to provide prompts to remind them about actions and gradually reduce the prompts as the behavior becomes steady. “If buildings could talk” prompts or reminds inhabitants about the actions, but participants say continuous prompt will be annoying. Further research in the frequency of prompts will help in designing LWLA and refining “If buildings could talk”. Second, it recommends “energy mentors,” and this can be incorporated as participants expressed the need to know how others are acting in a similar context. Lastly, they recommend an individual to self-reinforce and self-reflect by journaling their energy experience. While evaluating the three models “What if?” model was least preferred as the inhabitants need to explore and decide their action and its impact on energy use. Most participants said they would not be doing it and preferred the system to suggest the compare the data. Inhabitants’ want light-weight interactions and processes. Hence, self-reinforce and self-reflect will not be successful as it requires more effort from inhabitants.

In summary, each of LWLA’s eco-dialogues appear to address more than one ot the TTM’s steps. Perhaps this is not surprising, as LWLA is explicitly designed for meaningful exchange with inhabitants. Potentially more surprising is how such conversations appear to cross the behaviour change phases, suggesting perhaps that LWLA is but one possible example design in a yet-to-be-determined framework for behaviour change specific to sustainability. It may be that a feature of any successful system would be that its features must each address several aspects of behaviour change.

All the suggestions for redesigning LWLA need interaction and usability testing for understanding inhabitants’ perception of the data.
Chapter 9

Conclusions

Inhabitants’ interaction and operation of building elements and systems is one of the significant factors affecting differences between predicted and measured data. Understanding inhabitants’ use of the building is complicated for energy models. The uncertainties of the occupants in the simulation model are still unknown. My research also argues that inhabitants lack the knowledge and awareness of the design intent of the built environment. Current energy monitoring system displays measure data and project the future use. While such systems still have an impact, they lack the knowledge on why the inhabitants are doing the actions they are doing. They also do not suggest possible actions and their implications on energy consumption. Current tools do not display comfort but measured energy consumption data. My argument is that providing inhabitants with information on building comfort and the effects of their actions might influence their decisions. Designers are performing a beautiful act by designing sustainable buildings, but literature review shows the vast difference in predicted and actual energy consumption. My research argues that it is time to move from beautiful act to beautiful interactions, where inhabitants are involved in the entire process.

To resolve the gap between design intent and actual use of the buildings, I designed a system, LWLA, that provides information on comfort and energy usage. In addition to this data, LWLA allows the inhabitants to explore with three different models catering to different context and type of people. One of my main arguments is that people are not
aware of other available options to resolve comfort issues. Providing them with possible choices of actions with comfort and energy implications may influence their choices.

During pre-questionnaire of LWLA study, I noticed participants choosing actions that gave them immediate comfort and these actions often led to energy consumption. In the pre-questionnaire participants who hesitated to lower the thermostat started changing their opinions after seeing LWLA feedback display. The LWLA study shows that providing the inhabitants with information relating to comfort and energy usage along with possible interactions influences decisions. Inhabitants were able to negotiate and consult using the LWLA system. LWLA helps in the learning process for people with different knowledge levels about building and sustainable practices. Parents found that LWLA will help their children to understand and learn about energy usage and influence their actions. Also, the LWLA study shows that people like to be in control of their environment and LWLA meets the criterion, as in the end the inhabitants still make their decisions; the system only provides information. Participants suggested that automation and intelligence be incorporated based on their interactions. However, they expressed the importance of being in charge of controls, actions and the information for privacy. They conveyed the need to be aware of the changes to their living environment. LWLA can be a part of everyday living to help improve inhabitants’ living performance.

In conclusion, inhabitant living and interaction performances matter for beautiful interactions. Beautiful interactions involve inhabitants, designers, and buildings co-existing together for sustainable living practices.

9.1 Future Work

The LWLA system catered information to inhabitants and was evaluated with them as a primary design consideration. For further research, LWLA can understand how designers respond to the system and consider the inhabitants’ interaction in design. Multiple inhabitants and interactions will be the next exploration; this will increase the challenges in integrating data to provide information that meets different comfort and energy requirements. If and when LWLA is installed in residential buildings, it will help in analyzing
measured data with actual data for human comfort. It will help in creating models of inhabitants—for example, the simulated data might suggest that inhabitants are feeling warm, but in reality, the inhabitants feel just fine. LWLA has a strong potential for further research on occupant behavior when implemented in an actual house.
Bibliography


Appendix A Pre Questionnaire

Participants ID: __________________________

Family description (e.g., married couple, two children, and one elderly person):

Age groups (e.g., one 30-40 years, one child 0-5 years, one child 10-15 years):

Site Characteristics

House type: __________________________ (e.g., single bedroom apartment, 2 bedroom house)

Location: __________________________ (e.g., surrounded by trees or buildings, lower mainland)

Thermostat Type: conventional or programmable thermostat

Semi-Structured Interview

1. How concerned are you about your comfort (like cold or warm) in your residence? Tell me when and how much you are concerned? Use a scale of 1 to 10 (1 unconcerned, 10 very concerned).

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<tr>
<td>Unconcerned</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>Very concerned</td>
</tr>
</tbody>
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2. How concerned are you about your energy use (like electricity, gas) in your residence? Tell me about when and how much you are concerned? Use a scale of 1 to 10 (1 unconcerned, 10 very concerned).

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<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>Very concerned</td>
</tr>
</tbody>
</table>

3. Who plays the major role in your family on decision concerning comfort and energy use? Why do they play the major role?

4. What are the best features of your residence? Name one or two.

5. What are the most annoying features of your residence? Name one or two.
6. Cold clear winter day:
   a. In a cold clear winter day, when you are feeling very cold what actions do you perform to achieve comfort? (For example, some people have reported doing the following: turn thermostat up, wear a sweater, drink something hot etc.)
   b. Do you usually turn thermostat up or wear a sweater?
   c. Have you ever wondered why your building is cold after turning thermostat up? How did you resolve this issue?
   d. What do you do when one person is cold and the other person feels warm in the house?
   e. When you found the room is overheated, what do you do?
   f. Have you ever left the window open during night times in winter? Why?
   g. Do you use fans for air circulation during winter?
   h. Have your sleep got disturbed because you felt the room was very hot?
   i. Do you use programmable thermostat? Do you often override the settings? Why?
   j. What about your family members? Do you have conflicts in your comfort feelings?

7. Typical Rainy day:
   a. Imagine that it’s typically rainy day (March) in Vancouver and you are staying at home; have you felt any discomfort due to weather?
   b. How did you resolve it?
   c. Do you usually turn your thermostat up or wear a sweater or use a blanket?
   d. Any particular situation that comes to your mind?

8. Hot clear summer day:
   a. In a hot clear summer day, you feel very hot what actions do you perform to achieve comfort? (or to keep the buildings cool)
   b. Do you often use air conditioning or fans? Why?
   c. Have you felt very stuffy and did not know what to do in the building?
   d. Do you leave the windows open during night times?
   e. Do you have the blinds up or down during the day? Why?
   f. Any other issues that you have faced during summer time? How do you resolve it?

9. How often do you ask your children to close the windows or perform other actions to save energy in the building? Can you describe how this occurs? Or narrate events that happened?

10. Do you ask any other family members to perform the actions?

11. Do members of your family disagree about comfort and how to achieve it?

12. What would you like to have to resolve the issues? Please explain?

13. How long have you lived in this house? When moving to different houses did you face different situations concerning energy use and comfort? Could you explain the type of house and how it is different from the present house or apartment?
Appendix B Task Completion

Task 1: What if? Model

1. Cold clear winter day:
   It’s a cold clear winter day; the thermostat is set at 20° Celsius, you are wearing a warm (heavy clothing) dress and have been cooking. You are starting to find the room very warm and want to reduce the comfort level to neutral. Use the “What if” Model to achieve your desired comfort. Talk to me what you are doing, thinking, seeing and feeling?

2. Typical Rainy day:
   It’s a rainy Saturday afternoon (late March); you are in the living room and you are reading a novel or watching TV in a reclining position on the couch. You have the blinds up as you have a beautiful view. After sometime you are finding the room temperature cold. Use the system to explore different things you could do to feel warm. Talk to me about what you are doing, seeing and feeling?

3. Hot clear summer day:
   It’s a warm summer day; you are finding the room temperature very warm after your routine exercise. Use the system to explore different things you could do to feel cooler. Talk to me what you are doing, thinking, seeing and feeling?
Task 2: ‘I feel’ Model

Figure 2: Interface of ‘I Feel’ Model

1. Cold clear winter day:
   It’s a cold clear winter day; the thermostat is set at 22°C, you are wearing a warm dress and have been cooking. You are expressing the room is very warm. Use the system to express the feeling in the related room.
   a. What does the interaction show? What do the multiple options show you?
   b. What option would you choose and why? Name three options that you would choose in order.
   c. Would you like to see any other options? Why?
   d. Would you like to see any other information?

2. Typical Rainy day:
   It’s a rainy Saturday afternoon (late March); you are in the living room and you are reading a novel or watching TV in a reclining position on the couch. You have the blinds up as you have a beautiful view. You feel cold! After sometime you are finding the room temperature cold. Use the system to express the feeling in the related room.
   a. What does the interaction show? What do the multiple options show you?
   b. Which option would you prefer and why? Tell it in the order of preference!
   c. Would you like to see any other options?

3. Hot clear summer day:
   It’s a warm summer day; you are finding the room temperature very warm after your routine exercise. Use the system to explore different things you could do to feel cooler. You feel warm! Use the system to express the feeling in the related room.
Task 3: If buildings could talk!

1. Cold clear winter day:
   It’s a cold clear winter day; the thermostat is set at 22° C, you are wearing a warm dress and have been cooking. You find the room is very warm. You are not sure what to do in the building and you would like to see what the building could say to you.
   a. What is the system showing you?
   b. What you think about the available options?
   c. What do you think about the order of preference?
   d. Would you like to see any other information?

2. Typical Rainy day:
   It’s a rainy Saturday afternoon (late March); you are in the living room and you are reading a novel or watching TV in a reclining position on the couch. You have the blinds up as you have a beautiful view. After sometime you are finding the room temperature cold. You are not sure what to do in the building and you would like to see what the building could say to you.
   a. What does the interaction show? What do the multiple options show you?
   b. Which option would you prefer and why? Tell it in the order of preference!
   c. Would you like to see any other options?

3. Hot clear summer day:
   It’s a warm summer day; you are finding the room temperature very warm after your routine exercise. You feel warm! You are not sure what to do in the building and you would like to see what the building could say to you.
   a. What does the interaction show? What do the multiple options show you?
   b. Which option would you prefer and why? Tell it in the order of preference!
   c. Would you like to see any other options?
Appendix C Post Questionnaire

Participants ID: ______________________

Semi-Structured Interview

1. In the three models you worked on what works for you? Why? Could you say it in the order of preference? Any other thoughts?
2. What annoyed you? Why?
3. Where would you like to have this? And why?
4. If I were to give you expression buttons? Where would you like to have it? Stick it on 5 different locations, in order of preference. Why would you like to have it there?

5. Where would you use it? Why?
6. What would keep you from using it?
7. Are you able to trust the information that this tool is providing?
   a. If yes
      i. Why?
      ii. What features makes you trust the system?
   b. If no
      i. Why?
      ii. What would you do change the system to trust it more?
8. Do you feel you are in control with the decision that you make?
   a. If yes
      i. Why?
   b. If no
      i. Why?
      ii. What would you like to have in the system to make you feel that you are in control? (explain or sketch)
9. What other information you would like to see in a tool like this?