BCIT AFRESH HOUSE RETROFIT

FEASIBILITY REPORT

October 03, 2018

PREPARED BY:

Local Practice Architecture + Design

Joshua Monk Vanwyck Consulting

RDH

FOR:

Alexandre Hebert

Manager, Zero Emissions, Building & Energy Systems Application

BCIT, School of Construction and the Environment

local

JMV
CONSULTING

RDH

TABLE OF CONTENTS

TABLE OF CONTENTS

APPENDICES

EXECUTIVE SUMMARY 1

The AFRESH House is an existing energy efficiency demonstration home that aims to be a model sustainable home of the future. However, even with the addition of numerous active technologies to achieve Net Zero Performance, the AFRESH House performs well below it's energy efficiency targets and is uncomfortable to occupy many months of the year. With a poorly performing building envelope that does not meet today's minimum building code, the house is a prime candidate for a building envelope-focused energy retrofit.

BCIT contracted Joshua Monk Vanwyck Consulting, Local Practice Architecture + Design and RDH Building Science to conduct a feasibility study to retrofit the AFRESH House to Net Zero ready performance using a building envelope first approach. The team conducted a series of Integrated Design workshops with BCIT to define the project goals and determine a retrofit approach. Over the course of these workshops it became clear that this project has the potential to serve as a case study retrofit that would be applicable to existing Canadian homes across the country. A key consideration throughout the process was to ensure a retrofit that would be affordable and accessible to the average Canadian homeowner. Following the workshops, technical analysis that included thermal modeling and research was conducted to inform the recommended strategies for achieving a Net Zero Energy ready performance retrofit.

A building envelope first approach to achieve Net Zero Energy ready performance is a simple, and robust long-term solution for improving the energy performance of existing homes. The approach is focused on improving thermal performance and airtightness of the building envelope with the addition of thicker insulation, a new air barrier system, and high performance windows, doors and skylights. From a systems perspective, all existing mechanical equipment are removed and replaced with a simple heat recovery ventilator and a high performance boiler (either gas or electric) to meet the remaining heating and hot water requirements. Existing pipework and ducting will be retained or modified as necessary.

The project aims to develop a repeatable precedent that is affordable for the average homeowner and tell the story so that Canadian homeowners, builders and communities can apply these strategies to existing homes in Canada. This report outlines these goals, the metrics for success (Key Performance Indicators), retrofit scenarios, building envelope and architectural design considerations, and provides a cost estimate identifying the investment required to complete the retrofit.

2 PROJECT INTRODUCTION

Across Canada 63% of the single detached housing stock was built between 1960 – 2000[1]. Of this stock, 6.5% were self assessed as needing major repairs and 30% in need of minor repairs. Most of these homes were built to the minimum building energy code at the time, have poor building envelopes (minimum stud cavity insulation) and contribute significant carbon emissions to the atmosphere. Previous research has shown that most 1960s – 1970s homes can achieve a 75% reduction in energy consumption by performing an external retrofit[2].

The AFRESH House is an example of an existing detached home that is ready for a mid-life retrofit focused on improving energy performance and occupant comfort. As such, a retrofit of the AFRESH House will provide a directly applicable precedent to homeowners and builders across Canada, demonstrating how Net Zero Energy ready performance can be achieved on an existing home. Given this opportunity for demonstration and education, solutions and approaches were selected only if they would be applicable to other houses. For example, mechanical equipment such as high efficiency boilers and air-to-water heat pumps were selected rather than using the AFRESH House's existing geo-exchange system.

Located at the BCIT Burnaby campus, the AFRESH House is optimally located to serve as a case study for mid-life energy retrofits to Net Zero Energy ready performance. Within this higher education learning environment, the house is accessible to educators, students and a broad community of builders and trades, and can be used for future courses and seminars.

[1]Statistics Canada, 2016 Census of Population, Statistics Canada Catalogue no. 98-400-X2016222.
[2]RDH Building Engineering, Research report, Near Net Zero Energy Retrofits for Houses, CMHC, 2012

PROJECT OBJECTIVES 3

3.1 PROJECT PURPOSE

Through two workshops that included all of the project team, the following purpose statement and principles were established. It is the intention that these summarize the foundation and direction of the project and will be used to provide guidance and test project success throughout subsequent phases.

The purpose of this project is...

TO create a teaching and research facility, that serves as a repeatable precedent for upgrading existing homes in Canada to meet the requirements of Net Zero Energy ready standards;

IN A WAY THAT is legible, resilient, simple, affordable and explains the advantages of building science and technology to homeowners and students;

SO THAT homeowners, builders and communities can develop the capacity, skills and knowledge to propel the upgrade of all existing homes in Canada to Net Zero Energy ready performance.

3.2 PROJECT PRINCIPLES

The principles of this project are...

1. Achieve Net Zero Energy ready performance through load reduction and a building envelope first approach.
2. Be open source and transparent by sharing knowledge freely.
3. Be credible and build on a foundation of data.
4. Celebrate proven passive solutions and make building science accessible and fun.
5. Prioritize repeatability with simplicity, and accessible methods of construction.
6. Prioritize cost-effective solutions that utilize affordable materials and technologies, reclaim space, integrate multiple generations, and generate potential revenue for homeowners while reducing operating costs.
7. Improve quality, comfort and health through every intervention.

3 PROJECT OBJECTIVES

3.3 PROJECT GOALS & OPPORTUNITIES

With the established Project Purpose and Principles, the AFRESH House retrofit has the potential to make Net Zero Energy ready performance feasible for all Canadian homeowners through storytelling that communicates the benefits, execution and financial means necessary for its success. To share the strategies and the process, the team developed a series to storytelling goals:

- Create a compelling, legible story that encourages homeowners to pursue an energy retrofit on their existing home.
- Provide the teaching tools for builders, students and educators to build their knowledge and share it with others.
- Kickstart a culture shift towards resilient, envelope first approaches, that celebrates simple materials and technology.

To achieve these goals, the following storytelling topics have been identified:

1 COMMUNICATE THE BENEFITS OF ENERGY RETROFITS

- Increased thermal comfort
- Improved air quality
- Reclaimed mechanical spaces

2 COMMUNICATE AFFORDABILITY

- Homeowner's budget needed for retrofit
- Potential revenue generation opportunities
- Reduced operating costs

3 COMMUNICATE ADAPTABILITY

- Flexible floor plan: one-family home or two separate suites
- Future provisions for elevator

4 DOCUMENT AND MAKE ACCESSIBLE THE STRATEGIES, METHODS AND DETAILS USED TO ACHIEVE NET ZERO READY PERFORMANCE

- Documentation of the execution of construction
- Share building performance data during operation
- Provide AFRESH House tours
- Develop course material

Some potential methods of communicating the project's success include:

- Photo / Video for social media
- AFRESH House website

EXISTING CONDITION 4

PROBLEM STATEMENT

The AFRESH House's attempt to reach Net Zero Energy ready performance through advanced active mechanical technologies was a failure. In the last 10 years, over 90% of the mechanical systems have failed and are not maintained. Maintenance of such systems is beyond the skill and scope of the average homeowner. The building enclosure is below current minimum code requirements, is subject to significant air leakage and has many thermal bridges.

CURRENT STATE

The existing AFRESH House is a 190m^2 (2,050ft^2) house built in 1999 with help from CMHC to be a model home of energy efficiency and flexibility. As a modular home with the latest technologies, it was an example of the sustainable home of the future. In the early 2000s the AFRESH House was moved to the BCIT Burnaby campus as a demonstration home, and has been occupied as an office and training space. In 2008 the AFRESH House was retrofitted with a series of active technologies in an attempt to achieve Net Zero Energy performance. Unfortunately, much of the technology that was installed in 2008 failed within the first 5 years. This technology includes a combined heat and power fuel cell, a small wind turbine, an energy management system with a battery, inverter and CPU, and a heat pump geo-exchange system with 9 modes of operation. The owner does not have the budget to either replace or even dispose of the failed equipment. Investments of tens of thousands of dollars to date have not succeeded in fixing the operational problems. The building envelope was constructed with significant thermal bridges at nearly every critical transition (observed with infrared imaging, see Appendix B) and has an air leakage rate of 5.35 ACH at 50Pa pressurization. The air leakage rate is almost 30% above the average home currently built in Metro Vancouver, and five times greater than the 1.0 ACH at 50Pa required by Step 5 of the BC Energy Step Code. Temperature control in the house is extremely difficult with temperatures in the semi-occupiable attic space over 40°C and the bedrooms consistently exceeding 28°C during the summer months. Consequently, large areas of the house are not suitable for occupation for months at a time (see Appendix A for more detail).

The AFRESH House does not meet its Net Zero Energy performance target, consuming almost 100 kWh/m^2/yr and producing only 16 kWh/m^2/yr from photovoltaics. Even if the house was occupied by a family and operated as a home with proper climate control, the energy figures would likely increase by as much as 50% to 100%. Nevertheless, the house has significant value as a demonstration facility. Currently used for classes and training, the AFRESH House showcases some of the common energy efficiency and comfort issues that plague existing homes. In addition, the house was designed with accessibility, flexibility and modularity in mind. It is easy to adapt the house for either 1 or 2 families using the home for life concept, and these design strategies have survived the test of time, being as valuable today as at the house's inception.

To create a very clear baseline of the energy consumption and comfort levels in the house, detailed monitoring has been conducted for all four seasons. This data includes temperature, relative humidity, CO_2 levels, electricity demand for all major draws, airtightness testing and thermal imaging. This monitoring has enabled the team to focus on the key areas that need improvement, set meaningful goals, and will provide critical data for demonstrating measurable changes after the retrofit. A detailed summary of this data is included in Appendix A and B.

5 KEY PERFORMANCE INDICATORS (KPIs)

The following KPIs were established during the two project workshops to guide decision making and evaluate the success of the project. Additional details on the various KPIs are available in Appendix F:

1 ENERGY EFFICIENCY

- Net Zero Energy Ready: Meet Step 5 of BC Energy Step Code or the Passivhaus Institute's EnerPHit Standard
- Total Energy Demand Intensity (TEDI): 15 - 25 kWh/m²yr

2 OCCUPANT COMFORT

- Thermal Comfort
  - » Meet ASHRAE 55-2013 comfort standard
  - » Prevent Radiant Asymmetry with maximum 4.2°C temperature difference between indoor air temperatures and surface temperatures (Class A – DIN 15251)
- Acoustic Comfort
  - » Mechanical systems to meet Passive House Requirements (< 35dB(A) in installation room)
  - » Interior assemblies to meet the minimum BC Building Code requirements for STC ratings between suites
- Air Quality
  - » Ventilate with 100% outdoor air
  - » Provide natural ventilation including night flushing
  - » Provide minimum MERV 13 filter for mechanical supply air
  - » Provide adjustable ventilation rates based on occupancy

3 OCCUPANT HEALTH

- Architectural materials to exclude Living Building Challenge Red List Materials
- Building Envelope designed to have no potential for mold growth

4 AFFORDABILITY

- Retrofit must be achievable at an overall affordable cost that considers the mortgage for the retrofit, reduced operating costs, and potential separate suite income
- Value of increased comfort
- Value of increased usable area
- Assessed value of house after the retrofit

ENERGY RETROFIT SCENARIOS 6

A series of energy scenarios were developed to assess the feasibility, constructability and affordability of the potential retrofit alongside current housing stock and current minimum industry practice. Each of these scenarios was modelled in PHPP v9.6 using designPH to import the house geometry. A detailed list of assumptions and results is included in Appendix C. Although there are many different solutions possible, only solutions that are applicable to typical existing homes were considered.

To achieve a standardized comparison, the PHPP study uses the same geometry and orientation for all scenarios. Four distinct baseline cases and two Net Zero Energy ready retrofit options were modeled.

BASELINE CASES

1. The existing AFRESH home if it was operated to maintain reasonable comfort
2. 1970s Archetypical Home
3. 2018 code minimum, new home with no special systems
4. 2018 Classic Retrofit of a 1970s Archetypical Home

NET ZERO ENERGY READY RETROFIT OPTIONS

5. Option 1 - Natural gas fueled home
6. Option 2 - All electric home

Each baseline scenario provides a basis to compare the performance of the AFRESH House and existing 1970s archetypical homes with current new construction and retrofit practices. Scenario #1 demonstrates the performance of the existing AFRESH House if it was operated as a family occupied home. In Scenario #2, the 1970s archetypical home highlights the poor performance of the bulk of the existing Canadian housing stock. The performance of a new code minimum house in Scenario #3 demonstrates only a minimal improvement in performance over a 1970s archetype. In Scenario #4, the classic retrofit of a 1970s archetypical home demonstrates a minor increase in performance given that the envelope is typically not addressed.

Scenario 5 and 6 are two retrofit options that demonstrate how an envelope first approach greatly reduces a building's energy loads, and indicates that Net Zero Energy ready performance is achievable without expensive active technologies.

The two retrofit options investigated considered two different energy sources for heating: Option 1 is a gas-fueled home and Option 2 is an all-electric home. By comparing these two energy sources, homeowners can understand the economic and environmental trade-offs of these options. These are impacted by local utility rates, and the availability of natural gas or propane. As affordability and simplicity were key principles no heat pumps, geothermal, or other advanced technology was considered. A high efficiency gas boiler or an electrical resistance water heater were considered for domestic hot water. Localized space heating is provided through hydronic or electric resistance coils in the ventilation outlets. Although there are more efficient and lower carbon options for providing heat, all options are significantly lower carbon than the current scenario given that the total heat demand has been reduced by 93%. With this simple heating system, there will be no provisions for active cooling of the house. Therefore, passive ventilation strategies have been proposed to address the potential need for cooling in the summer months.

6 ENERGY RETROFIT SCENARIOS

Refrofit Scenario Matrix

	Baseline				Net Zero Energy Ready	
	1 Existing AFRESH House	2 1970s Archetypical Home	3 2018 New Construction (Code Minimum)	4 2018 Classic Retrofit of 1970s Archetypical Home	5 Option 1 Retrofit	6 Option 2 Retrofit
Envelope						
Walls	2x4 w/ R-19 batt w/ 1.5" exterior insulation u=0.36 W/m²K (R16)	2x4 w/ R-19 batt u=0.47 W/m²K (R12)	2x6 w/ R-19 batt, no exterior insulation u=0.34 W/m²K (R17)	2x4 w/ R-19 batt u=0.47 W/m²K (R12)	Remove exterior insulation and strapping, replace with 7" exterior insulation u=0.139 W/m²K (R41)	Remove exterior insulation and strapping, replace with 7" exterior insulation u=0.139 W/m²K (R41)
Roof	Semi-conditioned attic 2x10 w/ R28 batt insulation u=0.22 W/m²K (R25)	Semi-conditioned attic 2x6 w Fiberglass batt insulation u=0.4 W/m²K (R14)	R-20 insulation, conditioned attic u=0.36 W/m²K (R16)	Semi-conditioned attic 2x6 w Fiberglass batt insulation u=0.4 W/m²K (R14)	Add 6" insulation above roof deck u=0.109 W/m²K (R52)	Add 6" insulation above roof deck u=0.109 W/m²K (R52)
Grade / Basement	Uninsulated crawlspace	Uninsulated crawlspace	Conditioned crawlspace (4" of internal insulation) u=0.33W/m²K (R17)	Uninsulated crawlspace	Insulated and conditioned crawlspace (6" Internal Insulation) u=0.22W/m²K (R26)	Insulated and conditioned crawlspace (6" Internal Insulation) u=0.22W/m²K (R26)
Windows & Doors	Double glazed u=2.7 W/m²K (U-0.47)	Poor double glazed, u=2.9 W/m²K (U-0.5)	Double glazed, u= 2.0 W/m²K (U-0.35)	Double glazed, u= 2.0 W/m²K (U-0.35)	High performance triple glazed, optimized u=0.8 W/m²K (U-0.14)	High performance triple glazed, optimized u=0.8 W/m²K (U-0.14)
Skylights	Single glazed u=4.7 W/m²K (U-0.83)	Single glazed u=4.7 W/m²K (U-0.83)	Double glazed, u=2.0 W/m²K (U-0.35)	Double glazed, u=2.0 W/m²K (U-0.35)	Remove and fill with opaque roof assembly	Remove and replace replace with triple glazed, optimized smaller area u=0.8 W/m²K (U-0.14)
Deck / Porch	Attached	Attached	Attached	Attached	Address thermal bridges	Remove and replace with freestanding
Airtightness	5.35 ACH	6 ACH	3 ACH	3 ACH	1.0 ACH	1.0 ACH

Refrofit Scenario Matrix

	Baseline				Net Zero Energy Ready	
	1	2	3	4	5	6
	Existing AFRESH House	1970s Archetypical Home	2018 New Construction (Code Minimum)	2018 Classic Retrofit of 1970s Archetypical Home	Option 1 Retrofit	Option 2 Retrofit
Mechanical Systems						
Energy Source	Gas	Gas	Gas / Electricity	Gas	Gas	All electric
On-site energy source / generation	Solar PV & geoexchange	N/A	N/A	N/A	Solar PV	Solar PV
DHW Heating Equipment η100%	Heat pump	Gas boiler (η100%=85%)	Gas condensing boiler (η100%=90%)	Gas condensing boiler (η100%=90%)	Improved gas condensing boiler (η100%=95%)	Electric boiler (η100%=100%)
Space Heating Equipment	Water-to-water heat pump and boiler	Gas boiler furnace	Electric resistance heaters	High efficiency furnace	Boiler with hydronic heating coil	Electric resistance heater at each supply
Ventilation Equipment	AHUs with heating and cooling coils, HRVs (efficiency = 67%)	Exhaust only no HRV	Exhaust only no HRV	Exhaust only, no HRV	HRV (efficiency = 92%)	HRV (efficiency = 92%)
Space Conditioning Distribution	Forced air	Forced air	Forced air	Forced air	Forced air	Forced air
Location of mechanical equipment	Ground floor mechanical room	Ground floor mechanical room	Crawlspace or ground floor closet	Crawlspace	Relocate equipment to crawlspace / under stairs	Relocate equipment to crawlspace / under stairs
Ventilation System	Forced air	Forced air	No ventilation or forced air	Forced air	Install new ventilation ductwork	Air seal existing ductwork
Results						
Thermal Energy Demand Intensity (TEDI) (kWh/m^{2}a)	217.8	213.6	126	172.7	14.8	14.3
Mechanical Energy Demand Intensity (MEUI) (kWh/m^{2}a)	232.4	236.1	142.2	194	32.4	29.5
Electricity Demand (kWh/m^{2}a)	230.2	13.2	136.8	12.7	11.4	38.9
Primary Energy Renewable (PER) (kWh/m^{2}a)	358.6	411.3	225	337.7	56.5	47.9

7 DESIGN CONSIDERATIONS

7.1 BUILDING ENVELOPE

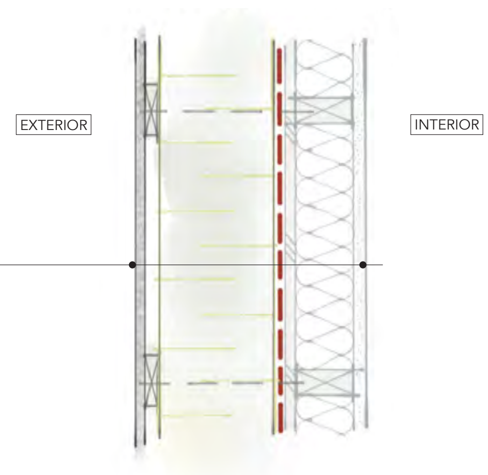
With a building envelope first approach, an exterior insulation retrofit was selected over an interior retrofit for various reasons. These included but are not limited to:

- Minimizes disruption to homeowners/tenants to live in place during the work
- Exterior installation is a more effective use of insulation
- Airtightness targets are easier to achieve
- Improves building enclosure durability from moisture penetration
- Avoids loss of interior floor space or ceiling height
- Simple to phase over time by the homeowner and coordinate with window and door replacements
- Dovetails with aging homes need to replace deteriorated cladding permitting an aesthetic upgrade

ASSEMBLIES

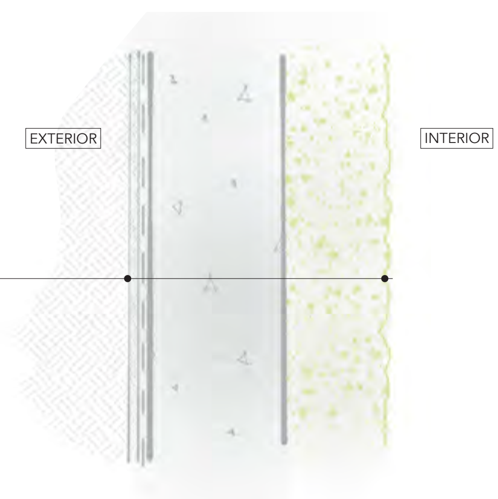
Typical Wall Assembly
(Existing components in grey)

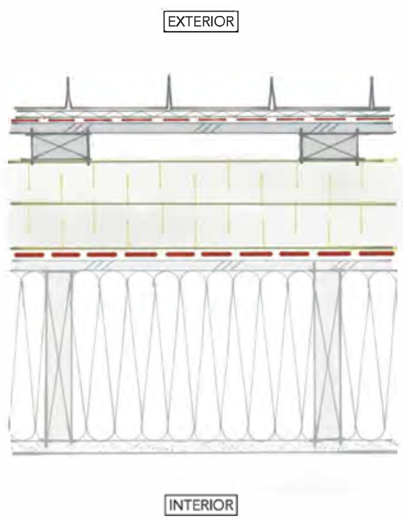
Cladding
Wood strapping (rainscreen)
178mm (7") (R-28) Rigid mineral wool insulation (vapour permeable so that inaccessible interior vapour barrier can be safely left in place)
Vapour-permeable self-adhered membrane (AB/WRB)
13 mm (1/2”) plywood sheathing
38x89mm (2x4,') wood studs@ 400mm (16") O.C.
c/w u=0.474 W/m 2K (R12) batt insulation
19mm (5/8") Gypsum board
Vapour barrier paint (VR)



Typical Below-Grade Wall Assembly (at crawlspace)
(Existing components in grey)

Cement Parging on wire mesh
Dampproofing
Cast-in-place concrete
152mm (6") u=0.22 W/m 2K (R26) spray foam insulation over interior of concrete and into rim joistspace.
Interior insulation selected where exterior excavations are not necessary to address existing moisture/drainage problems.





Typical Roof Assembly
(Existing components in grey)

Metal roofing over vent/drain mat

Roofing underlayment (WRB)

13mm (1/2") Roof sheathing

2x4 cross strapp ing for ventilation

152mm (6") XPS (R-30) insulation in 2 layers with stagg and taped joints (sufficient thickness and R-value to sh dewpoint outboard of the existing assembly so that indoor air convection and vapour diffusion is managec

Self-adhered roofing membrane (AB/VR)

19mm (5/8") T&G Plywood decking

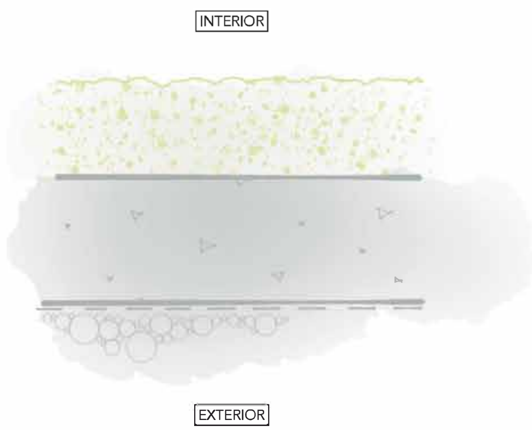
38x254mm wood joists@ 400 (16") O.C. c/w u=0.203 W/m 2K (R28) batt insulation

Blown-in cellulose or fiberglass insulation to fill cavity above exist ing batt insulation

Existing roof vents sealed over (unvented)

19mm (5/8") Gypsum board

Vapour barrier paint



Typical Slab-on-grade Floor Assembly (at crawlspac
(Existing components in grey)

152mm (6") u=0.22 W/m2K (R26) spray foam insulatic

Cast-in-place concrete

Polyethylene sheet

CRITICAL AREAS

- Thermal bridging at floor, wall and roof transitions
- Air Barrier continuity at transitions from floor-to-wall and wall-to-roof

7 DESIGN CONSIDERATIONS

7.2 ARCHITECTURAL

With an envelope first approach, there are many design opportunities that become available to improve the quality, appearance and usability of the AFRESH House. First, the performance-based approach of the BC Energy Step Code and Passivhaus standards provide a flexible framework for choosing the performance of the assemblies, windows and mechanical system. While the retrofit scenarios provide specific performance requirements to achieve the TEDI targets, these performance requirements can be optimized based on quality, capital cost and impact on operating cost to provide the best value for the homeowner within an affordable budget. For example, a high performance, triple glazed window may fall outside a typical retrofit budget. A slightly lower performing window could be used and offset with additional wall insulation to make up for the reduction in performance. Second, this approach uses a smaller mechanical system that can be relocated to the crawlspace and under stairs. By doing so, the usable floor space of the home is increased creating opportunities for thoughtful repurposing for other uses such as a den or office. Third, by removing the home's exterior, opportunities for improving the architectural expression and street presence of the home become available. Together, these architectural design considerations provide homeowners with opportunities to improve the quality, usability, and potentially the assessed value of their home. The architectural design opportunities and their impacts to consider have been summarized in the diagram below.

EXTERIOR ENVELOPE

- Updated wall and roof assemblies with increased thickness for exterior insulation
  - » Potential projection into setbacks
- Optimized/ triple glazed windows
  - » Openings should be large in area to minimize losses through frames
  - » Small windows could be combined into one large window as structure and framing permits
- Reduce area of skylights, replaced with triple-glazed
- Address thermal bridging at balcony
  - » Option 1 - add insulation
  - » Option 2 - remove and replace with free-standing

INCREASED USABLE SPACE

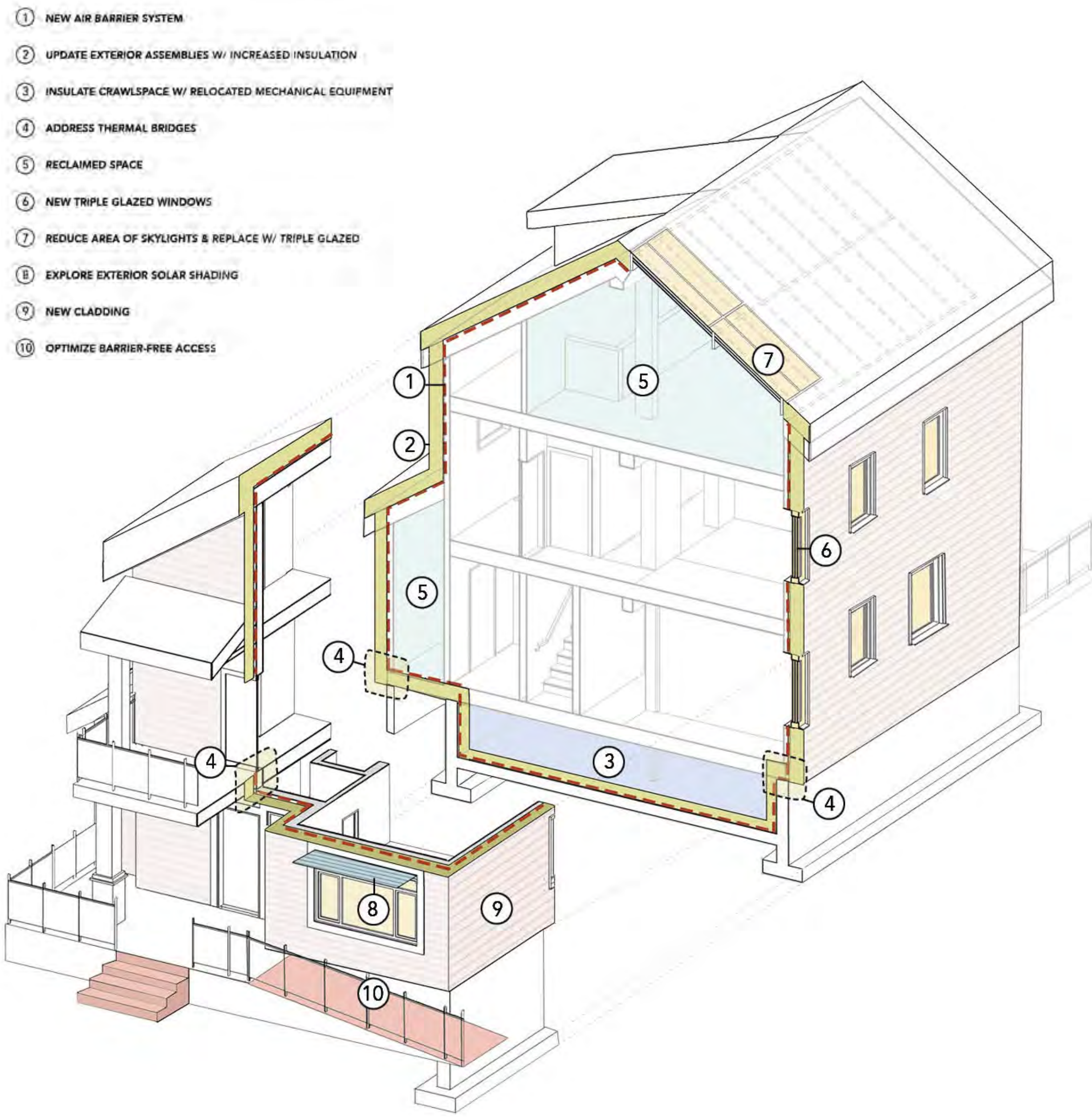
- Repurposed mechanical room
- Conditioned attic/third floor to comfortable temperatures
- Conditioned crawlspace for storage, mechanical duct-work and equipment

EXTERIOR ARCHITECTURAL EXPRESSION

- New cladding
- New/reconfigured windows
- Explore the addition and integration of exterior solar shading as required
- Consider optimizations in design of roof overhangs

EXTERIOR STREET PRESENCE

- Optimize barrier-free access ramp and entry to create a more welcoming front door experience


1 NEW AIR BARRIER SYSTEM
2 UPDATE EXTERIOR ASSEMBLIES W/ INCREASED INSULATION
3 INSULATE CRAWLSPACE W/ RELOCATED MECHANICAL EQUIPMENT
4 ADDRESS THERMAL BRIDGES
5 RECLAIMED SPACE
6 NEW TRIPLE GLAZED WINDOWS
7 REDUCE AREA OF SKYLIGHTS & REPLACE W/ TRIPLE GLAZED
8 EXPLORE EXTERIOR SOLAR SHADING
9 NEW CLADDING
10 OPTIMIZE BARRIER-FREE ACCESS

8 COST ESTIMATE

RETROFIT COST ESTIMATE SUMMARY

CONSTRUCTION COSTS

BUILDING ENVELOPE	$252,837.50
MECHANICAL SYSTEMS	$20,100.00
ARCHITECTURAL DESIGN	$60,000.00
NET RETROFIT COST	$332,937.50
Design Contingency	$83,234.38
Escalation Allowance (To Spring 2020)	$26,635.00
Construction Allowance	$33,293.75
General Conditions	$47,610.06
Contractor's Profit	$16,646.88
TOTAL RETROFIT CONSTRUCTION COST	$540,357.56
Cost per m^2 (190 m^2)	$2,843.99
Cost per ft^2 (2,045 ft^2)	$264.22

SOFT PROJECT COSTS

CONSTRUCTION DESIGN FEES	$135,089.39
DEVELOPMENT COSTS	$43,228.61
TOTAL RETROFIT CONSTRUCTION COST	$178,318.00

Refer to Appendix D for a detailed cost breakdown.

CONCLUSION & NEXT STEPS 9

Using a building envelope first approach to the retrofit of the AFRESH House, this study has demonstrated through preliminary energy analysis that the AFRESH House can achieve Net Zero Energy ready performance. Further, this retrofit has the potential to serve as a demonstration and teaching tool for Canadian homeowners, builders and communities to apply to existing Canadian homes.

The proposed retrofit strategies may be implemented on the AFRESH House for approximately $540,358 or $2,843.99/m^2 ($264.22/ft^2). When these strategies are applied to a typical Canadian home, the construction cost may vary substantially, however it might be slightly lower for several reasons. First, a typical Canadian home may have fewer complexities in the design to address during the retrofit. Second, through the development of resources and knowledge from the AFRESH House demonstration, this knowledge would be available to future projects, which may result in reduced design fees for the homeowner. Third, pricing for the AFRESH House was developed in a commercial context, and residential construction costs may be lower. As such, the cost of a Canadian homeowner's project may range significantly due to variable factors, including the size and existing condition of the house, the expertise of the contractor, market conditions, the materials used and the selected quality of finishes.

While this investment may be a significant for many homeowners, the undertaking may be made more affordable with potential monthly income from the addition of a rental suite, and savings in monthly operating costs from the reduction in energy consumption. Together, these benefits may help offset the financing costs of the retrofit.

In addition to the financial benefits, homeowners may receive additional benefits of increased comfort, increased resilience to extreme temperatures in summer and winter months and unexpected natural events, increased usable floor area, and reduced maintenance requirements and cost.

In summary, with the proposed retrofit approach, and through careful documentation, modeling, monitoring and storytelling, the AFRESH House retrofit has the potential to generate knowledge that will enable all Canadian homeowners to retrofit their homes to Net Zero Energy ready performance.

NEXT STEPS / FUTURE CONSIDERATIONS

On the assumption that funding is available to execute the project, a three-part approach is recommended to execute the project:

Step 1 – Conduct design and documentation activities.

Step 2 – Construct the project with thorough documentation of the process.

Step 3 – Develop an analytical and teaching program to expand the ongoing benefit of the project to the broader community.

APPENDICES

A NETATMO DATA

Measured Results from 10 Months of Metered Temperature Data for BCIT AFRESH Home

July 12, 2018

Prepared by Joshua Monk Vanwyck, JMV Consulting

Prepared for Alexandre Herbert, BCIT

It has been clear for years that the AFRESH House was not maintaining comfortable conditions but the extent of the problem had not been quantified. Using four indoor weather stations and two outdoor weather stations, data has been collected to understand exactly the conditions experienced in the AFRESH House.

The below set of graphs highlight the inconsistent temperatures on all floors and the lack of control the users currently have to make the space more comfortable.

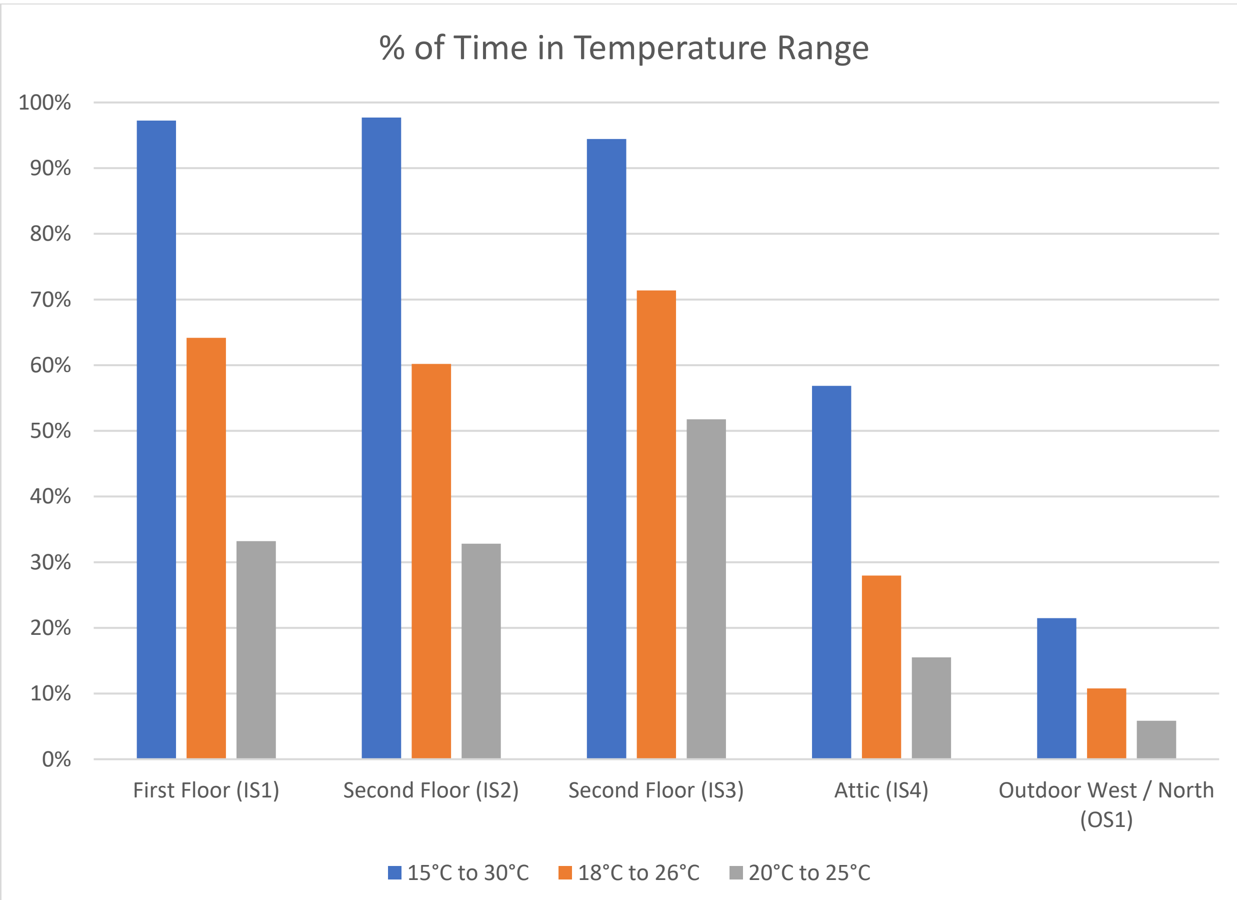


Figure 1: % of Time in Temperature Range

Figure 1 highlights how little of the time the house is within acceptable comfort parameters. Typical temperature ranges are between 18 – 26°C or the more strict 20 – 25°C. As can be seen in the figure above, the occupied spaces of the first and second floor are only in the comfort range for 60 – 70% of the time. Whereas the attic only had 28% of the hours falling into that range. For the stricter comfort range the first and second floors were between 33 – 52% and the attic was 16%. This represents unacceptable conditions for living and working.

The following graphs show temperature ranges compared to outdoor temperatures for each floor at 30 minute intervals. The stricter comfort range is also shown as context. In the winter temperature ranges are typically below 18°C and in the summer the temperature is consistently warmer than outside.

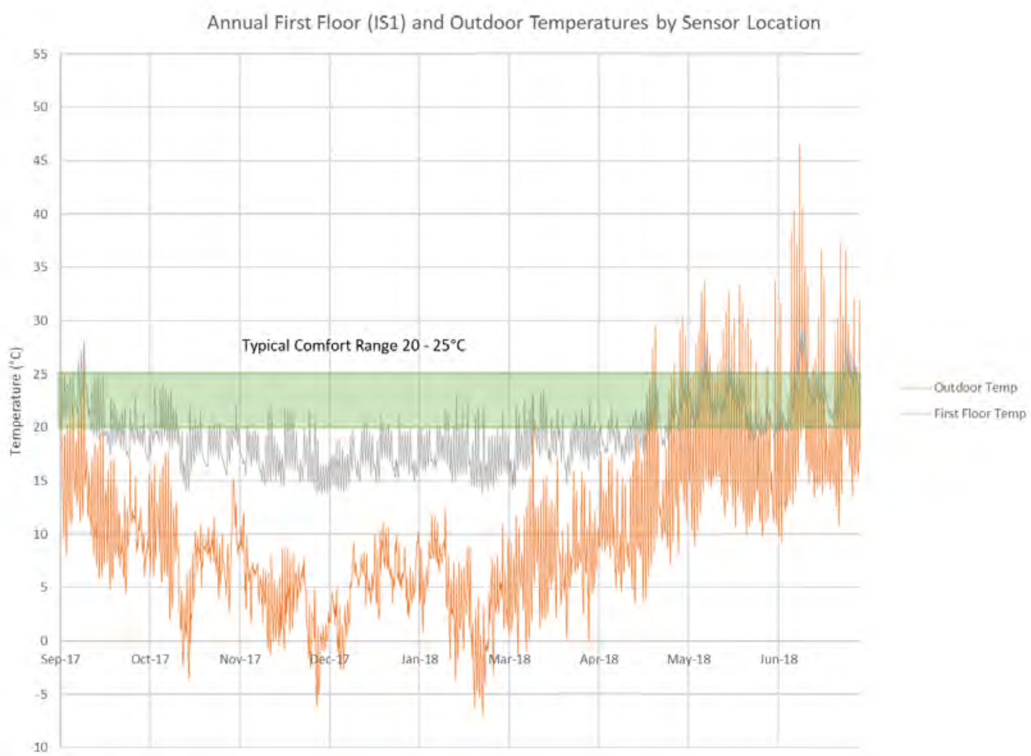


Figure 2: First Floor Annual Temperatures

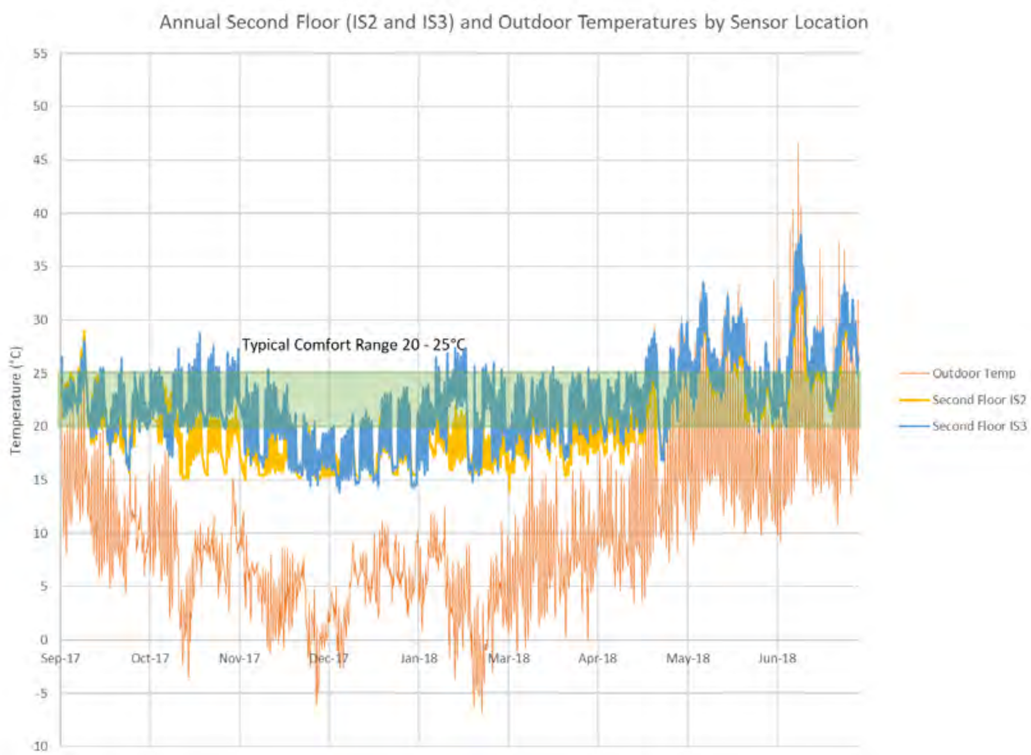


Figure 3: Second Floor Annual Temperatures

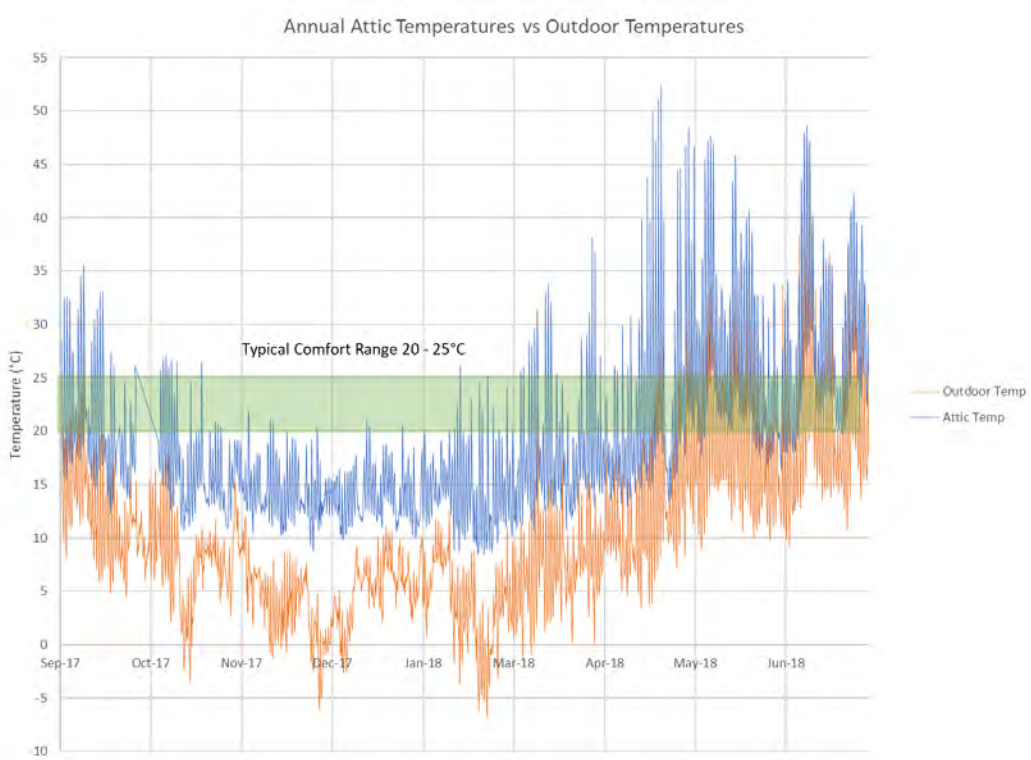


Figure 4: Attic Annual Temperatures

The final set of graphs, summarize the minimum, average and maximum temperatures experienced each month on each floor. Although temperatures exceed 25°C in the summer on average the temperature range is acceptable on the first and second floors. The attic experiences much hotter and colder temperatures both as maximums but also as average temperatures.

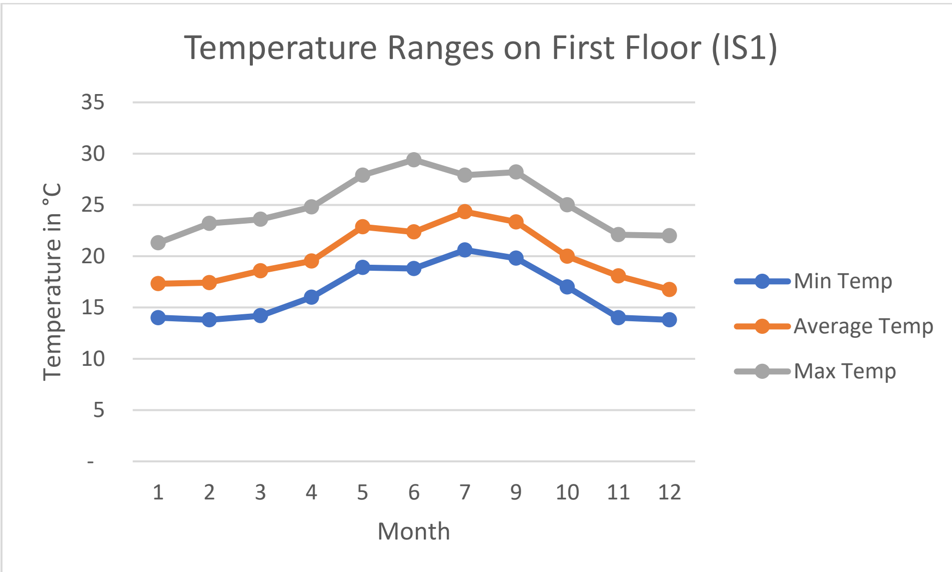


Figure 5: Temperature Range on First Floor (IS1)

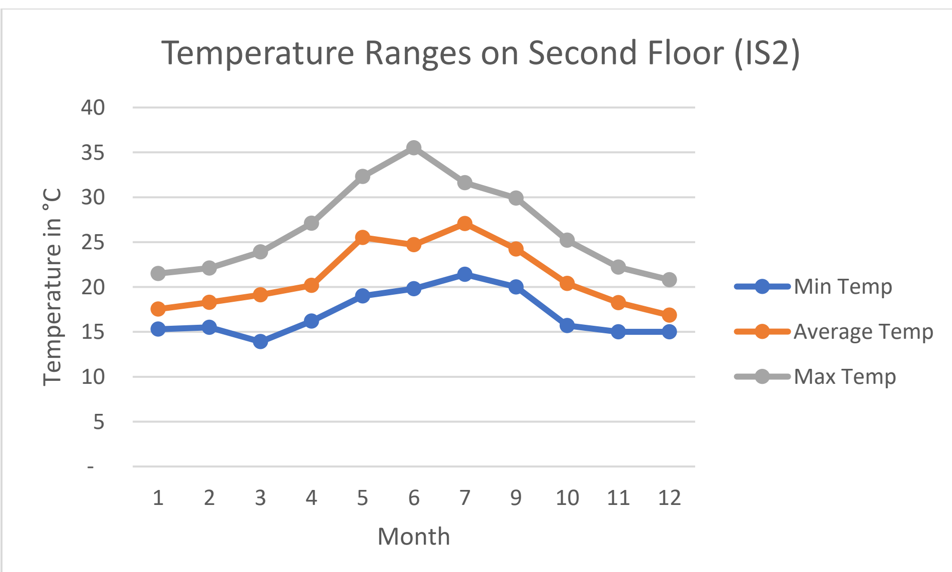


Figure 6: Temperature Range on Second Floor (IS2)

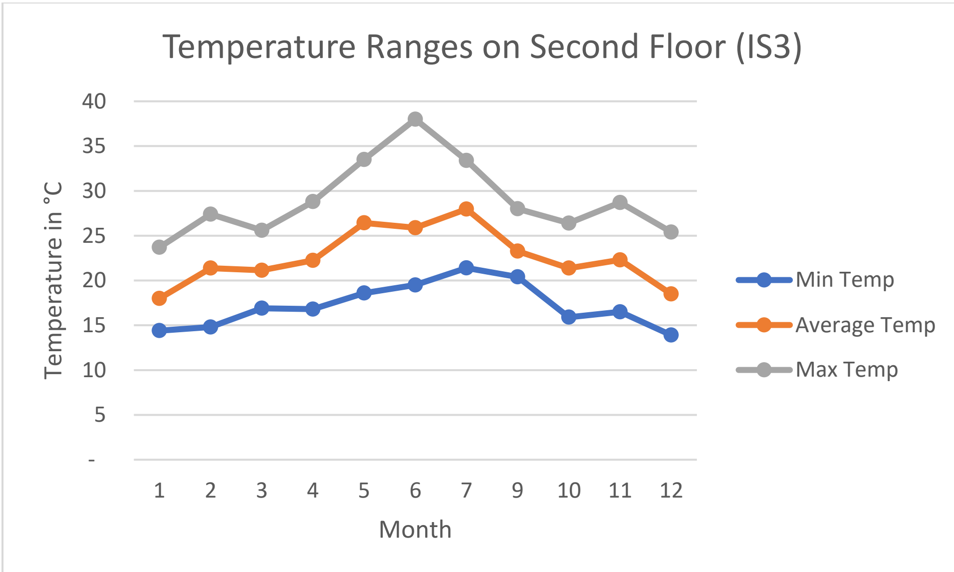


Figure 7:Temperature Range on Second Floor (IS3)

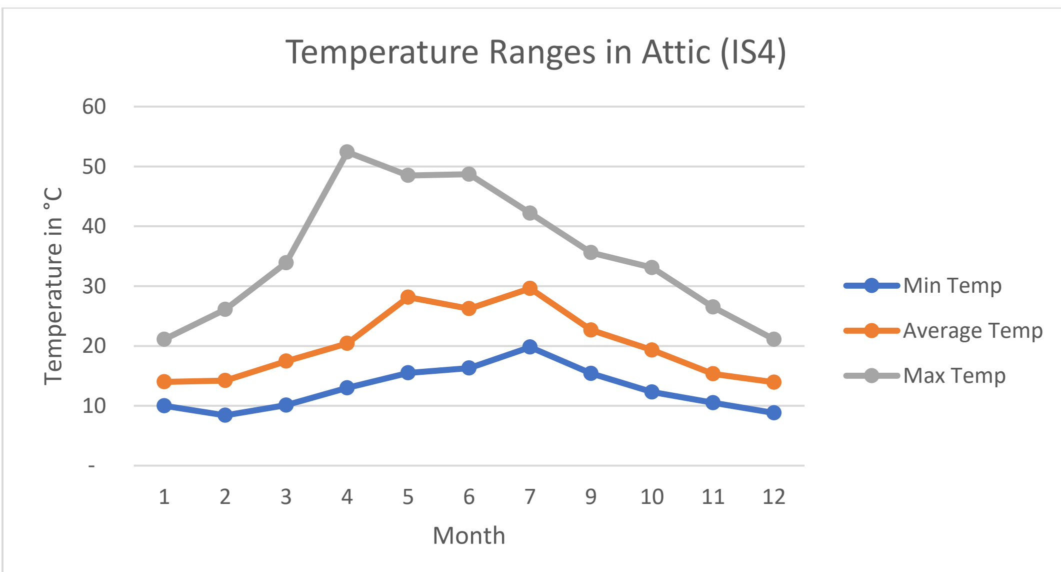


Figure 8: Temperature Range in Attic (IS4)

B INFRARED IMAGES

Infrared Images from BCIT AFRESH Home

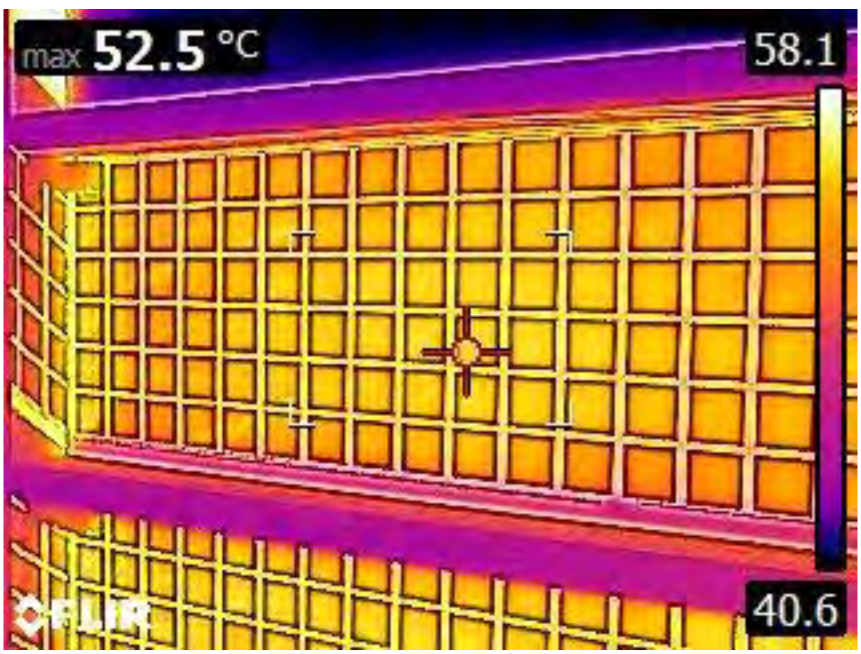
July 10, 2018

Images from Summer and Winter Conditions:

The images contained in this short report highlight the extent of thermal bridging, over heating and inconsistent construction in the building. It is clear that the windows do not perform well in the winter months, however it is also clear that there is little insulation between the first floor and the attic leading to unbearable conditions when the attic is overheating. Additionally images of the mechanical systems clearly show that in summer conditions the geothermal system is not functioning at all as designed. Temperatures are much too high.

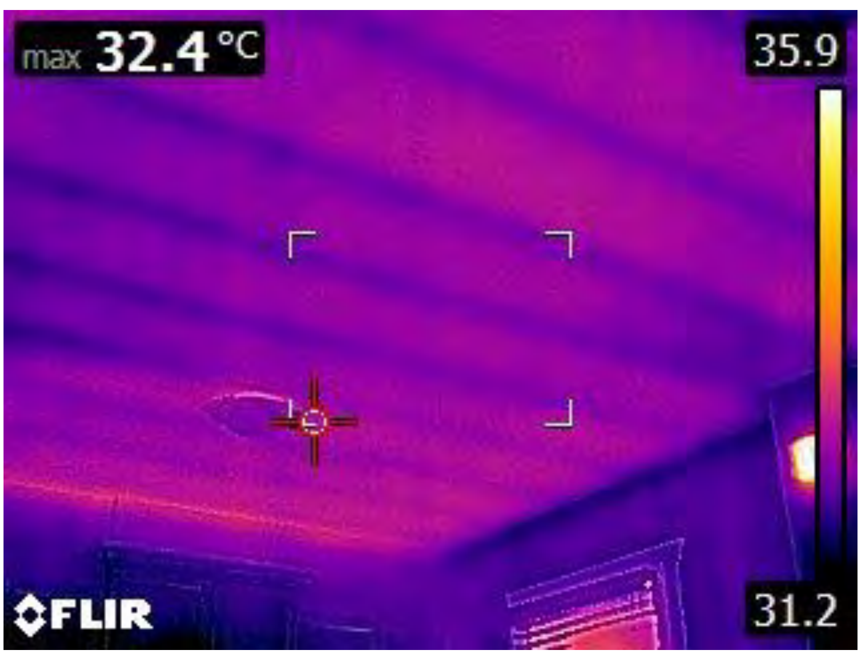
Summer 2018 from June 20, 2018 at 3PM PST:

Attic Built In Photovoltaics (BIPV) have temperatures around 56°C. Walls are heated to over 40°C.

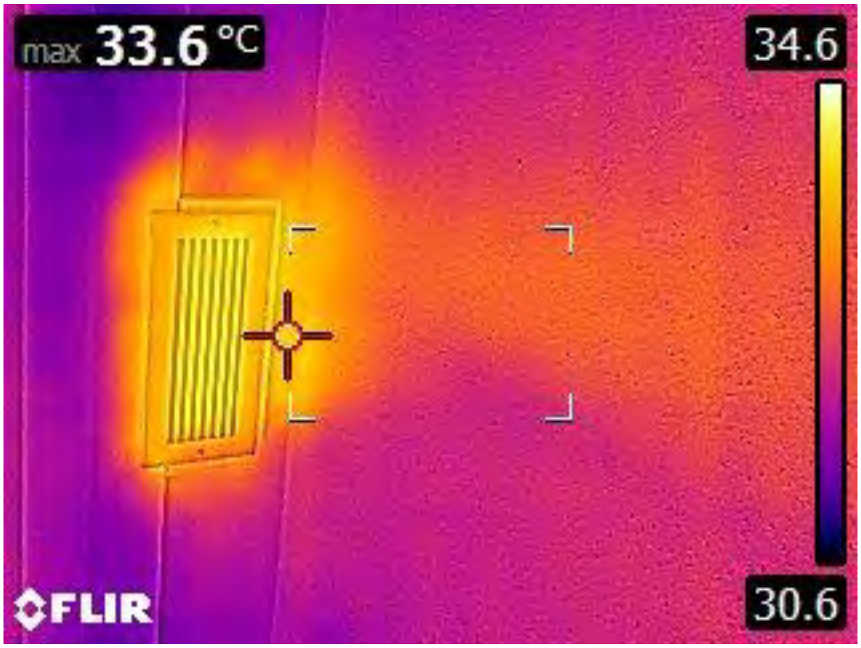


BIPV panels act as radiators to the internal space. Their temperature is similar to a hydronic wall radiator in winter time (providing a large amount of radiative heat over a large area).

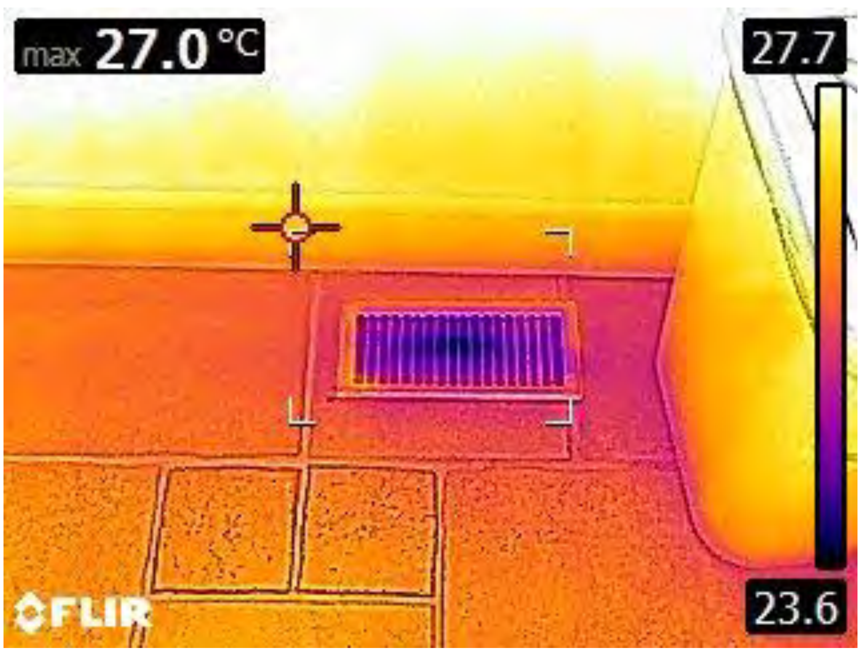
Temperatures in attic are such that studs in the wall act as thermal bridges to lower outdoor temperatures.



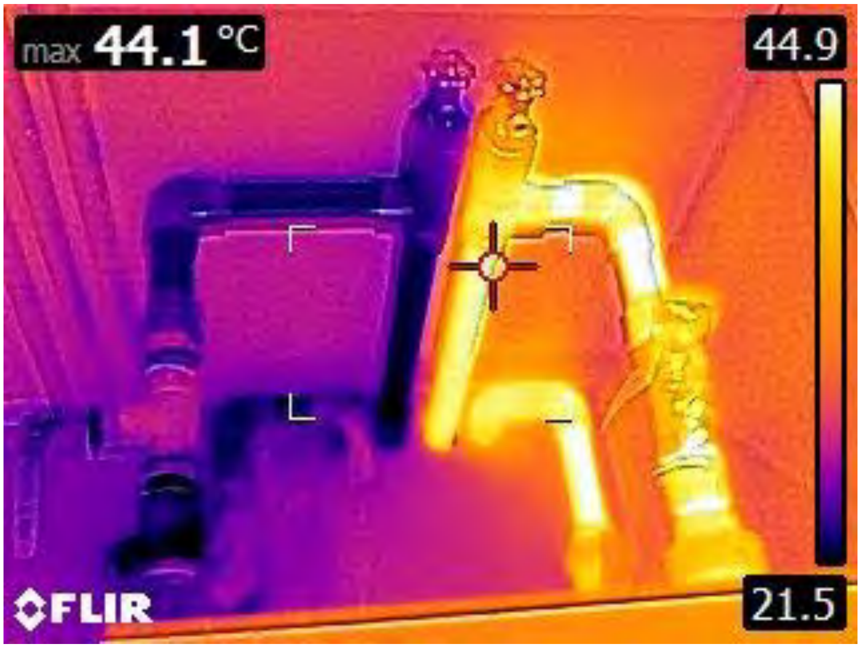
First Floor Ceiling looking up to attic. The temperatures in the attic are driving up ceiling temperatures in the first floor. These temperatures are similar to that of an active slab ceiling in winter. Again causing great discomfort and unnecessary heat gains.



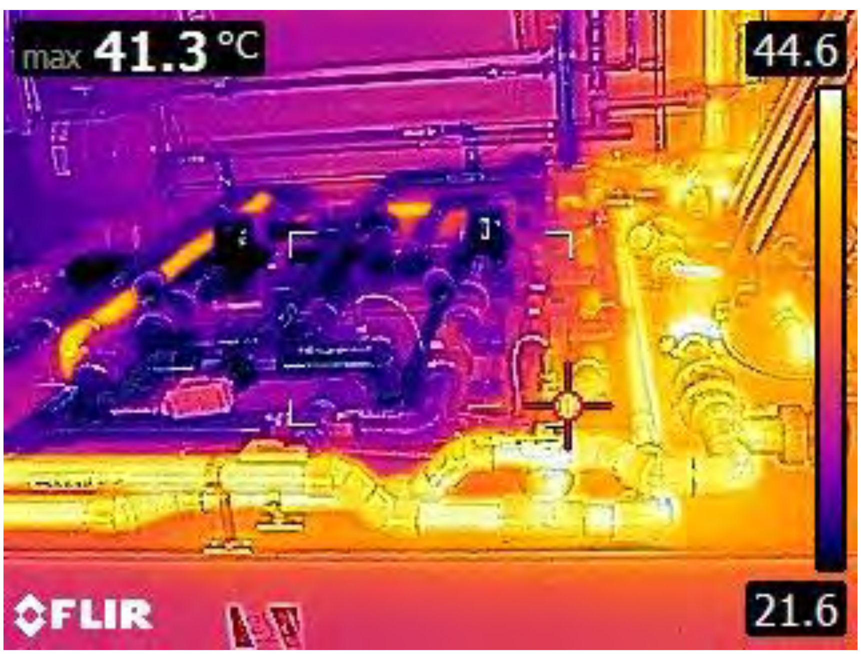
First Floor Exhaust Grill: The ventilation system is exhausting air upwards of 34°C air from the occupied space.



Ground floor Supply Grill: This air is slightly cooler than the exhaust but is at least 8 – 10°C hotter than design temperatures should be. This shows that the ventilation system is not functioning as designed.



Geothermal input and output: The temperatures shown here are far beyond the typical geothermal range and show that the system is not functioning as designed. Geothermal input (the blue side) should be between 6 – 12°C. The Output should be not much higher than 25°C.



Geothermal control piping: This designed system of piped controls has never worked and it is clearly still not working to enter a proper cooling mode.

Winter Conditions: Winter 2017

Description of Images:

1) Exterior
    a. Front West Corner of House: Note the extensive heat loss on the west façade and inconsistent construction quality. Windows are also clearly causing significant heat loss.
    b. South Façade: In general the front façade performs quite well other than the windows and frames.
    c. East Façade: Join connecting the two floors / modules of the house show significant heat loss. Note how the studs are clearly visible on this façade suggesting extensive thermal bridging. Windows and Frames are also contributing to heat loss.
    d. West Façade: Extensive heat loss throughout this façade is occurring. Detailed analysis is recommended to understand the difference in construction and performance.
2) Interior

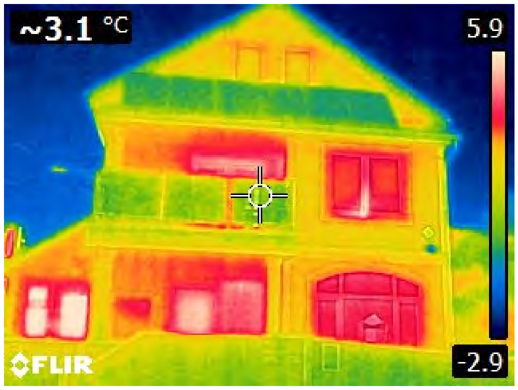
    All images from the interior show that there is risk of condensation and mold due to temperatures approaching 12°C. In the attic this is present for almost the entire façade, in the lower levels this is mainly occurring in corners, wall connections, the floors and window frames. These should be addressed in the retrofit to avoid any future mold growth.

AFRESH Home Thermal Imaging Test

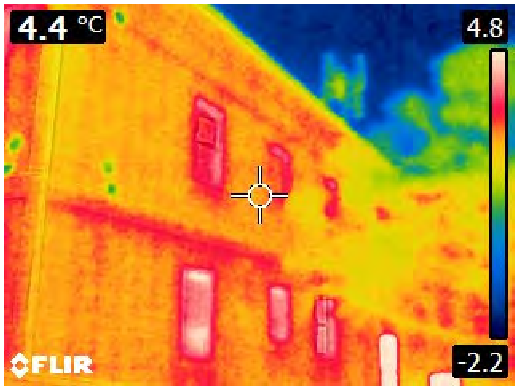
1. **Exterior**

a

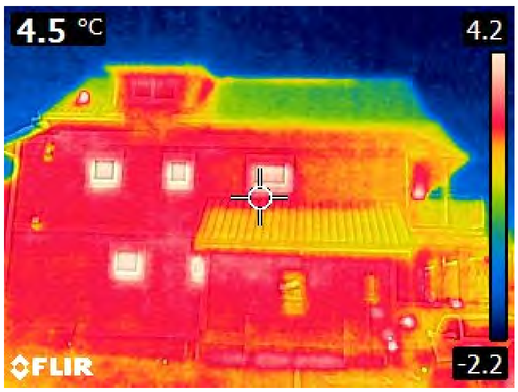
b



c

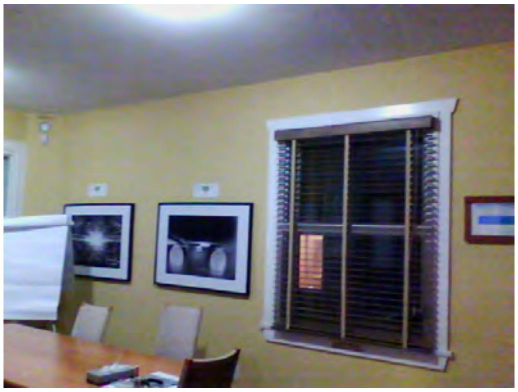


d

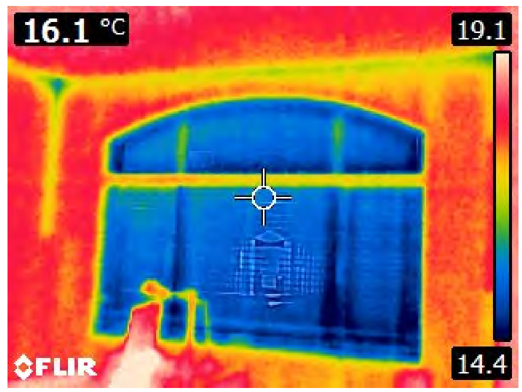


2. **Interior**

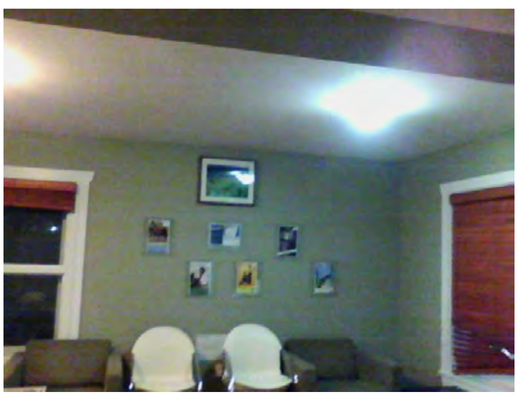
a

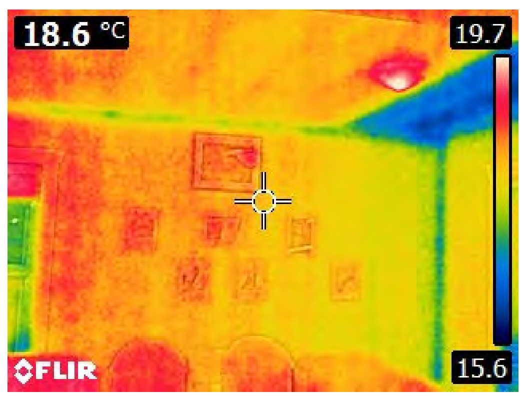


b

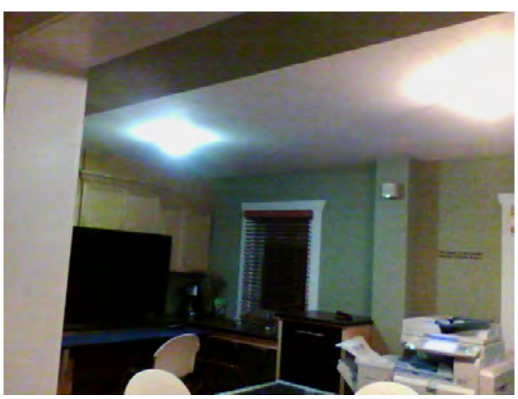


c

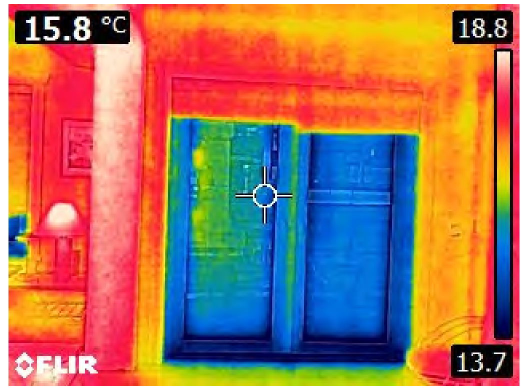




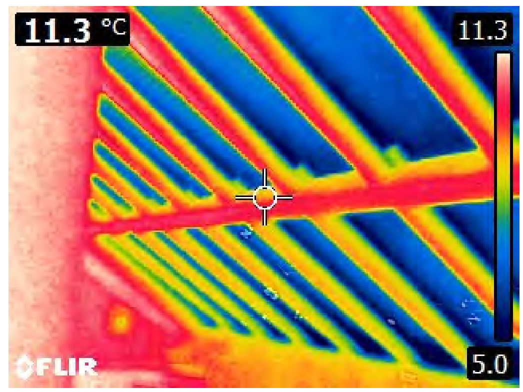
d



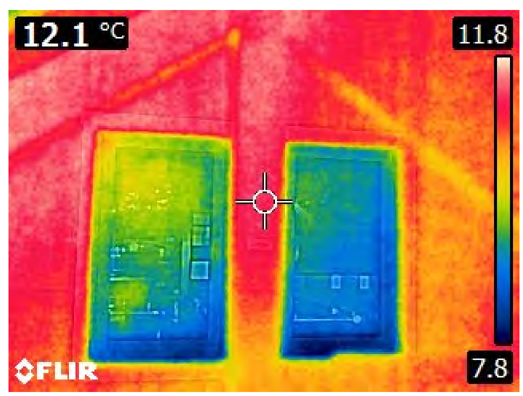
e


15.8 °C
18.8
13.7
FLIR

f


11.3 °C
11.3
5.0
FLIR

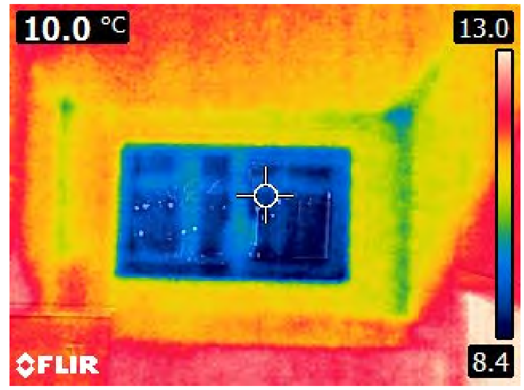
g


12.1 °C
11.8
7.8
FLIR

h


11.9 °C
13.3
5.9
FLIR

i



C PHPP RESULTS

Appendix C: PHPP Model Results:

The below tables summarize the results from the thermal model studies.

Scenario 1: Existing AFRESH Home:

Specific building characteristics with reference to the treated floor area					The PHPP has not been filled completely; it is not valid as verification		
	Treated floor area	m²	257.0		Criteria	Alternative criteria	Fullfilled?[2]
Space heating	Heating demand	kWh/(m²a)	218	≤	25	-	no
	Heating load	W/m²	85	≤	-	-	
Space cooling	Cooling & dehum. demand	kWh/(m²a)	-	≤	-	-	-
	Cooling load	W/m²	-	≤	-	-	
	Frequency of overheating (> 25 °C)	%	9	≤	10		yes
	Frequency of excessively high humidity (> 12 g/kg)	%	0	≤	20		yes
Airtightness	Pressurization test result n_{50}	1/h	5.4	≤	1.0		no
Moisture protection							
	Smallest temperature factor $f_{Rsi=0.25\ m^2K/W}$	-	-	≥	0.70		-
Thermal Comfort	All requirements fulfilled?	-			yes		no
	U-value	W/(m²K)		≤	1.02		
	U-value	W/(m²K)		≤	1.22		
	U-value	W/(m²K)		≤	1.33		
	U-value	W/(m²K)		≤	0.56		
Non-renewable Primary Energy (PE)	PE demand	kWh/(m²a)	611	≤	363		no
Primary Energy Renewable (PER)	PER demand	kWh/(m²a)	359	≤	-	-	-
	Generation of renewable energy (in relation to projected building footprint area)	kWh/(m²a)		≥	-	-	

[2] Empty field: Data missing; '-': No requirement

Scenario 2: 1970s Archetypical Home

Specific building characteristics with reference to the treated floor area				The PHPP has not been filled completely; it is not valid as verification			
	Treated floor area	m²	257.0		Criteria	Alternative criteria	Fullfilled?[2]
Space heating	Heating demand	kWh/(m²a)	214	≤	25	-	no
	Heating load	W/m²	87	≤	-	-	
Space cooling	Cooling & dehum. demand	kWh/(m²a)	-	≤	-	-	-
	Cooling load	W/m²	-	≤	-	-	
	Frequency of overheating (> 25 °C)	%	12	≤	10		no
	Frequency of excessively high humidity (> 12 g/kg)	%	0	≤	20		yes
Airtightness	Pressurization test result n_{50}	1/h	6.0	≤	1.0		no
Moisture protection							
	Smallest temperature factor $f_{Rsi=0.25\ m^2K/W}$	-	-	≥	0.70		-
Thermal Comfort	All requirements fulfilled?	-			yes		no
	U-value	W/(m²K)		≤	1.02		
	U-value	W/(m²K)		≤	1.22		
	U-value	W/(m²K)		≤	1.33		
	U-value	W/(m²K)		≤	0.56		
Non-renewable Primary Energy (PE)	PE demand	kWh/(m²a)	290	≤	358		yes
Primary Energy Renewable (PER)	PER demand	kWh/(m²a)	411	≤	-	-	-
	Generation of renewable energy (in relation to projected building footprint area)	kWh/(m²a)		≥	-	-	
						[2] Empty field: Data missing; '-': No requirement	

Scenario 3: 2018 Code Minimum Home:

Specific building characteristics with reference to the treated floor area				The PHPP has not been filled completely; it is not valid as verification			
	Treated floor area	m²	257.0		Criteria	Alternative criteria	Fullfilled?[2]
Space heating	Heating demand	kWh/(m²a)	126	≤	25	-	no
	Heating load	W/m²	57	≤	-	-	
Space cooling	Cooling & dehum. demand	kWh/(m²a)	-	≤	-	-	-
	Cooling load	W/m²	-	≤	-	-	
	Frequency of overheating (> 25 °C)	%	6	≤	10		yes
	Frequency of excessively high humidity (> 12 g/kg)	%	0	≤	20		yes
Airtightness	Pressurization test result n_{50}	1/h	3.0	≤	1.0		no
Moisture protection							
	Smallest temperature factor $f_{Rsi=0.25\ m^2K/W}$	-	-	≥	0.70		-
Thermal Comfort	All requirements fulfilled?	-			yes		no
	U-value	W/(m²K)		≤	1.02		
	U-value	W/(m²K)		≤	1.22		
	U-value	W/(m²K)		≤	1.33		
	U-value	W/(m²K)		≤	0.56		
Non-renewable Primary Energy (PE)	PE demand	kWh/(m²a)	372	≤	253		no
Primary Energy Renewable (PER)	PER demand	kWh/(m²a)	225	≤	-	-	-
	Generation of renewable energy (in relation to projected building footprint area)	kWh/(m²a)		≥	-	-	
						[2] Empty field: Data missing; '-': No requirement	

Scenario 4: 2018 New Construction (Code Minimum)

Specific building characteristics with reference to the treated floor area				The PHPP has not been filled completely; it is not valid as verification			
	Treated floor area	m²	257.0		Criteria	Alternative criteria	Fullfilled?[2]
Space heating	Heating demand	kWh/(m²a)	173	≤	25	-	no
	Heating load	W/m²	71	≤	-	-	
Space cooling	Cooling & dehum. demand	kWh/(m²a)	-	≤	-	-	-
	Cooling load	W/m²	-	≤	-	-	
	Frequency of overheating (> 25 °C)	%	2	≤	10		yes
	Frequency of excessively high humidity (> 12 g/kg)	%	0	≤	20		yes
Airtightness	Pressurization test result n_{50}	1/h	6.0	≤	1.0		no
Moisture protection							
	Smallest temperature factor $f_{Rsi=0.25\ m^2K/W}$	-	-	≥	0.70		-
Thermal Comfort	All requirements fulfilled?	-			yes		no
	U-value	W/(m²K)		≤	1.02		
	U-value	W/(m²K)		≤	1.22		
	U-value	W/(m²K)		≤	1.33		
	U-value	W/(m²K)		≤	0.56		
Non-renewable Primary Energy (PE)	PE demand	kWh/(m²a)	243	≤	309		yes
Primary Energy Renewable (PER)	PER demand	kWh/(m²a)	338	≤	-	-	-
	Generation of renewable energy (in relation to projected building footprint area)	kWh/(m²a)		≥	-	-	

[2] Empty field: Data missing; '-': No requirement

Scenario 5: Option 1 Retrofit (Gas)

Specific building characteristics with reference to the treated floor area				The PHPP has not been filled completely; it is not valid as verification			
	Treated floor area	m²	257.0		Criteria	Alternative criteria	Fullfilled?[2]
Space heating	Heating demand	kWh/(m²a)	15	≤	25	-	yes
	Heating load	W/m²	12	≤	-	-	
Space cooling	Cooling & dehum. demand	kWh/(m²a)	-	≤	-	-	-
	Cooling load	W/m²	-	≤	-	-	
	Frequency of overheating (> 25 °C)	%	0	≤	10		yes
	Frequency of excessively high humidity (> 12 g/kg)	%	0	≤	20		yes
Airtightness	Pressurization test result n_{50}	1/h	1.0	≤	1.0		yes
Moisture protection							
	Smallest temperature factor $f_{Rsi=0.25\ m^2K/W}$	-	-	≥	0.70		-
Thermal Comfort	All requirements fulfilled?	-			yes		yes
	U-value	W/(m²K)		≤	1.02		
	U-value	W/(m²K)		≤	1.22		
	U-value	W/(m²K)		≤	1.33		
	U-value	W/(m²K)		≤	0.56		
Non-renewable Primary Energy (PE)	PE demand	kWh/(m²a)	63	≤	120		yes
Primary Energy Renewable (PER)	PER demand	kWh/(m²a)	57	≤	-	-	-
	Generation of renewable energy (in relation to projected building footprint area)	kWh/(m²a)		≥	-	-	

[2] Empty field: Data missing; '-': No requirement

Scenario 6: Option 2 Retrofit (Electricity)

Specific building characteristics with reference to the treated floor area							Alternative criteria	Fullfilled?[2]
		The PHPP has not been filled completely; it is not valid as verification				Criteria		
	Treated floor area	m²	257.0					
Space heating	Heating demand	kWh/(m²a)	14	≤	25	-		yes
	Heating load	W/m²	13	≤	-	-		
Space cooling	Cooling & dehum. demand	kWh/(m²a)	-	≤	-	-		-
	Cooling load	W/m²	-	≤	-	-		
	Frequency of overheating (> 25 °C)	%	1	≤	10			yes
	Frequency of excessively high humidity (> 12 g/kg)	%	0	≤	20			yes
Airtightness	Pressurization test result n_{50}	1/h	1.0	≤	1.0			yes
Moisture protection								
	Smallest temperature factor $f_{Rsi=0.25\ m^2K/W}$	-	-	≥	0.70			-
Thermal Comfort	All requirements fulfilled?	-			yes			yes
	U-value	W/(m²K)		≤	1.02			
	U-value	W/(m²K)		≤	1.22			
	U-value	W/(m²K)		≤	1.33			
	U-value	W/(m²K)		≤	0.56			
Non-renewable Primary Energy (PE)	PE demand	kWh/(m²a)	101	≤	120			yes
Primary Energy Renewable (PER)	PER demand	kWh/(m²a)	48	≤	-	-		-
	Generation of renewable energy (in relation to projected building footprint area)	kWh/(m²a)		≥	-	-		

[2] Empty field: Data missing; '-': No requirement