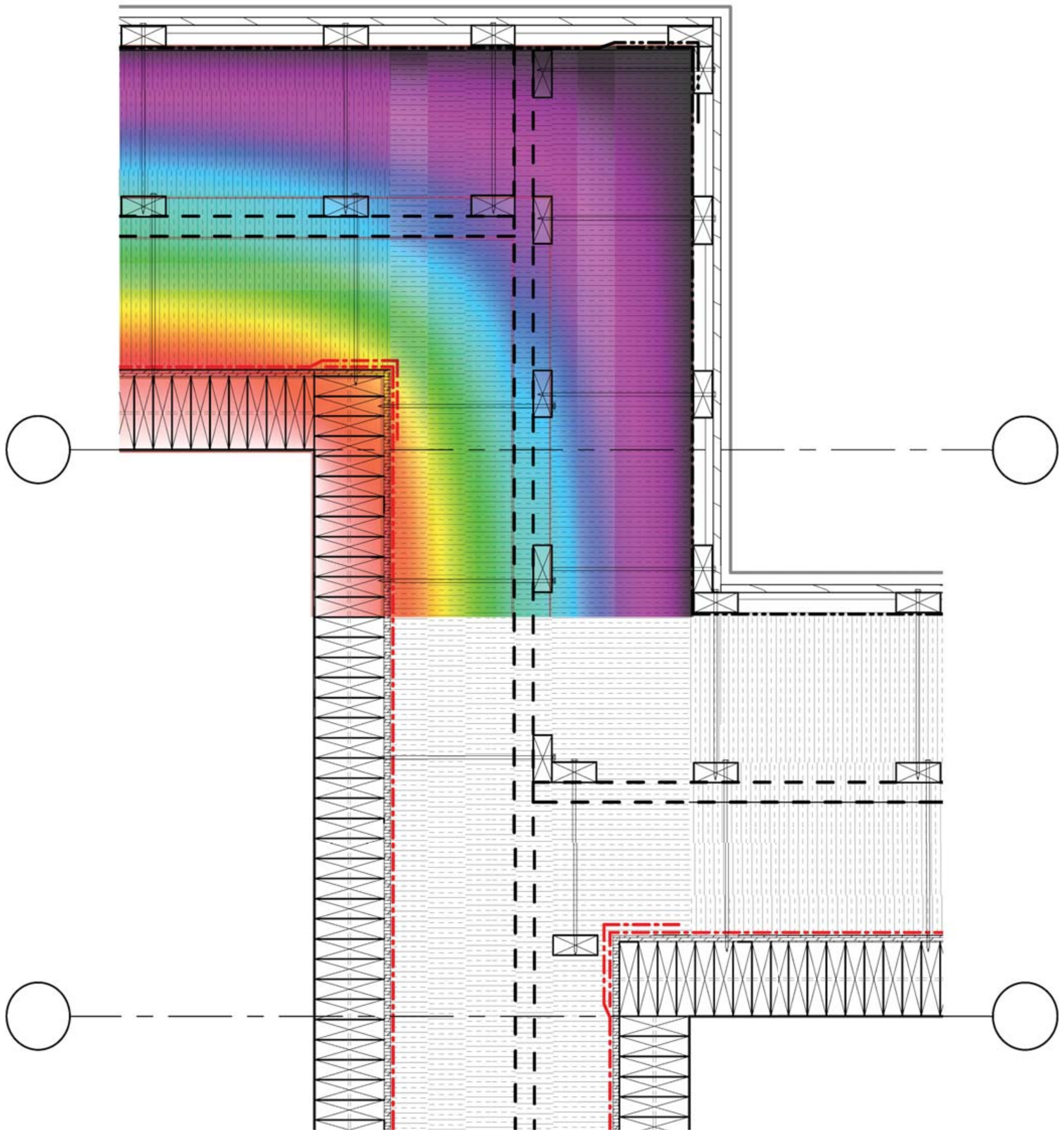

INCREASING UNDERSTANDING OF THE ROLE OF THERMAL BRIDGING IN BUILDING PERFORMANCE AND THE DESIGN PROCESS

Cillian Collins

Alysia Baldwin

Ebulimiti Aikebai

Image: passivehouse project detail

PERKINS+WILL

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Image: passivehouse project section looking east

"Building envelope heat loss has historically been simplified due to past difficulties in cost-effectively providing more accuracy. This has generally led to overly optimistic assessments of building envelope performance by way of ignoring or underestimating the impact of thermal bridging."

City of Vancouver Energy Modelling Guidelines Referenced in the Green Building Rezoning Policy

"In certain complex assemblies, the research identified facades with as much as a 70% reduction in effective R-value [because of thermal bridging] "

Thermal Performance of Facades - 2012 AIA Upjohn Grant Research Initiative Final Report Nov 2014 p. 1

SUMMARY

This Innovation Incubator focuses on the role of Thermal Bridging in the performance of the building envelope and its mitigation through good detailing. The trend towards performance-based standards means an increased focus on the building envelope. This in turn places an increased focus on the effects of thermal bridging in the performance of the building envelope, requiring a means and methodology within the design process to test the design within the design process.

Thermal bridge modelling is typically a specialist service offered by a building envelope professional or mechanical engineer. While thermal bridge modelling need not necessarily become a core competency of the architects there are advantages to having the capacity to do so in-house and increased awareness of the effects within the architectural team:

- It provides **early validation of details and enhanced understanding within the architectural team of the thermal performance of their proposed detailing**. The aesthetic of a building is heavily influenced by the elegance of the detailing. At the very least the architect should understand the process involved in identifying and calculating the effect of thermal bridges. Having additional tools in his/her repertoire can help validate and guide the detailing process as opposed to having them imposed later which may compromise the architectural intent.

- It leads to **increased understanding of the performance of materials and components that are being specified for inclusion in the building envelope.** If the project is aiming for high performance certification such as the Passive House standard the methodology for achieving thermal bridge free design needs to be documented in the Tender package through detail drawing and specification, requiring an understanding from the architect of the performance of the components specified.

This also leads to better understanding of the effect of any changes or substitutions to the contract documents if (and when) these are suggested on site. The effect any changes on the overall performance of the building needs to be understood and if it affects certification. It also helps when weighing up the (often competing requirements) of building envelope components (e.g. structural, fire protection, thermal performance etc).

- **Demystify the idea of thermal bringing and normalizing it as part of the design process.** Passive House projects aim for thermal bridge free design. This can be a source of fear for many architects and contractors. It may not always be possible to completely eliminate thermal bridging in a detail but the effects should be calculated, the heat loss mitigated and comfort issues dealt with. Having a simplified process for analyzing our details makes this process a lot more accessible.

U-value [or R-value] alone is a blunt instrument for gauging the thermal performance of a building

Passive House Plus Magazine [https://passivehouseplus.ie/articles/heating/thermal-bridging]

Energy standards and codes in BC jurisdictions (BCBC, VBBL, ASHRAE 90.1and NECB) do not currently effectively address, or explicitly allow designers to ignore, major thermal bridges such as slab edges, shelf angles, parapets, window perimeters, etc

The contribution of details that are typically disregarded can result in the underestimation of 20% to 70% of the total heat flow through walls.

Morrison Hershfield, Building Envelope Thermal Bridging Guide (2014), i.

https://www.bchydro.com/powersmart/business/programs/new-construction.html#thermal

1.0 BACKGROUND [RELEVANCE AS A RESEARCH TOPIC]

1.1 Closing the Performance Gap

There is significant evidence to suggest that buildings do not perform as well when they are completed as was anticipated when they were being designed. This difference between what was anticipated and actual performance is known as the 'performance gap'.

Increasingly stringent energy codes have increased the levels of insulation required in buildings. However post occupancy studies show that these increases in requirements have not necessarily led to improved performance. A study[1] of energy use in a sample of mid- to high-rise MURBs has shown that those constructed after 1990 use on average more energy than those constructed in the 1970s and 1980s. antother study[2] undertaken in New York found *"With regard to energy consumption and GHG emission the LEED-certified buildings, collectively, showed no savings as compared with non-LEED buildings".*

Buildings are complex systems designed and built from scratch and there are a number of potential reasons for the existence of this gap in terms of energy performance and GHG emissions e.g.

- the traditional methodology of a presentence better approach to a baseline reference or prescriptive standards versus performance standards
- emphasis on mechanical systems over building enclosure
- the conflict between fuel cost reduction and GHG reduction objectives
- overly simplified or not truly representative energy modelling
- assumptions on building occupancy or operations that are not borne out
-

Negating the performance gap starts at the beginning of a project with a stringent energy performance in-use targets and accurate validation (energy modelling protocol).

The City of Vancouver is addressing this by implementing performance based standards for buildings are beginning to place absolute targets on limits on energy performance coupled with comprehensive energy modelling guidelines. The Architectural Institute of BC and Engineers and Geoscientists of BC introducing the concept of a energy modelling supervisor and the qualified modeler as a means to quality control of the energy modelling process. A potentially key component in closing this performance gap is paying more attention to the effect of thermal bridging at design stage (and following this attention through in construction).

1 RDH Building Engineering, Energy Consumption and Conservation in Mid-and High-Rise Residential Buildings in British Columbia (2012), 233. http://www.hpo.bc.ca/sites/www.hpo.bc.ca/files/download/Report/MURB-EnergyStudy-Report.pdf

2 Efficacy of LEED-certification in reducing energy consumption and greenhouse gas emission for large New York City office buildings - John H Scofield https://www.sciencedirect.com/science/article/pii/S037877881300529X

The shift to an absolute performance targets approach will require some procedural changes … including… Accounting for envelope heat loss, including thermal bridging;

City of Toronto Zero Emissions Buildings Framework

building envelope heat loss has historically been simplified due to past difficulties in cost-effectively providing more accuracy. This has generally led to overly optimistic assessments of building envelope performance by way of ignoring or underestimating the impact of thermal bridging.

[This document] also clarifies inputs where current industry practice for those inputs does not support the Policy's intended outcomes or leads to performance gaps (ex. not properly accounting for total envelope heat loss through thermal bridges)

City of Vancouver Energy Modelling Guidelines vancouver.ca/files/cov/energy-modelling-guidelines-v1.0.pdf

1.2. Performance Targets

There is a common drive towards carbon neutrality or zero emissions from buildings with various policies and regulatory bodies implementing performance targets with associated timelines:

This policy shift is evidenced at a variety of governmental levels:

- a global UN framework[3] ,
- a Federal Build Smart program[4] ,
- the B.C. Energy Step Code[5]
- City of Vancouver Zero Emissions Plan for New Buildings Rezoning Policy[6]
- City of Toronto Zero Emissions Framework[7]

A shared methodology for achieving these goals is to place limits or thresholds on the Energy Use Intensity (EUI) of a building and a specific limit on the requirements for heating or cooling the building – in the City of Vancouver Green Building Rezoning Policy this is known as a TEDI (Thermal Energy Demand Intensity) Target.

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3 UN Framework guidelines for energy efficiency standards in buildings.

Press release https://www.unece.org/info/media/presscurrent-press-h/sustainable-energy/2017/new-guidelines-onenergy-efficiency-standards-pave-the-way-for-more-sustainable-buildings/doc.html

Document: https://www.unece.org/fileadmin/DAM/energy/se/pdfs/geee/geee4_Oct2017/ECE_ENERGY_GE.6_2017_4_EEBuildingGuidelines_final.pdf

4 BUILD SMART CANADA'S BUILDINGS STRATEGY - A Key Driver of the Pan-Canadian Framework on Clean Growth and Climate Change 2017

https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/emmc/pdf/Building_Smart_en.pdf
https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/emmc/pdf/BuildSmart-infographic_EN_accessible.pdf

5 The BC Energy Step Code is a voluntary provincial standard enacted in April 2017 that provides an incremental and consistent approach to increase energy-efficiency requirements in the BC Building Code to make buildingsnet-zero energy ready by 2032.

https://www2.gov.bc.ca/gov/content/industry/construction-industry/building-codes-standards/energyefficiency/energy-step-code

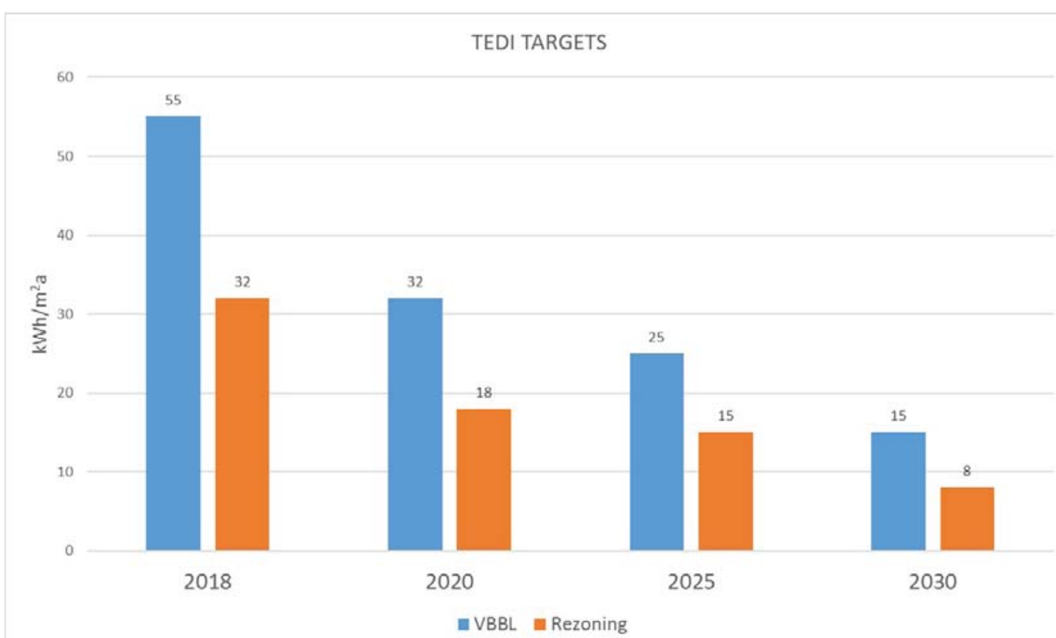
6 The City of Vancouver is targeting zero operational greenhouse gas (GHG) emissions from all new buildings by 2030 http://vancouver.ca/home-property-development/zero-emissions-buildings.aspx

7 Toronto has a plan to achieve near zero emissions in all new buildings by 2030

https://www1.toronto.ca/City%20Of%20Toronto/City%20Planning/Developing%20Toronto/Files/pdf/TGS/Zero%20Emissions%20Buildings%20Framework%20Report.pdf

The inclusion of a specific TEDI target results in greater occupant comfort and ensures that building designers focus on minimizing a building's demand for energy prior to producing or procuring renewable energy. The target also helps to ensure long-term energy performance, as building envelopes have long life spans and yield very reliable efficiency gains.

CaGBC Zero Carbon Building Standard May 2017



Progression of Rezoning and Building Bye-Law requirements in Vancouver

1.3 Focus on TEDI

Both the BC Step Code and City of Vancouver Rezoning Policy place the Passive House standard as administered by the Passive house Institute as a compliance pathway to highest levels of compliance in achieving Net Zero or Zero emissions buildings.

The Passive House Standard (as defined in Appendix B) places limits on both overall energy (with a limit on primary or source energy) and thermal energy (space heating and space cooling). Within recent BC frameworks this has become know as TEDI. The TEDI (Thermal Energy Demand Intensity) is the sum of the energy uses for comfort heating and cooling over the course of one year.

The primary driver of the Passive House standard is ensuring superior indoor air quality and the thermal comfort of the occupants is maintained year round. The TEDI target places the focus on the building envelope, a 'fabric first' approach that results in a building that has a lower carbon footprint, low operating costs in terms of energy bills and a smaller heating and cooling system which results in lower maintenance, replacement and repair costs. This low-energy use design also protects the tenant from rising energy costs.

Successful execution and realization of these performance targets requires attention to building envelope design, a well-insulated, airtight envelope, and an optimized ventilation system with mechanical heat recovery. Thermal bridge free design or at the very least mitigation of thermal bridging is a key piece of the puzzle. The Passive House standard requires 'thermal bridge free design' and has a strict protocol for how this is modelled, calculated and signed off on via certificaiton. In order to achieve this level of performance we first need to understand how to analyze the performance of our details and calculate the thermal bridging effect in order to deal with it effectively.

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Research and monitoring of buildings is increasingly showing the importance of reducing thermal bridging in new construction and mitigating the impact in existing buildings. The impact can be significant to whole building energy use, the risk of condensation on cold surfaces, and occupant comfort.

Morrison Hershfield, Building Envelope Thermal Bridging Guide (2014), i.

https://www.bchydro.com/powersmart/business/programs/new-construction.html#thermal

2.0 THERMAL BRIDGING EXPLAINED /

2.1 The effect of Thermal Bridging

In a heating dominated climate heat makes its way from the heated space inside a building towards the outside once there is a difference in temperature between the inside and the outside (the effect is reversed in a cooling dominated climate). In doing so, it follows the path of least resistance. The resistance to heat transfer through the walls, roof and floor (know as clear field assemblies or plane elements) is given by the R-Value of the assembly. A thermal bridge is a localized area of the building envelope where the heat flow is different (usually increased) in comparison with the adjacent clear field assemblies.

Plane element (or clear field assembly) heat loss and thermal bridging together constitute all the conduction heat loss through the thermal envelope of a building, measured in W/K, watts per kelvin in metric (BTU/h.F in imperial)

The two principal effects of thermal bridges are:

- **Lower interior surface temperatures**; this will affect occupant comfort (through the sensation of a draft due to radiant heat loss) and in the worst case can lead to condensation (warm moist air hitting a cold surface) leading to moisture build-up and mold growth in building components if unchecked.

- **Increased heat loss:** as the rest of the thermal envelope is improved through code requirements for increasing R-values of clear field assemblies the heat loss becomes focused on the weakest points of the envelope (similar to water seeking out a hole in a bucket), the thermal bridges if not accounted for .

The details studied in this report are calculated as part of the process to achieve the international Passive House standard certification (the Passive House standard is described in Appendix A, the Case Study project is described in Appendix B).

The Passive House standard seeks to avoid these risks through thermal bridge free design by ensuring that internal surface temperatures are so high that comfort is not compromised and critical moisture build-up cannot occur and accompanying heat loss becomes negligible.

Typically, the approach in Passive House buildings is to avoid/eliminate thermal bridging by ensuring continuity of insulation. While this takes a bit of consideration in the design stage, it is a simpler and in the long run more cost-effective in terms of energy loss and building detailing. Thermal bridges are often unavoidable, particularly where there are other multiple issues to be resolved at a junction (e.g. structure, fire safety). Where they cannot be eliminated, they should be minimized and heat loss accounted for in the PHPP energy model.

2.2 Types of Thermal Bridges

Thermal bridges can be categorized in a number of ways, but there are two main types:

- **Geometrical thermal bridges** occur due to the building form. It may be due to shape alone where the construction assembly does not change but the thermal envelope changes shape, such as an external or internal wall corner.
- **Construction thermal bridges** occur where there is a penetration, gap or reduction in the insulation due to the construction.

Within the construction thermal bridge category, there are two sub-categories:

- **Repeating thermal bridges** are construction-based and follow a regular pattern and are evenly distributed over an area of the building envelope, such as wood stud in a wall assembly, cladding attachments, masonry wall ties, etc.
- **Non-repeating thermal bridges** are intermittent and occur at a specific point in the construction. These may be 2D/linear (e.g. a length of parapet) or 3D/point thermal bridges (e.g. a steel beam penetration).

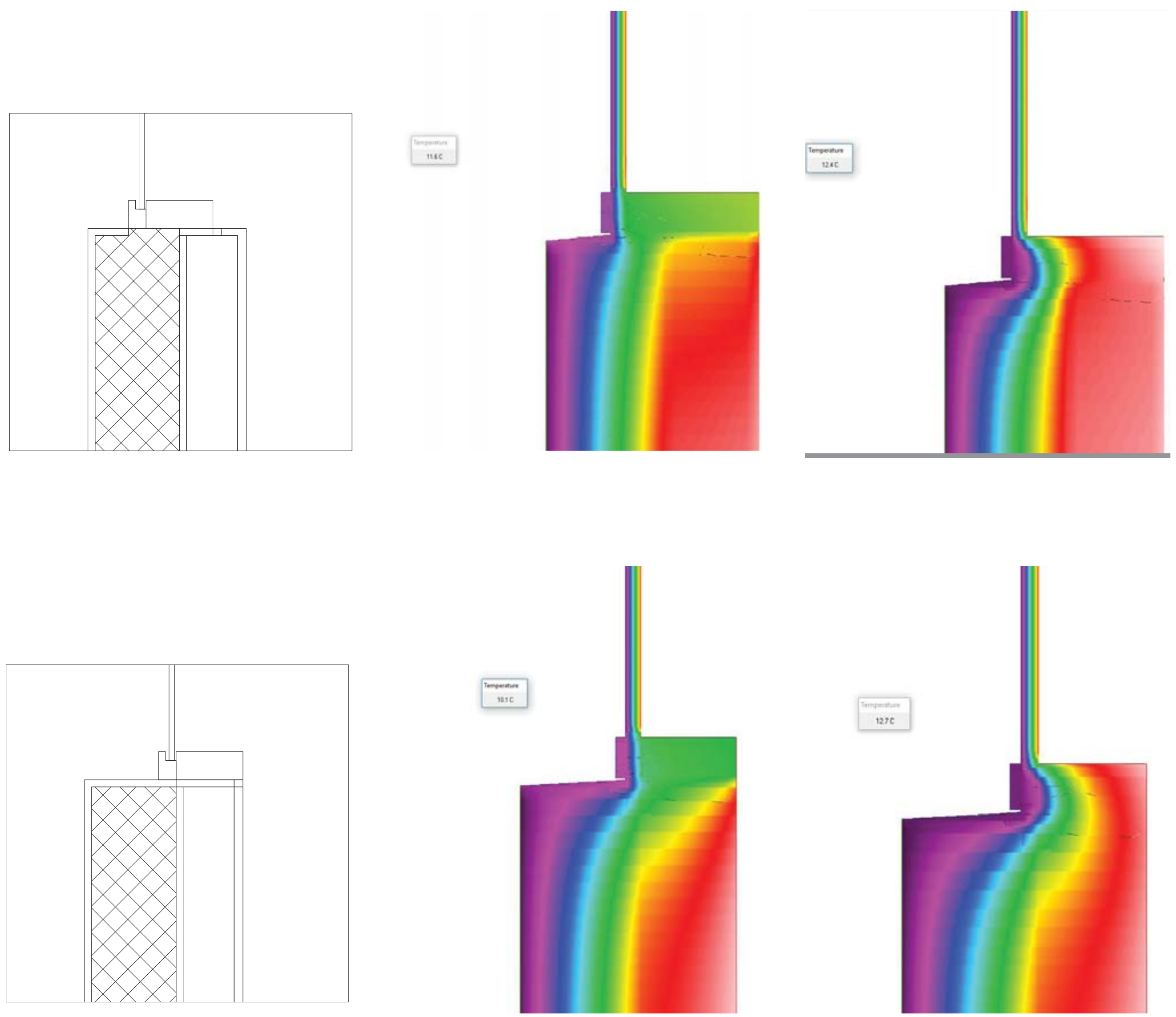
Generally repeating thermal bridges are accounted for in energy modelling via the effective R-Value of an assembly, where by the overall or nominal R-value is degraded. Repeating thermal bridges can have a significant effect on heat loss, see example. Currently these are the only thermal bridges accounted for in ASHRAE 90.1

Non-repeating thermal bridges need to be accounted for in order to get a full idea of the actual heat loss through the envelope. Using modeling software, such as THERM, the design team can determine the exact heat loss through a detail of a building component and compare it to the heat loss that is estimated within an energy model by using the U-values and areas of the clear field assemblies. This comparison of real versus estimated values gives an adjustment factor to be applied to the detail to account for the thermal bridging effects. This is essentially an accounting principle that compensates for the difference in heat loss between values modelled based on assemblies and the actual heat loss.

For linear (2d) thermal bridges, this value is known as the **PSI (Ψ) value.** For point (3d) thermal bridges, the correction factor is known as the **Chi (χ) Value**. This process for calculating these values is described in **Section 2.4.**

As well as the more typical examples (e.g. a door threshold or balcony slab penetrations) there are also a number of thermal bridges that may come as a surprise to the design team if pursuing the rigorous methodology of the Passive House Standard may need to be included in the energy model e.g.

- Curtain wall anchors are point (3d) thermal bridges
- Rainwater liters and sanitary pipes if uninsulated and penetrating the envelope are not only point thermal bridges but with cold air/ fluid may also need to be modelled as linear thermal bridges for the length of the main trunk. PHPP has an in-built calculator for this. There are alternative solutions being prepared for Passive House projects to allow Air Admittance Valves (AAV)
- Any direct venting (e.g. a kitchen extract hood, dryer exhaust etc) directly to the outside needs to be accounted for – if a damper is fitted it may be a point thermal bridge, if no damper it is treated as a linear thermal bridge (with higher heat losses).



Early trial of modelling process - examining the effect of curtain wall back-section material (aluminum left vs timber right) and placement in wall depth. In addition to mitigating heat loss thermal bridge free design aims to avoid low internal surface or interstitial temperatures to avoid the risk of condensation and occupant discomfort.

A building envelope with low thermal transmittances or highly effective R-values is critical to achieving low thermal energy demand. This is achieved by well insulated assemblies and minimizing thermal bridging. ***Thermal bridging is best minimized and avoided early in the design process*** *by evaluating the impact using default values founds in catalogues, such as the Building Envelope Thermal Bridging (BETB) Guide or ISO 14683. Assumptions can then be revisited and refined with project specific values as the design evolves and the other design requirements become more tangible.*

Guide to Low Thermal Energy Demand for Large Buildings

https://www.bchousing.org/research-centre/library/residential-design-construction/guide-low-energy-demand-large-buildings

Image from thermal bridge modelling undertaken as part of previous innovation incubator [Spring 2016 - Comparing and Adapting Pitt River School to the Passive House Standard]. The coloured isotherms denote lines of constant temperature. Deviation of these lines from being straight indicates the presence of a thermal bridge.

2.3 Identifying Thermal Bridges

Thermal bridges can be identified and from there assessed in a number of ways:

1. Visual inspection of a detail – is continuous insulation present at a junction or is there a reduction in the thickness, thermal conductivity of the insulating materials or penetration of a material with higher thermal conductivity. If pursuing Passive House certification the certifier will know based on prior experience if a detail requires further calculation of if visual inspection is sufficient to declare it thermal bridge free. .

2. Reference details – based on similar details. The design team may use standard details from a previous project or from reliable reference with a listed Ψ / χ Value. An example of this is the Building Envelope Thermal Bridging Guide. However, care must be taken when referencing these catalogues. The Ψ Value is a correction factor and will be a project of the assemblies and configuration of the detail e.g. if the thermal performance (U-value/R-value) of the assembly adjacent changes then the Ψ-value will also change. These catalogues will not cover all variations of the details and indeed different reference materials may calculated using different protocols e.g. using internal dimensions as opposed to external dimensions which would give a different value for the same detail. In the case of Passive House certification use of reference or past project details would need certifier approval for use in PHPP.

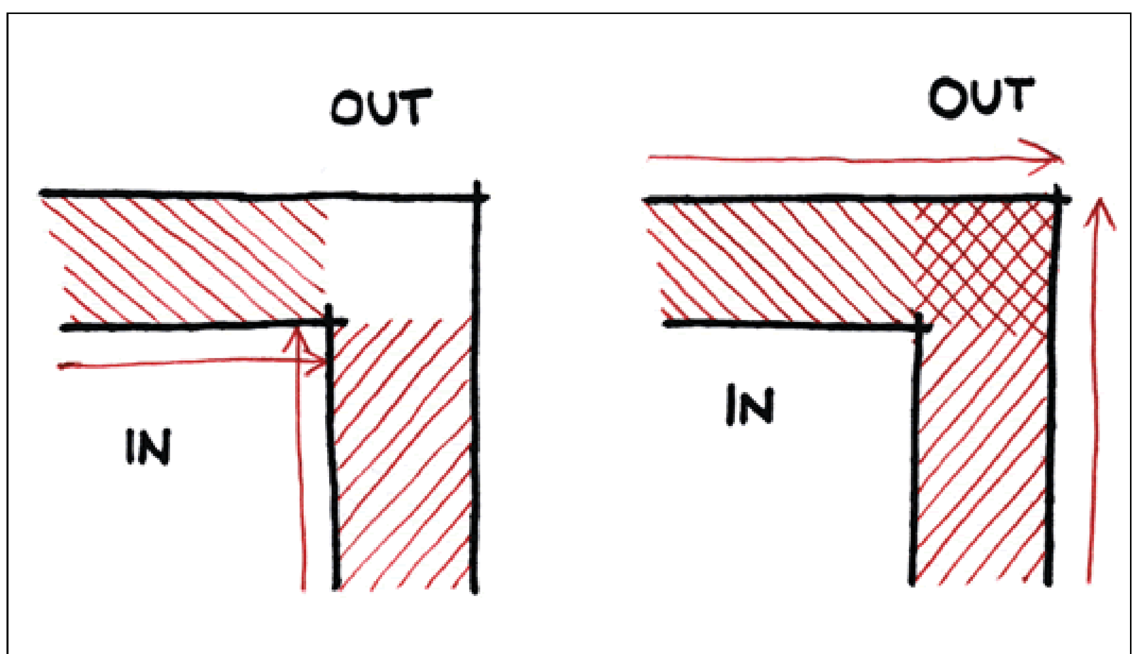
3. Thermal Bridge modelling –This is the how the design team actually quantifies the heat loss in order to account for it in the energy model. This process is described in Section 3 and 4 below. The main focus of this Innovation Incubator is on Linear thermal bridges (e.g. wall to floor, wall to roof, slab penetrations etc) and determining the -values for input into PHPP.

4. Thermal imaging – this is for built work to identify where thermal bridging (and/or lack of airtightness) may be present in the envelope - usually too late to rectify for a project seeking Passive House certification but useful in retrofit work. There are set protocols for the conditions in which to undertake thermal imaging. There is no post occupancy thermal imaging requirement for Passive House certification.

The biggest impact to realizing low thermal transmittance is the quality of the details and design teams aggressively minimizing thermal bridging.

Guide to Low Thermal Energy Demand for Large Buildings p 83

https://www.bchousing.org/research-centre/library/residential-design-construction/guide-low-energy-demand-large-buildings



The BETB Guide measures building fabric from the inside and Passive House from the outside. This will give different values for the same detail.

2.4 Calculating Thermal Bridges - PSI (**Ψ**) and Chi (**χ**) Value

Thermal bridges are measured by assigning a thermal bridge loss coefficient. This is essentially an accounting principle that compensates for the difference in heat loss between that modelled based on assemblies and the actual heat loss (as modelled in a software such as e.g. THERM, HEAT 2 & 3, Flixo).

Linear (2d) thermal bridges are assigned a linear transmittance value known as a PSI (Ψ) value, measured in W/mK *(Btu/hr.ft.F)*. Multiplying the Ψ Value by the linear length (m or ft) of the junction will give the heat loss as a result of thermal bridging for this detail. This is inputted into the energy model to give the correct heat loss from thermal bridging. Best practice under Passive House design looks to eliminate all thermal bridging with thermal bridge free design defined as $\Psi \leq 0.01$W/mK *(0.006 kBtu/hr-ft-F)* – this occurs when the insulation level of the adjacent assembly is continuous through the junction.

Where a junction has two assemblies meeting at an angle (e.g. wall to roof) the PSI Ψ-value can be calculated using internal or external dimensions, depending on the methodology followed (and the overall energy model area protocols). This will result in a different PSI value depending on which method is used.

The Passive House Standard references ISO 10211 and thermal bridges are calculated using external dimensions. This is why when we look at Passive House details with thick assemblies we can get negative PSI value – the heat loss at external junctions may be overestimated (accounted for twice). The negative PSI discounts this to give the true heat loss value.

The BETB Guide mentioned above provides procedures for calculating thermal transmittances that combines North American conventions with the ISO 10211 methodology and some refinements to more accurately simulate steel-framed assemblies. The calculated values within are reference interior dimensions. This is why it is important to note when referencing a catalogue of detail to note how the detail was modelled. There is a methodology for converting a PSI value form exterior to interior dimensions but generally, care must be taken when referencing a reference guide for comparable PSI (Ψ) values it should be noted how the calculation was undertaken in order to use the correct value.

Point (3d) thermal bridges are assigned a point transmittance value, measured in W/K (Btu/hr.F), the correction factor is known as the Chi (χ) Value. In Passivhaus design these bridges are usually designed out and can be ignored unless they contribute to significant heat losses (in which case they may require specialist thermal bridge modelling such as for a steel beam penetration).

The biggest impact to realizing low thermal transmittance is the quality of the details and design teams aggressively minimizing thermal bridging.

Guide to Low Thermal Energy Demand for Large Buildings p 83

https://www.bchousing.org/research-centre/library/residential-design-construction/guide-low-energy-demand-large-buildings

3.0 THERMAL BRIDGE DETAILS /

This section lists the PSI (Ψ) values of the details of the case study project (described in **Appendix B**). The details studied were for a prototype building (described in Appendix B) seeking low energy performance in harsh climate conditions. The assemblies as a result have above average levels of insulation even for a Passive House project in order to mitigate heat loss. The details appear thermal bridge free on visual inspection ($\Psi < 0.01$W/mK). Calculating the PSI (Ψ) value for all the details allows the negative values to be used in the energy model, reducing the over estimation of heat loss through these junctions.

The details reviewed are all simple geometry conditions, introducing glazed elements adds additional complications.

To complete a basic thermal bridge model of a simple the designer needs the thermal conductivity values of each material in the detail, the U-values (or R-Values) of the assemblies in question and the boundary conditions for each assembly.

thermal conductivity (λ) - A measure of the ability of a material to transfer heat. Measured in W/mK (BTU/(hr·ft·°F) in imperial or more commonly given as an R per inch figure). Insulation materials are typically 0.033-0.04 W/mK (3.6-4.2 R per inch).

boundary conditions - accounts for the air film resistance results from convection currents at the external and internal surface of an assembly. These are labelled as internal surface resistance **Rsi** and external surface resistance **Rse**. The external value varies depending on the exposure of the final insulating layer (e.g. if a ventilated rainscreen cladding) and the internal value depends on the orientation of the assembly (wall versus roof).

MATERIALS			
#	TYPE	λ [W/mK]	COMMENT
1	CLT / DLT	0.13	
2	PLYWOOD SHEATHING	0.13	
3	TIMBER FRAMING GENERALLY	0.13	
4	GLULAM BEAM	0.13	
5	MINERAL WOOL [SCREW FIXED]	0.041	0.038 base - 8% degradation due to screw fixing
6	MINERAL WOOL [LATTICE]	0.044	0.038 base - 16.67% timber content allowed for
7	RHINOKORE [WINDOW BLOCKING]	0.056	Manufacturers data
8	WARMBOARD UNDERLAY		Manufacturers data
9	FRAME REPLACEMENT (FENSTER OPERABLE)	0.108	Based on Uf=0.87, 106mm window frame - Fenster PHI certified
10	FRAME REPLACEMENT (RAICO CW)		
11			
12			
13			
14			

SURFACE RESISTANCES				
#	TYPE	ϑ [°C]	R [m2K/W]	Hc [W/m2K]
R1	EXTERIOR AMBIENT	0	0.04	25.000
R2	EXTERIOR VENTILATED	0	0.13	7.692
R3	GROUND	0	0	0.000
R4	INTERIOR UP	20	0.17	5.882
R5	INTERIOR HORIZONTAL	20	0.13	7.692
R6	INTERIOR DOWN	20	0.1	10.000

ASSEMBLY U-VALUES				
#	TYPE	U [W/m2K]	REVIT #	PHPP #
U1	WALL	0.066	E1.1	E1.1 - External Wall
U2	ROOF	0.063	R3.1	R1.1 - Roof
U3	SOFFIT	0.062	EFT1.	F0.1 - Floor / Soffit

DETAIL 01-01:

WALL EXTERNAL CORNER

PROJECT: **SOO VALLEY DUPLEX**
BUILT: **N**
VERIFIED: **N**

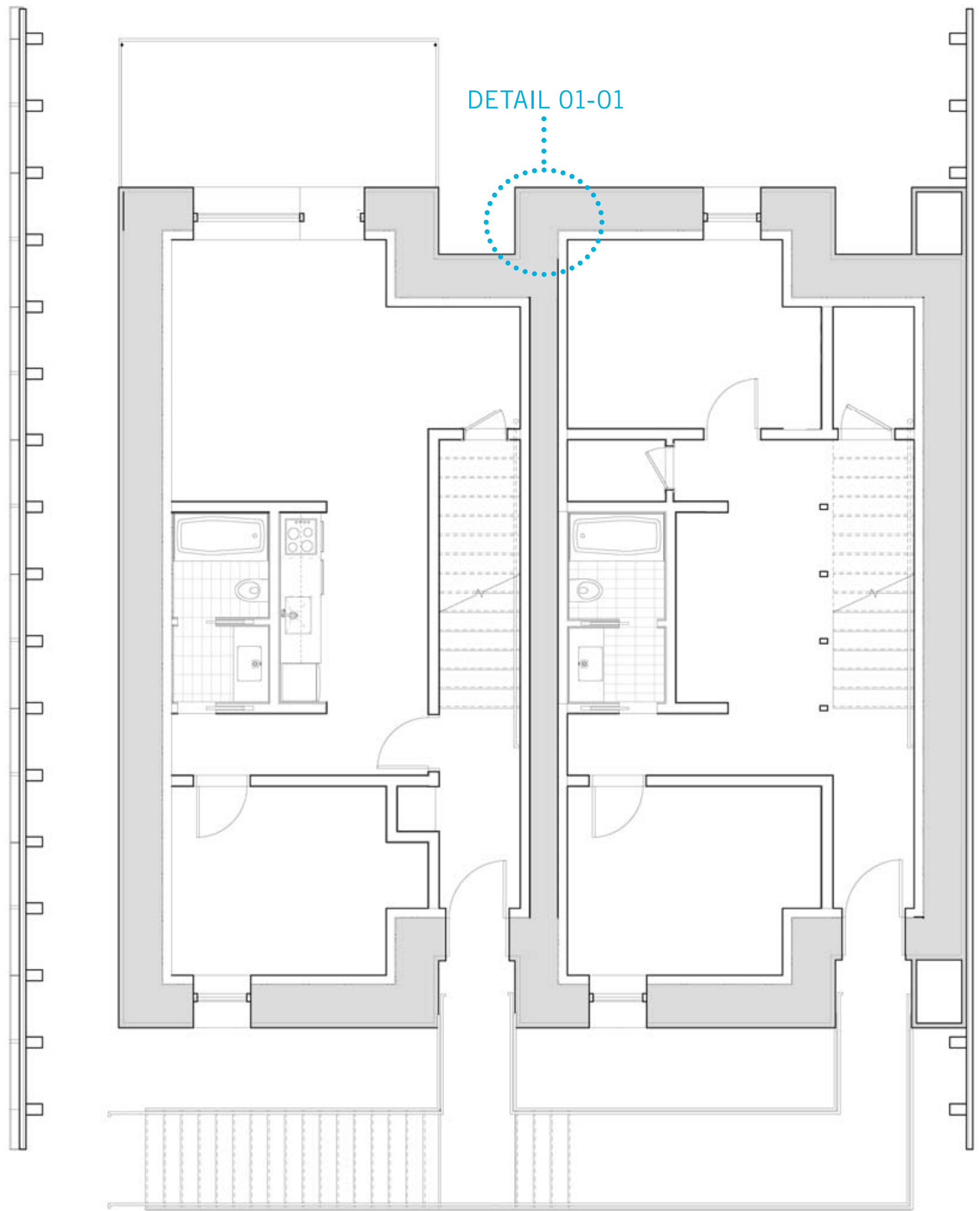
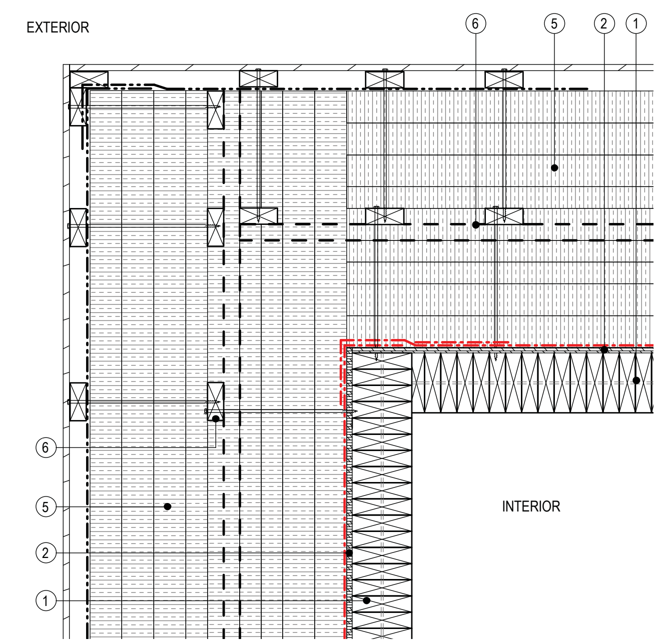
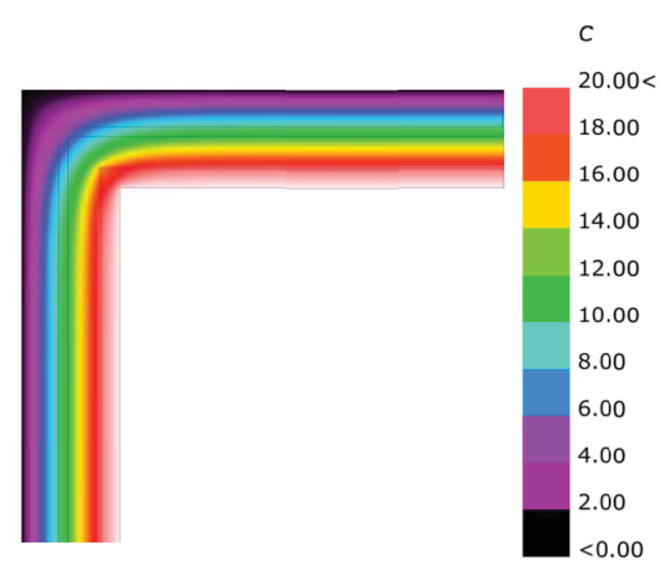


Image: passivehouse project floor plan





Temperature
THERM Simulation

THERMAL PROPERTIES

ψ value: **-0.061 W/mK**

TECHNICAL DESCRIPTION

Typical external corner. Will likely result in negative ψ value due to thickness of insulation.

DETAIL 01-01:

WALL EXTERNAL CORNER

PROJECT: **SOO VALLEY DUPLEX**
BUILT: **N**
VERIFIED: **N**

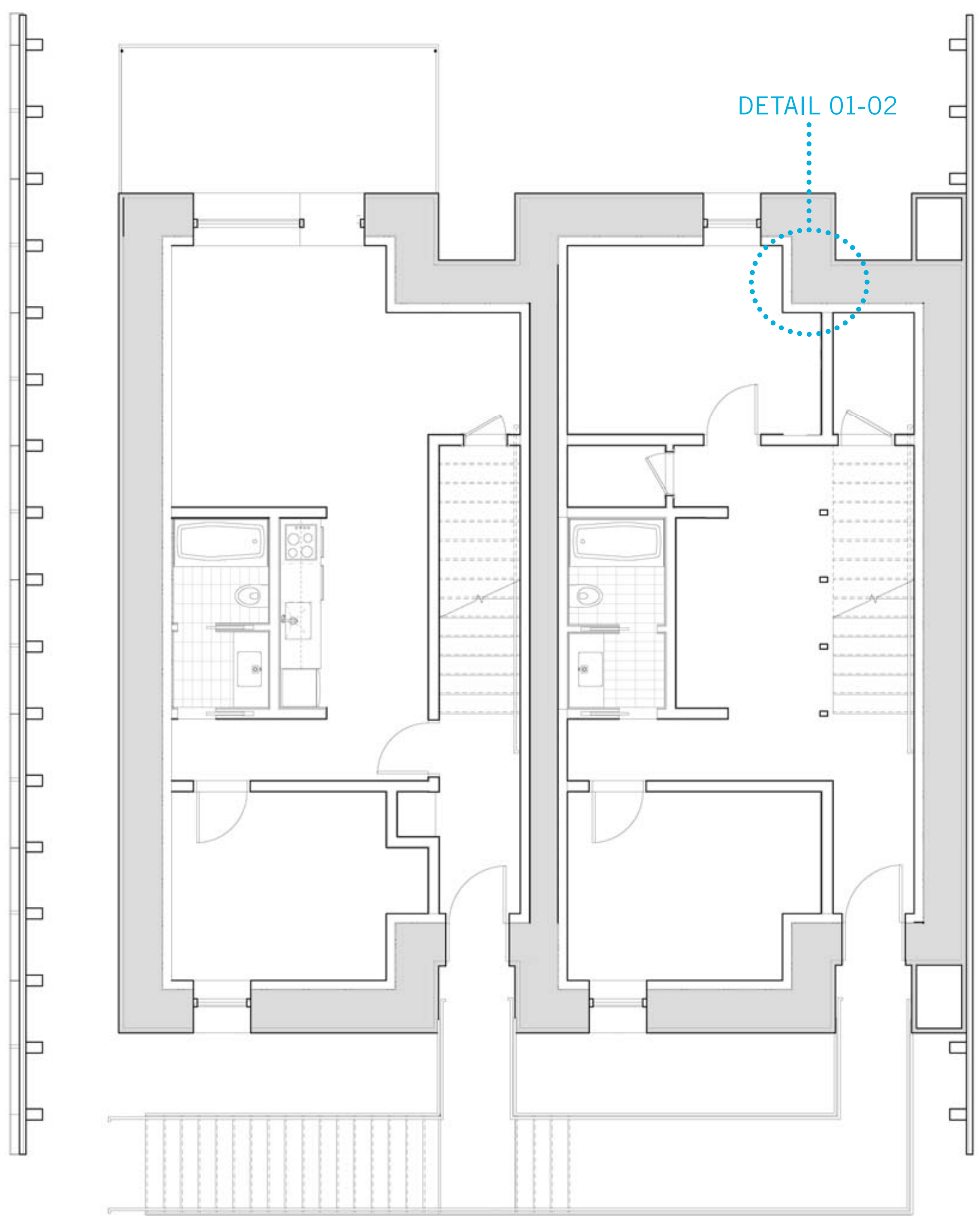
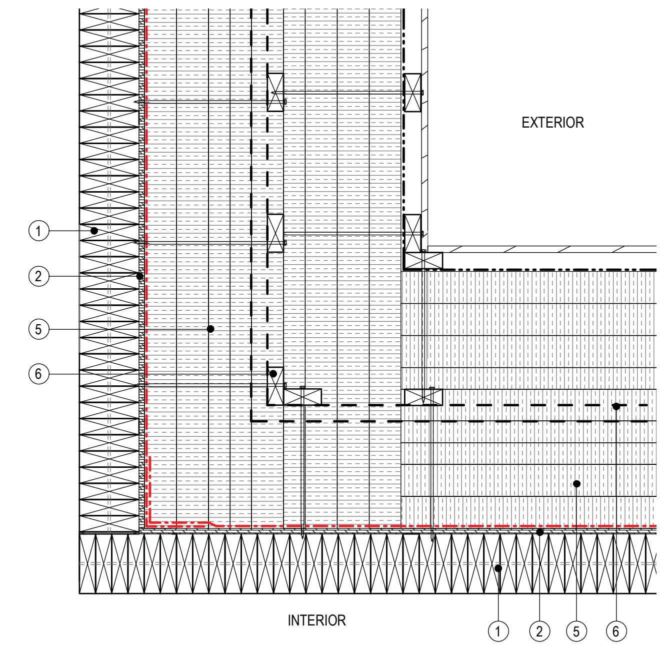


Image: passivehouse project floor plan

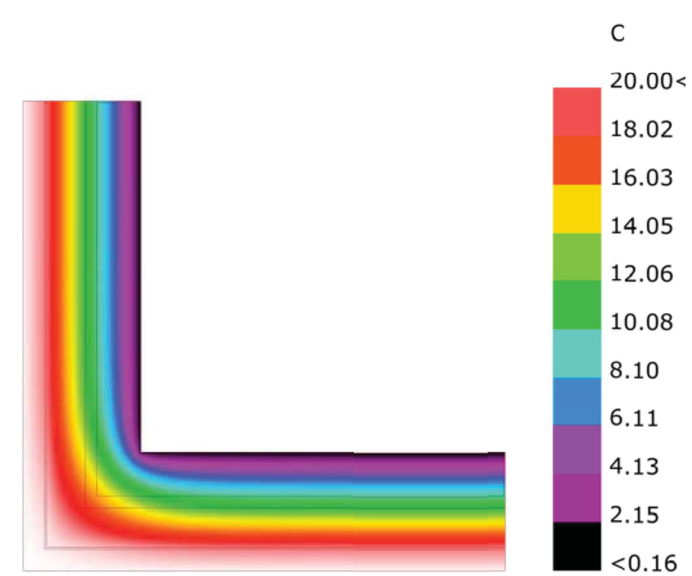


THERMAL PROPERTIES

ψ **value: 0.023 W/mK**

TECHNICAL DESCRIPTION

Typical internal corner. Will likely result in a positive ψ value due to thickness of insulation.



Temperature
THERM Simulation

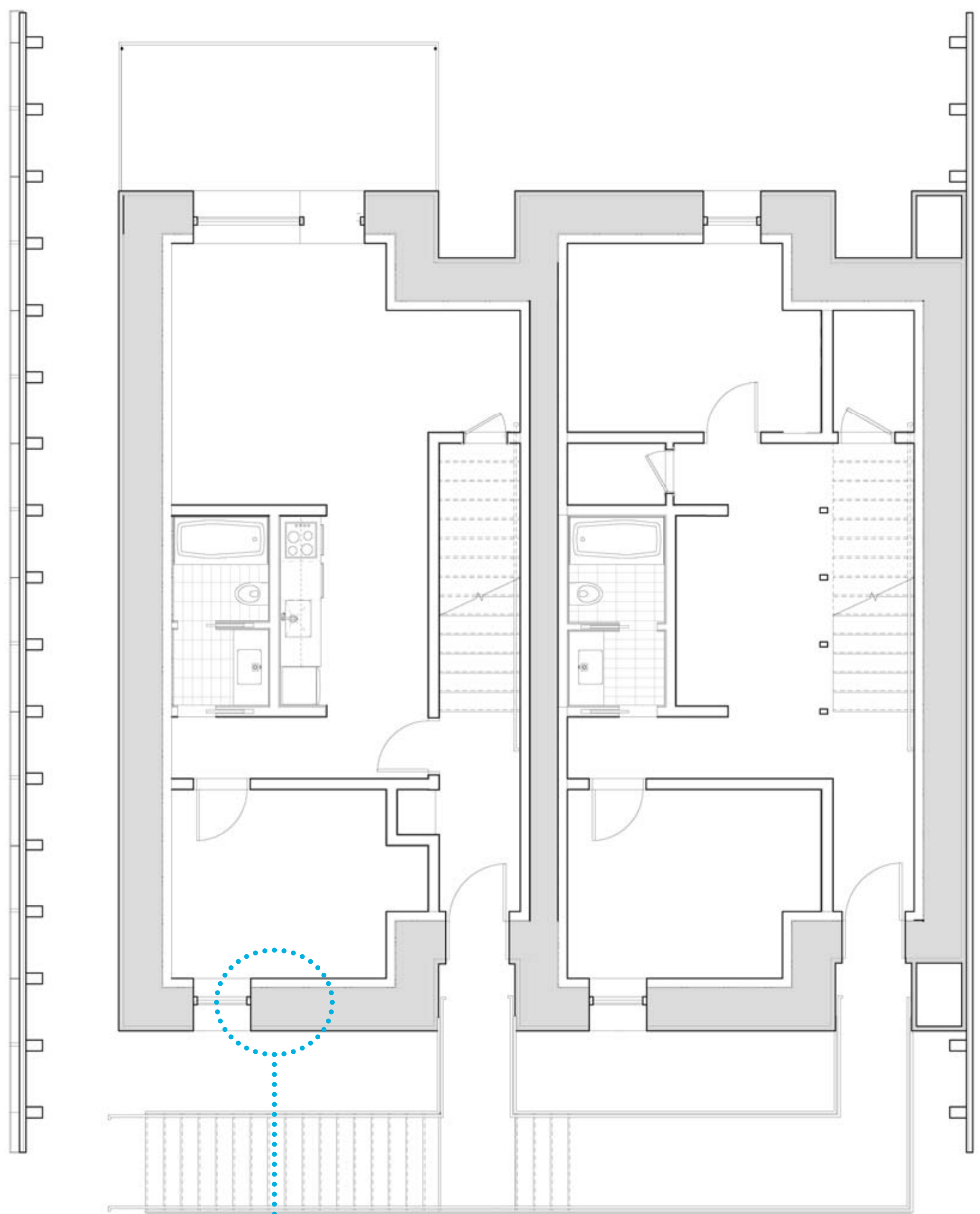
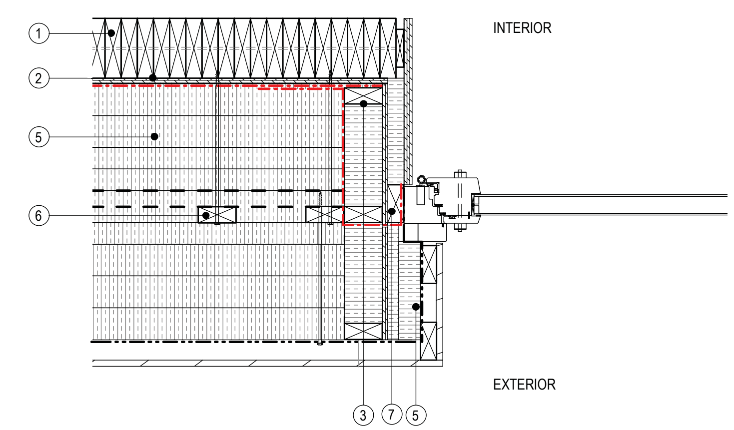


Image: passivehouse project floor plan

DETAIL 01-01:

WALL EXTERNAL CORNER

PROJECT: **SOO VALLEY DUPLEX**
BUILT: **N**
VERIFIED: **N**

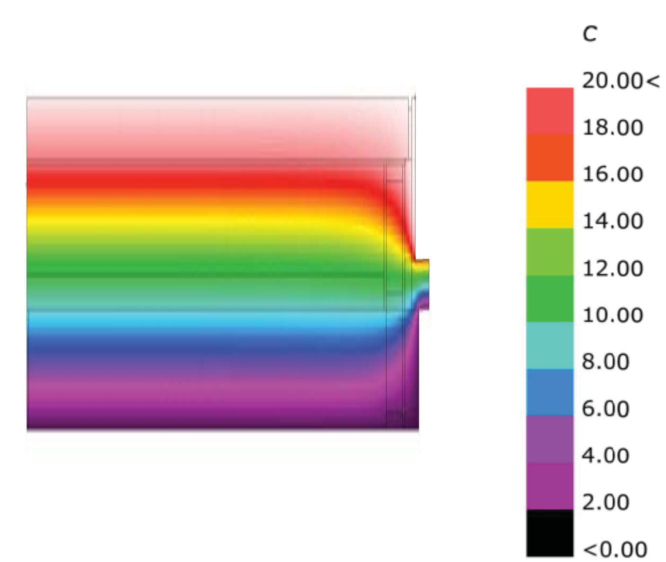


THERMAL PROPERTIES

ψ value: 0.015 W/mK

TECHNICAL DESCRIPTION

Typical window jamb detail. The PHPP default is 0.04W/mK which allows for a good installation detail. By improving the insulation over the frame and positioning the window into the center of the assembly the ψ value is improved.



Temperature
THERM Simulation

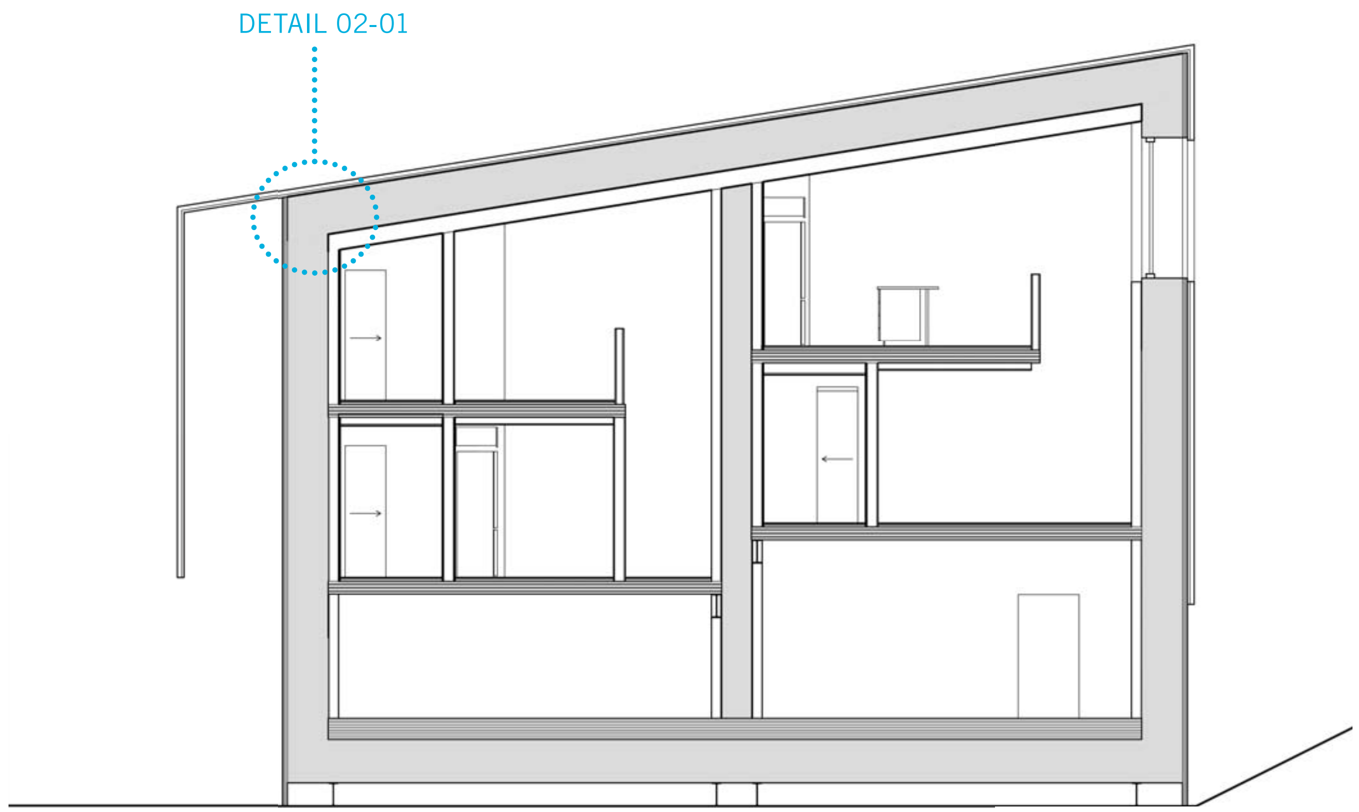
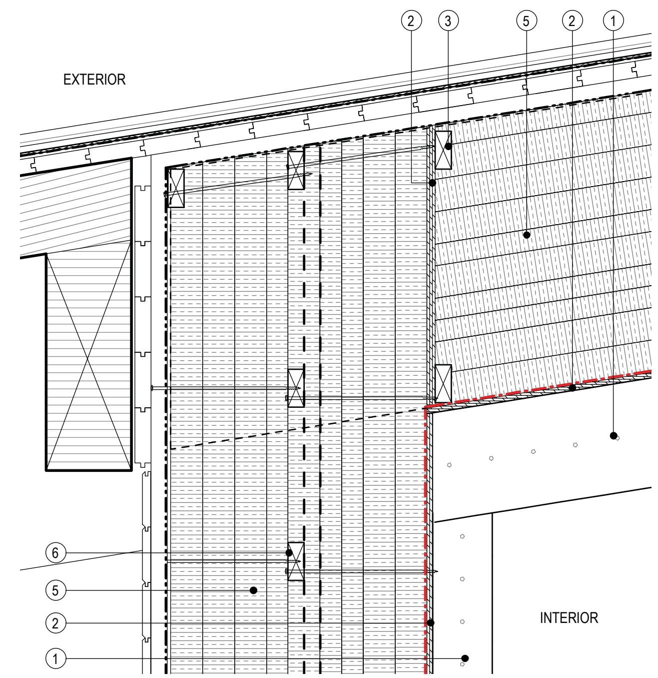


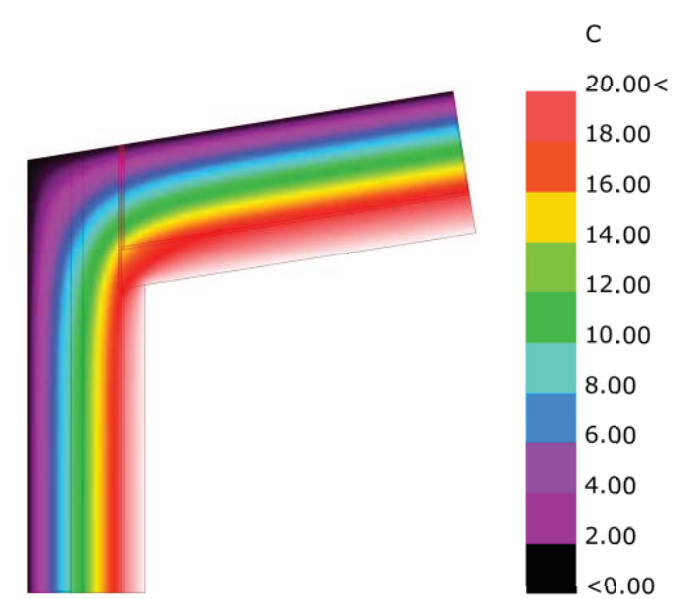
Image: passivehouse project section

DETAIL 01-01:

WALL EXTERNAL CORNER

PROJECT: **SOO VALLEY DUPLEX**
BUILT: **N**
VERIFIED: **N**





Temperature
THERM Simulation

THERMAL PROPERTIES

ψ value: **-0.047 W/mK**

TECHNICAL DESCRIPTION

Typical lower roof external corner. Will likely result in negative ψ value due to thickness of insulation.

DETAIL 01-01:

WALL EXTERNAL CORNER

PROJECT: **SOO VALLEY DUPLEX**
BUILT: **N**
VERIFIED: **N**

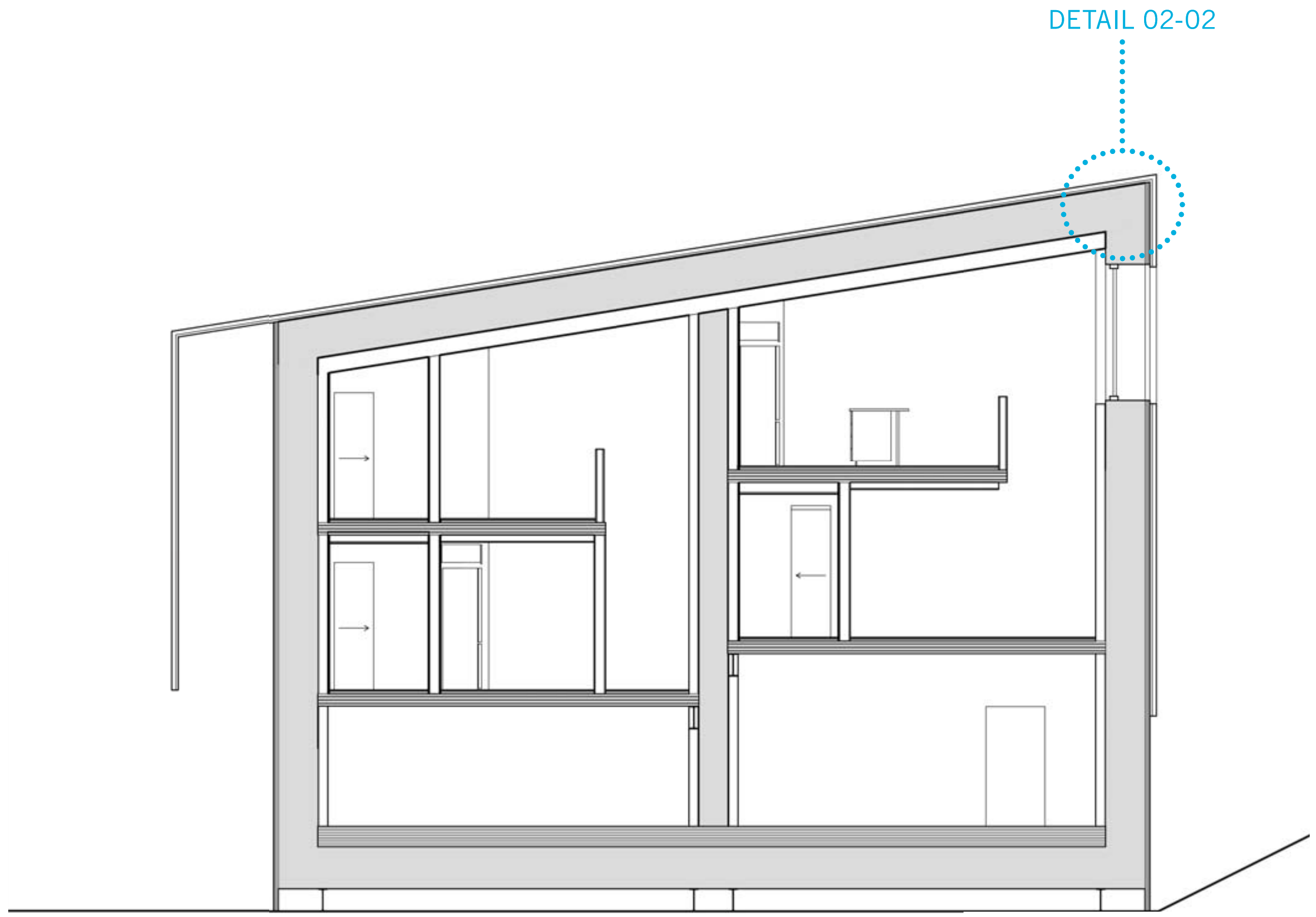
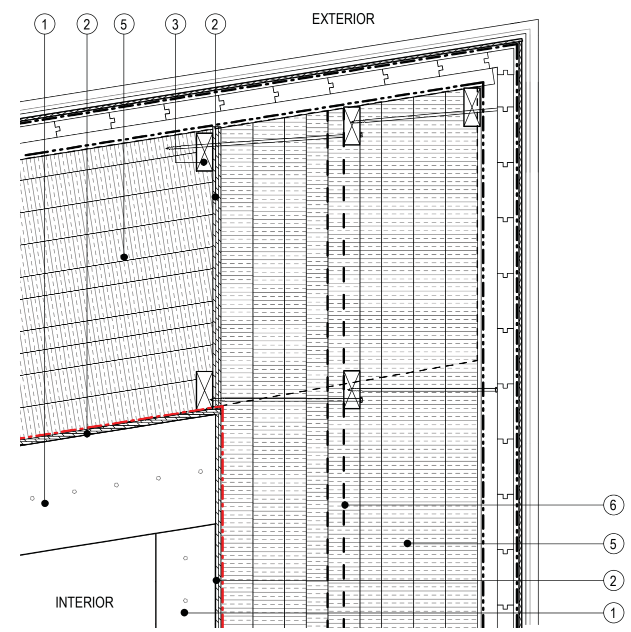
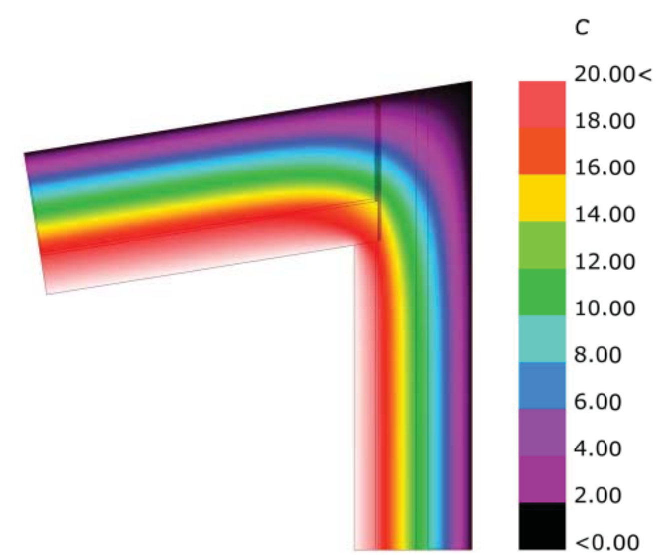


Image: passivehouse project section





Temperature
THERM Simulation

THERMAL PROPERTIES

ψ **value:** **-0.074 W/mK**

TECHNICAL DESCRIPTION

Typical upper roof external corner. Will likely result in negative ψ value due to thickness of insulation.

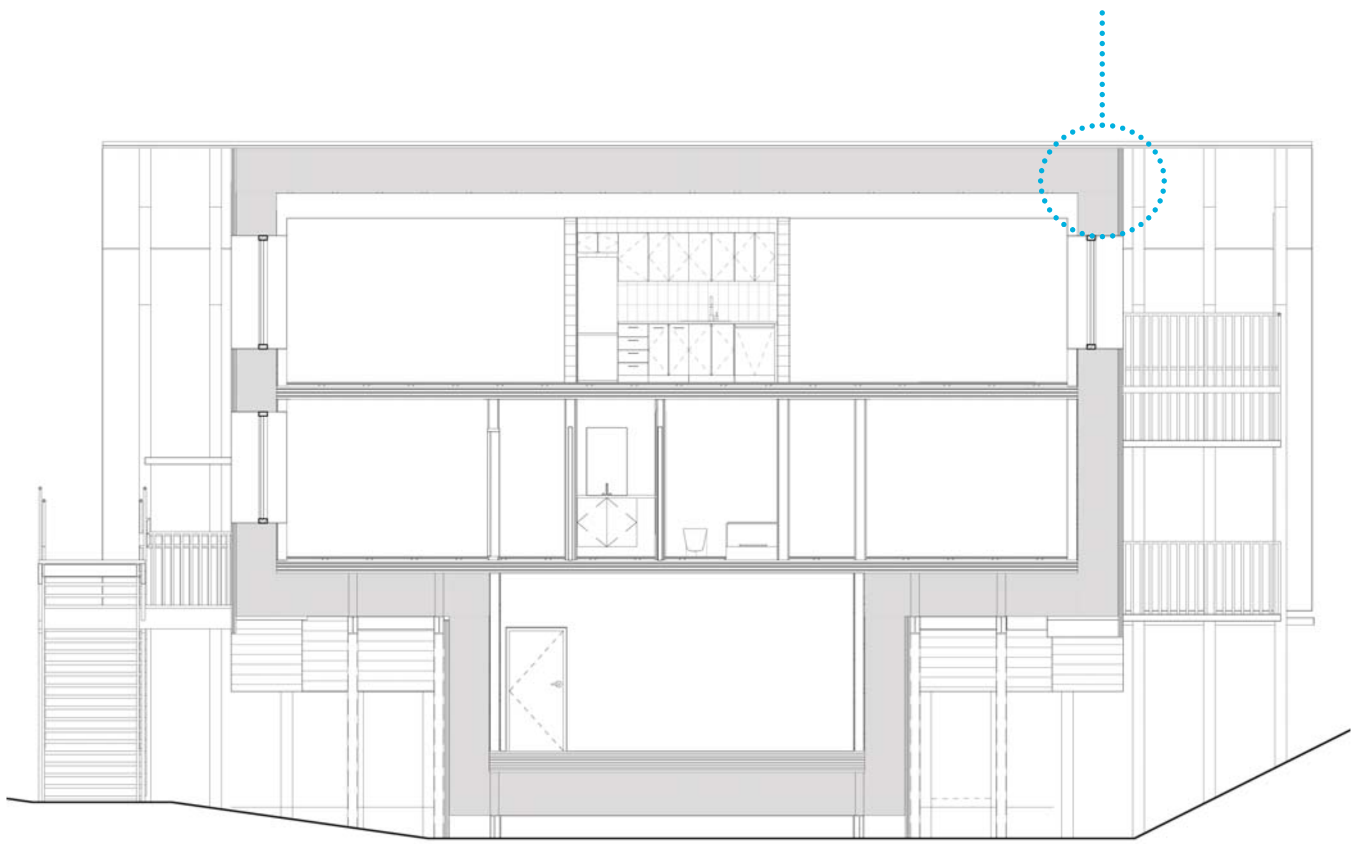
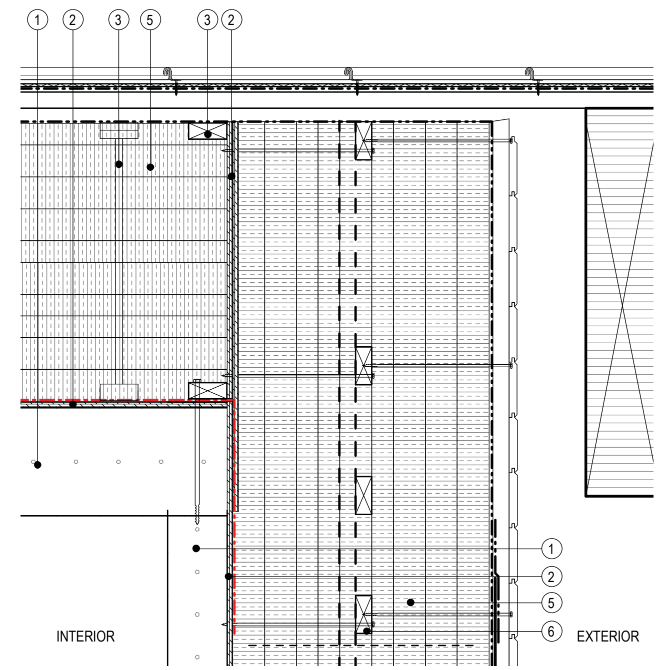


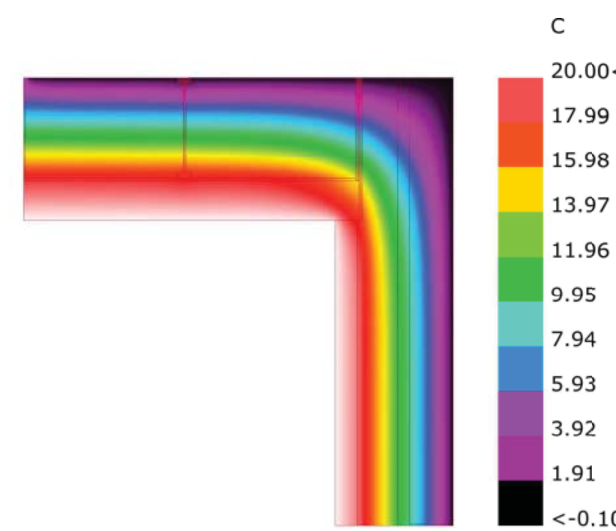
Image: passivehouse project section

DETAIL 01-01:

WALL EXTERNAL CORNER

PROJECT: **SOO VALLEY DUPLEX**
BUILT: **N**
VERIFIED: **N**





Temperature
THERM Simulation

THERMAL PROPERTIES

ψ **value: -0.058 W/mK**

TECHNICAL DESCRIPTION

Typical external corner at roof. Will likely result in negative ψ value due to thickness of insulation.

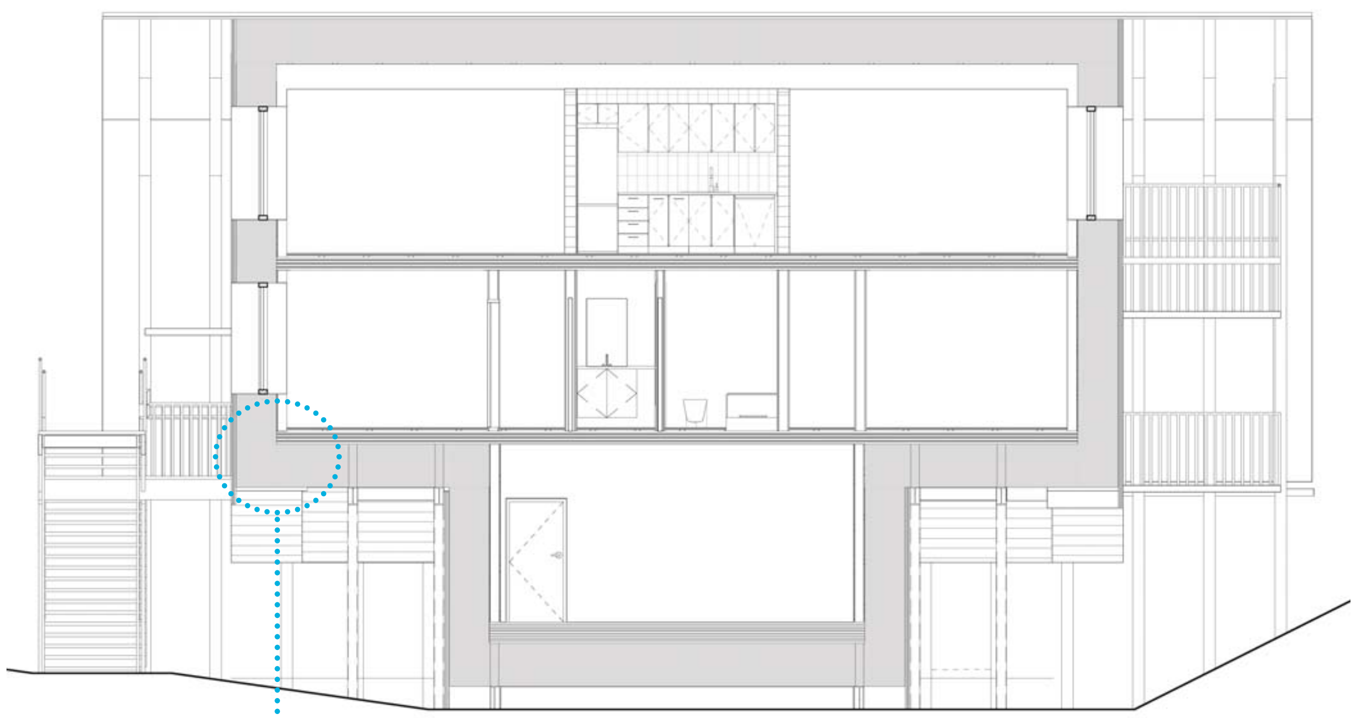
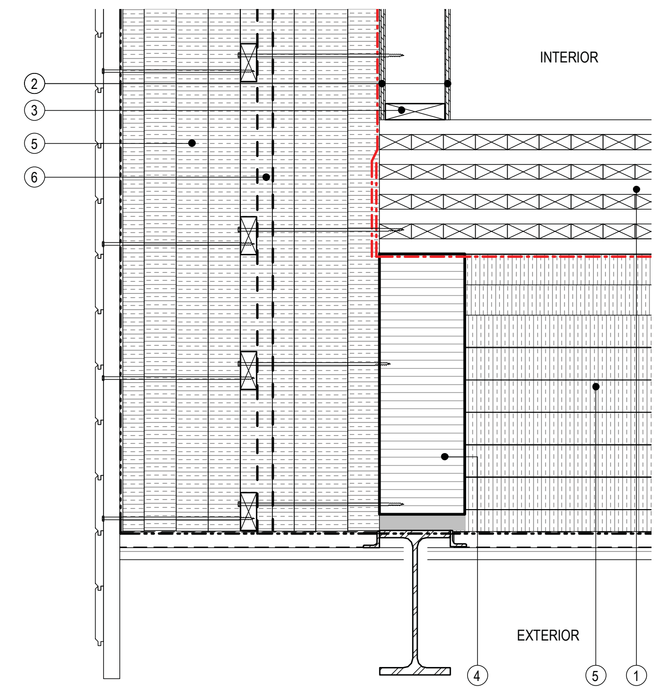


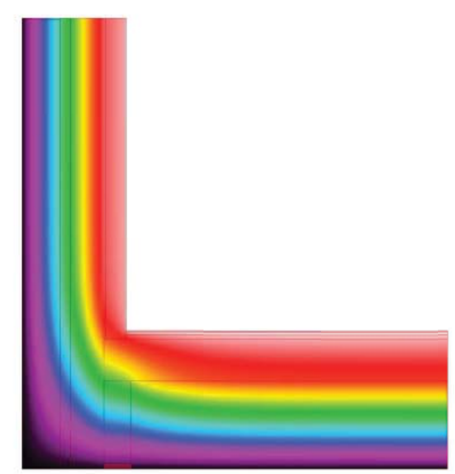
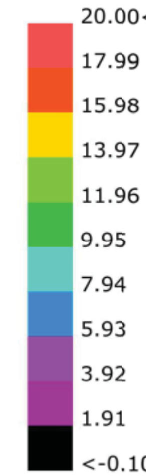
Image: passivehouse project section

DETAIL 01-01:

WALL EXTERNAL CORNER

PROJECT: **SOO VALLEY DUPLEX**
BUILT: **N**
VERIFIED: **N**



Temperature
THERM Simulation

THERMAL PROPERTIES

ψ value: **-0.056 W/mK**

TECHNICAL DESCRIPTION

Typical external corner at floor. Will likely result in negative ψ value due to thickness of insulation.

DETAIL 01-01:

WALL EXTERNAL CORNER

PROJECT: **SOO VALLEY DUPLEX**
BUILT: **N**
VERIFIED: **N**

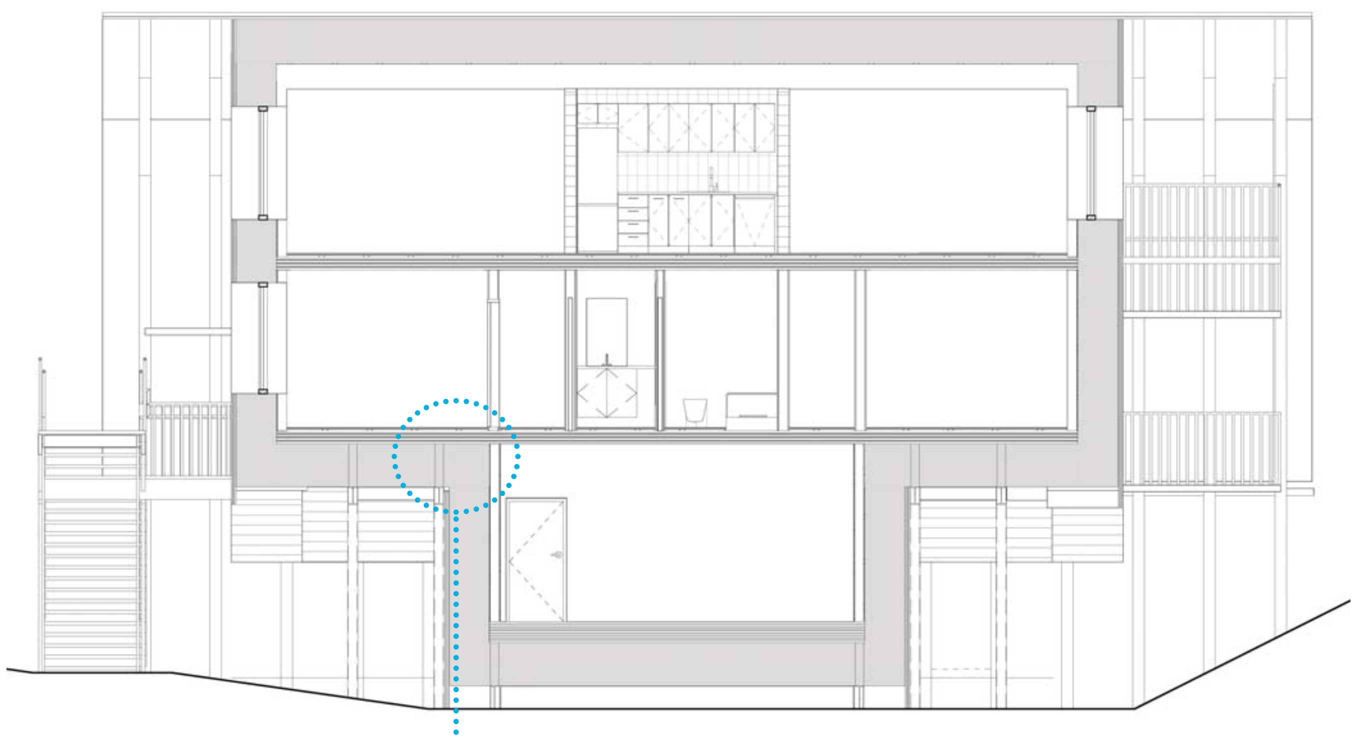
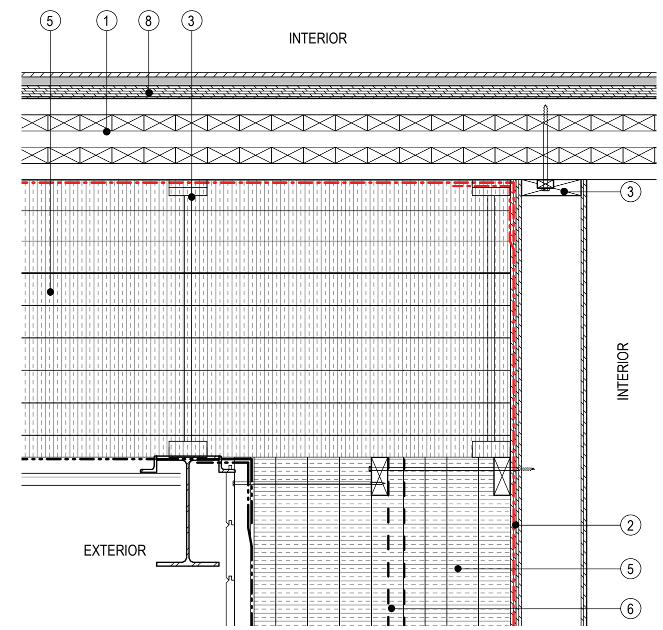
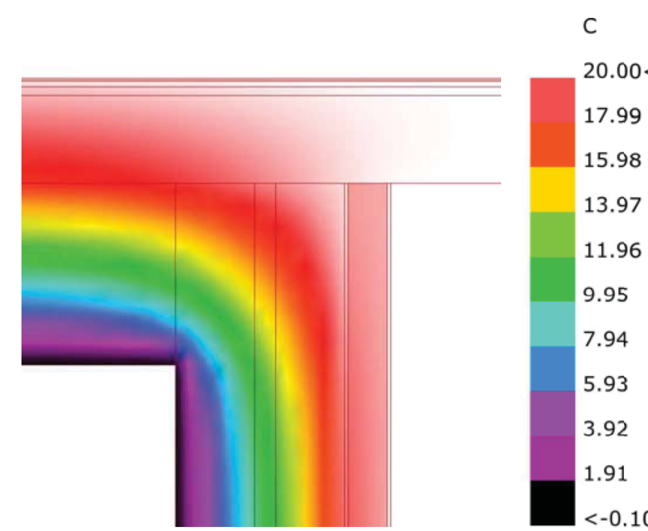


Image: passivehouse project section





Temperature
THERM Simulation

THERMAL PROPERTIES

ψ value: **0.024 W/mK**

TECHNICAL DESCRIPTION

Typical soffit condition at mechanical level. Will likely result in positive ψ value.

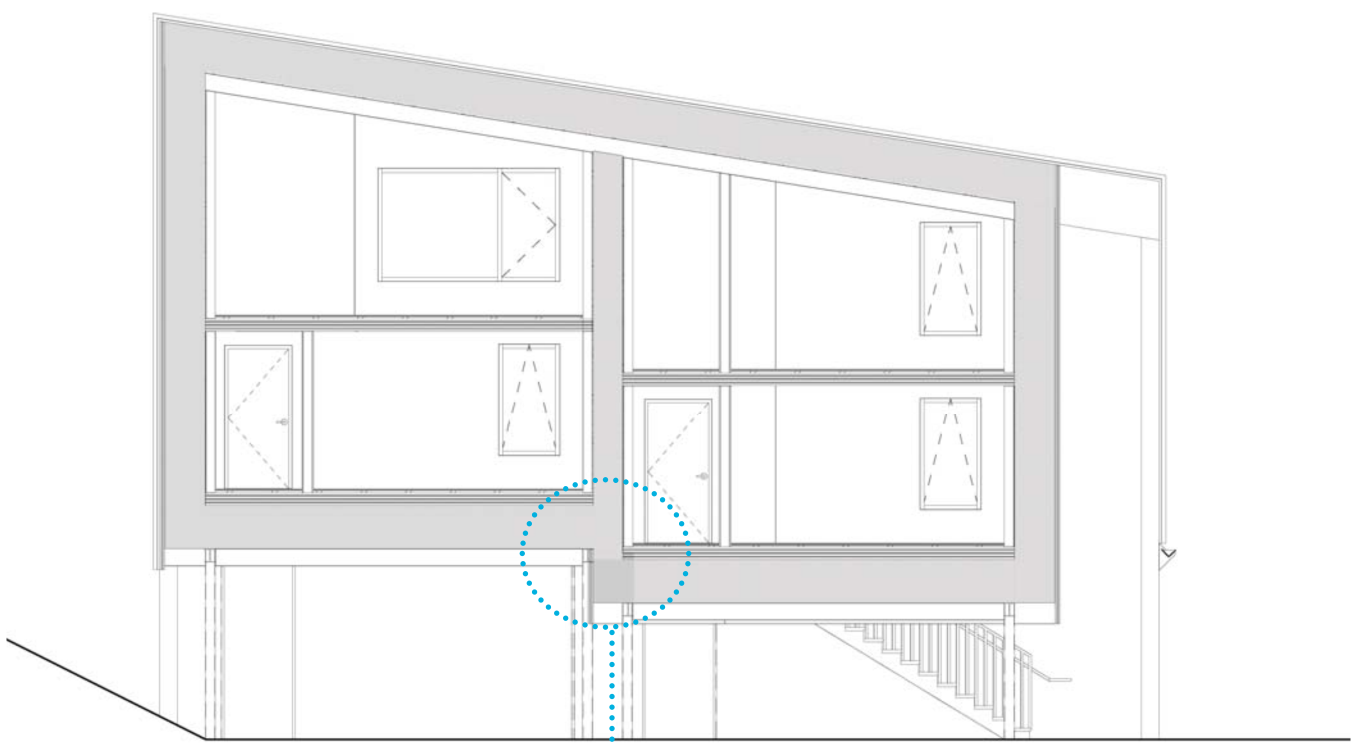
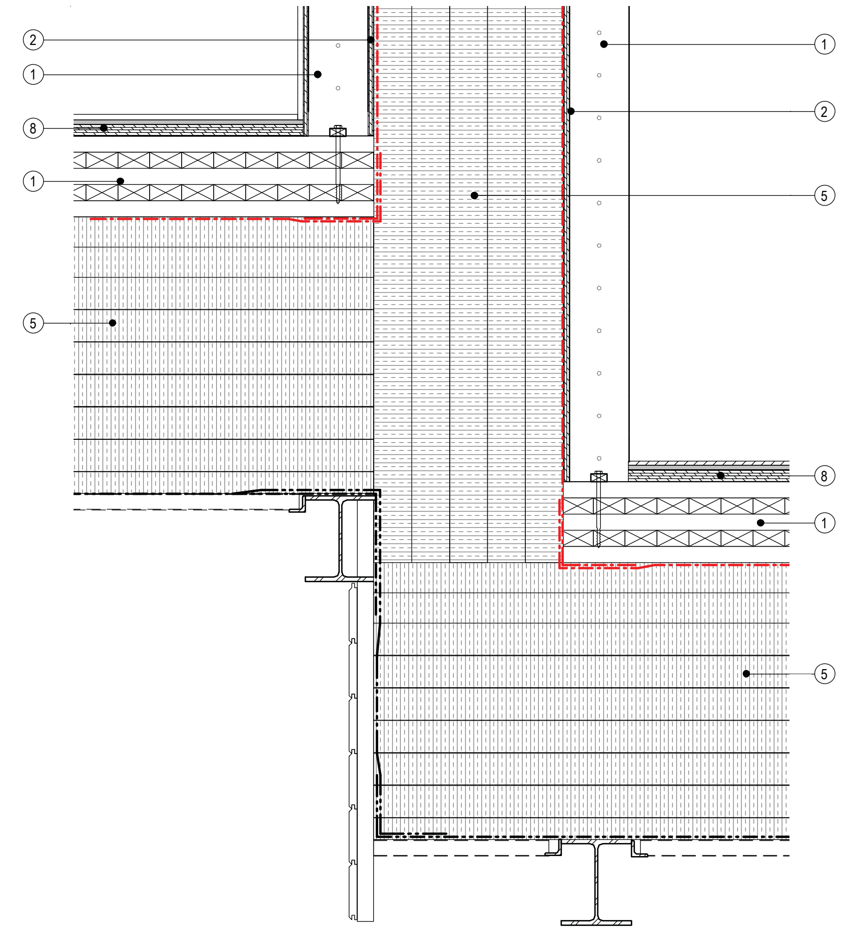


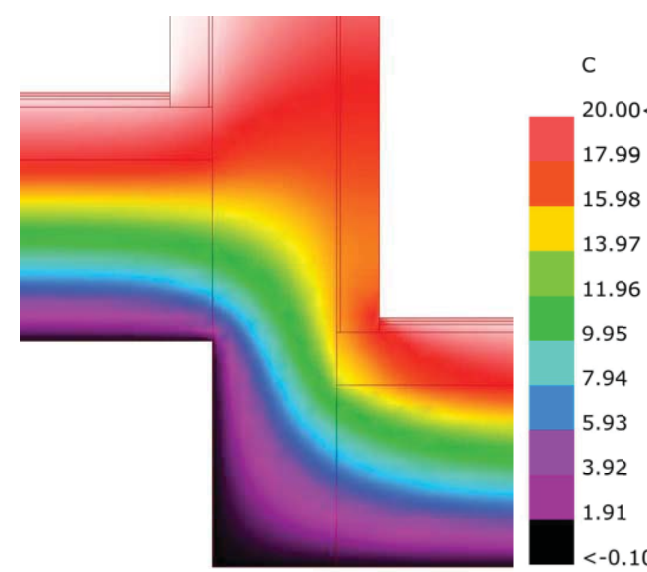
Image: passivehouse project section

DETAIL 01-01:

WALL EXTERNAL CORNER

PROJECT: **SOO VALLEY DUPLEX**
BUILT: **N**
VERIFIED: **N**





Temperature
THERM Simulation

THERMAL PROPERTIES

ψ value: **0.024**

TECHNICAL DESCRIPTION

Typical transition detail between floor levels. Will likely result in positive ψ value. This could also be modeled as two seperate details.

The biggest impact to realizing low thermal transmittance is the quality of the details and design teams aggressively minimizing thermal bridging.

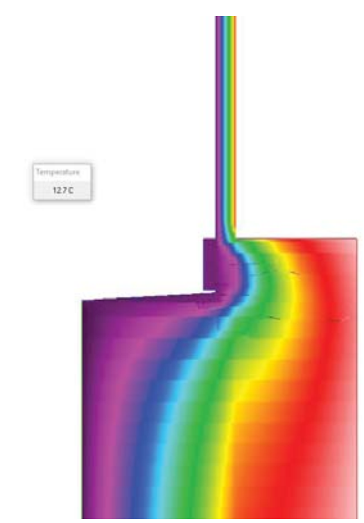
Guide to Low Thermal Energy Demand for Large Buildings p 83

https://www.bchousing.org/research-centre/library/residential-design-construction/guide-low-energy-demand-large-buildings

4.0 THERMAL BRIDGING CALCULATION PROCESS /

This section describes the process undertaken as part of the Innovation Incubator to determine the PSI (Ψ) values listed in **Section 3**.

This builds on a previous Innovation Incubator by the author (Spring 2016: Comparing and Adapting Pitt River School to the Passive House Standard, Cillian Collins) where a number of details of a build project were analyzed using Therm software to determine the thermal bridging effect. This was a time intensive process. Since then a process has established within the Vancouver office[1] of analyzing simple linear thermal bridges. This leverages the power of Grasshopper to build the thermal bridge file within a free software (Therm, developed by Lawerence Berkely Library). This process already has efficiencies and is quicker than building the detail from scratch within the Therm software. This process was disconnected, requiring the use of Autocad, Rhino, Grasshopper and finally Excel to get the required Psi value. This Innovation Incubator sought to improve the process,particularly in integrating Revit into the process.



1 Developed and tested by Cheney Chen [Cheney.chen@perkinswill.com] and Cillian Collins[cillian.collins@perkinswill.com]

4.1 Documentation process:

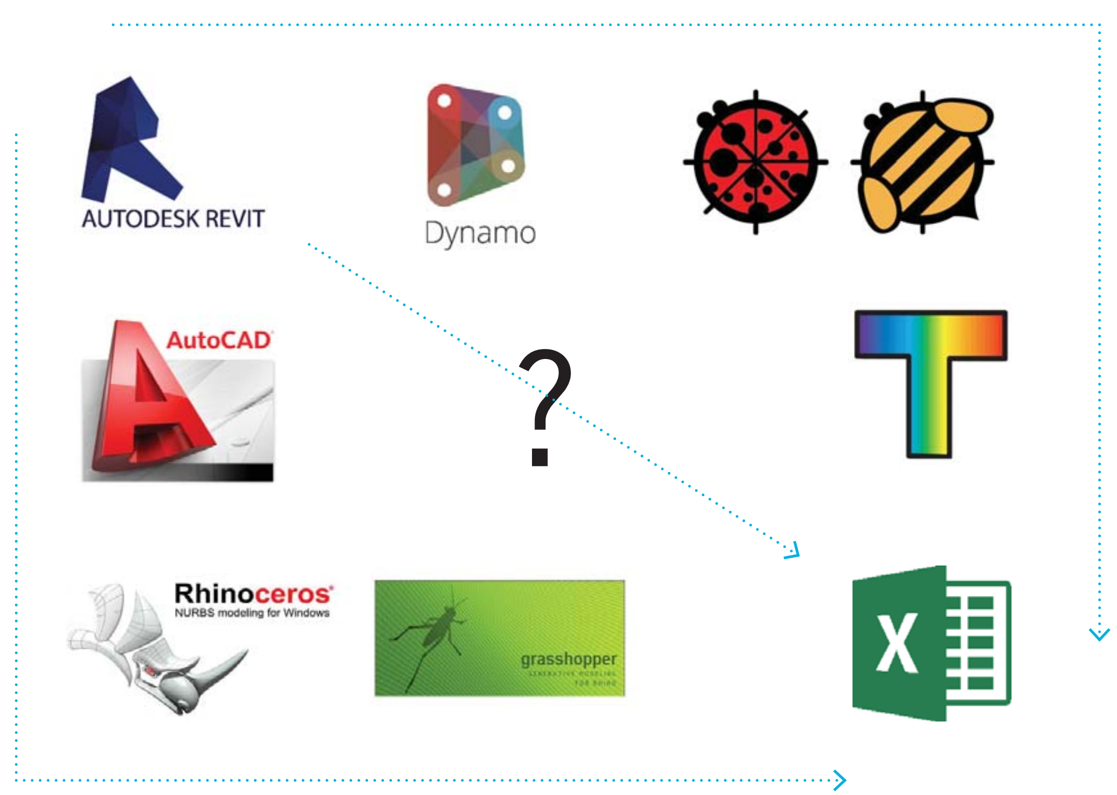
One of the objectives of this innovation incubator project is to establish a robust, simplified, and user-friendly workflow to perform the thermal bridge modeling in house especially for details that are relatively simple. This required us not only to carefully examine the exsiting workflow which was developed in the office at the beginning of the report, but also to look after a better approach.

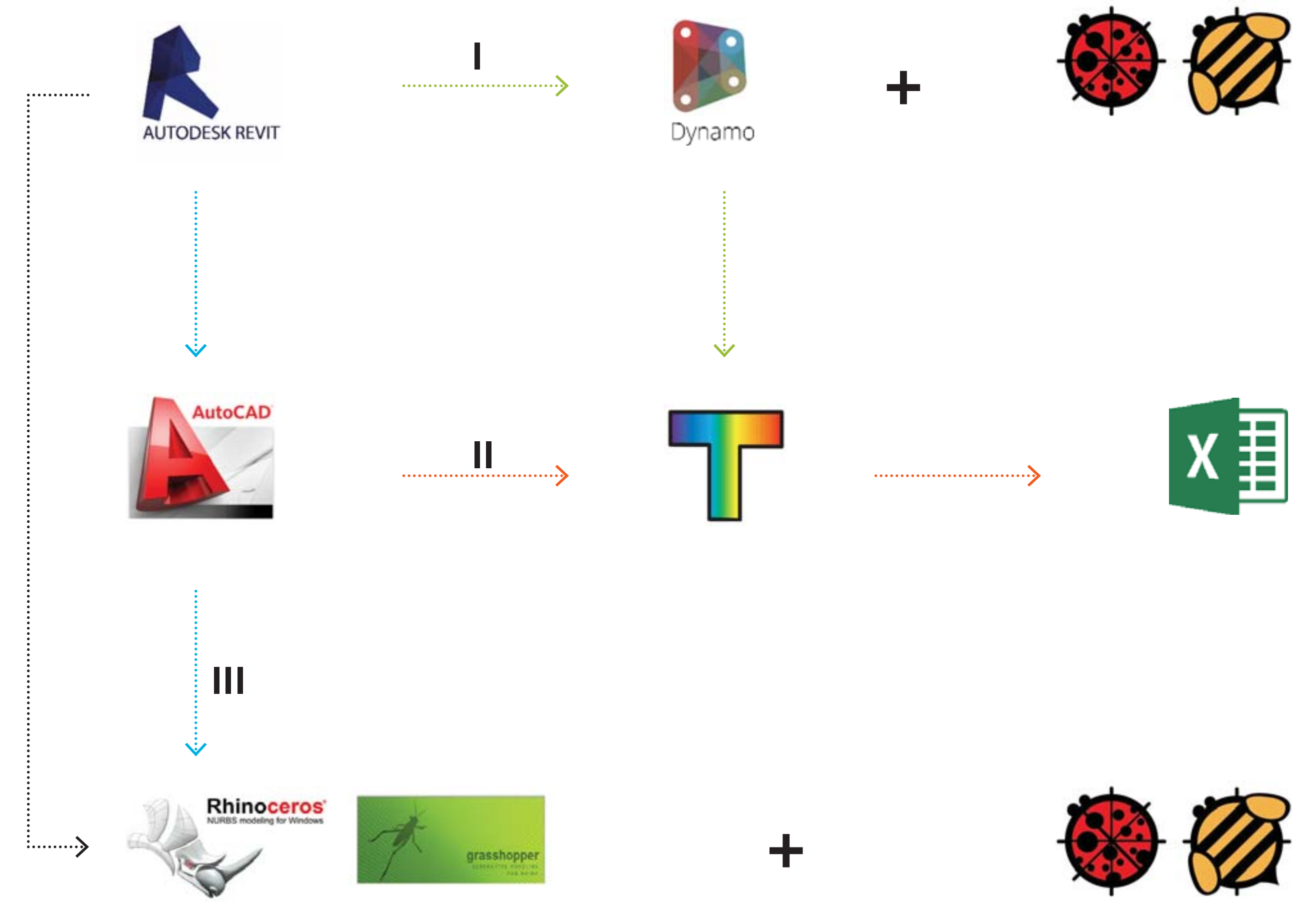
We started with a simple question of how a building detail drawn in Revit can be imported as directly as possible into the THERM which is a free software developed by Berkeley Lab for thermal bridge analysis. The idea was to eliminate all the unneccessary steps or automate the process whenever possible. As a result, our findings suggested that there are three different approaches, with each having its own advantages and disadvantages.

I. Examination of Revit/Dynamo

II. DXF Overlay

III. Rhino/Grasshopper





DOCUMENTATION APPROACH I

- While this approach looks quite simple and most of the thermal bridge modeling preparation work could be done within a Revit platform, it has its own limitations mostly due to lack of direct link between Dynamo and Therm and requires further research and investigation.

DOCUMENTATION APPROACH II

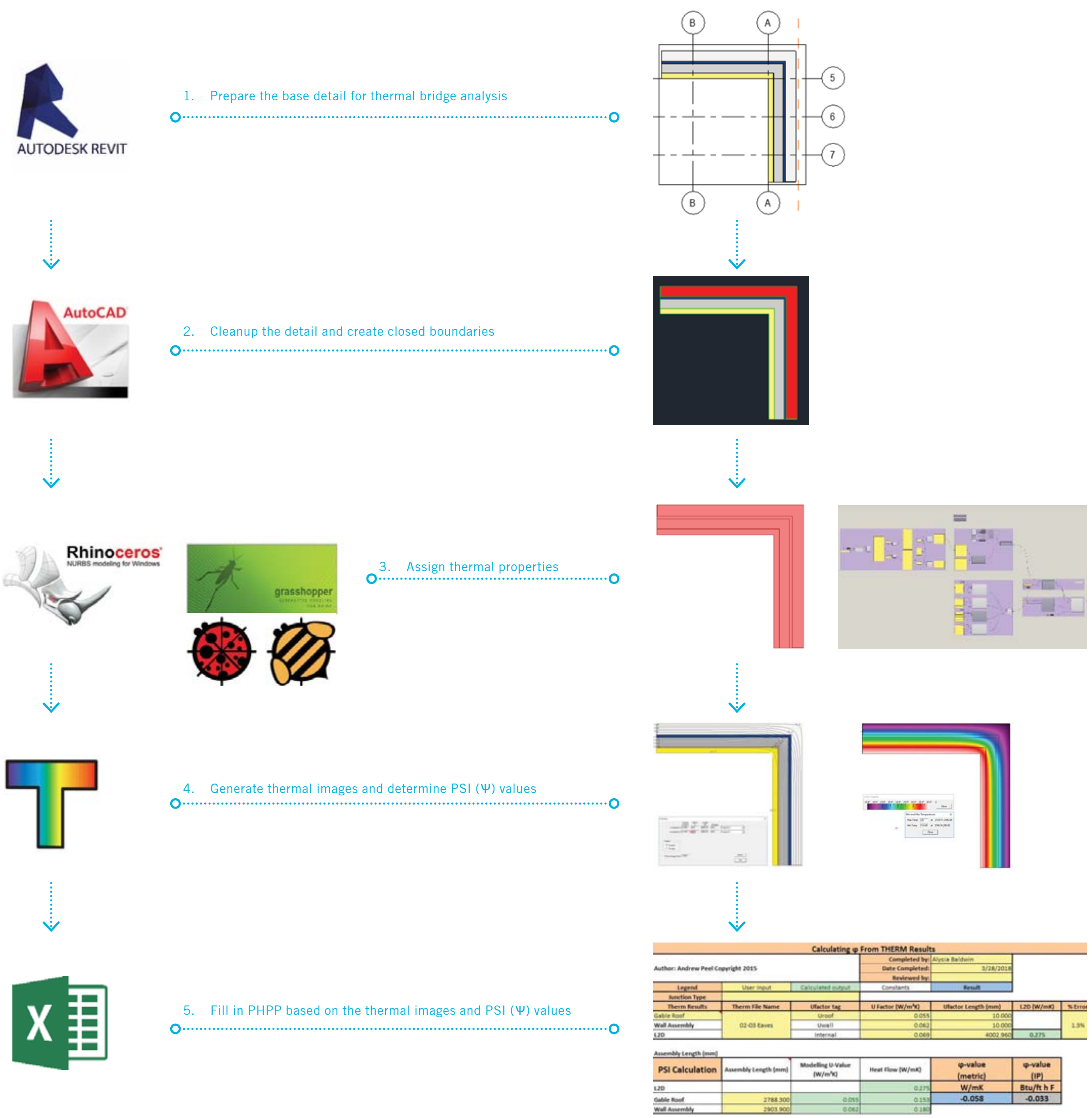
- This is a method developed by Berkeley Lab in late 1990s. As an old school approach, it relies heavily on THERM platform which can be time consuming and complicated when analysing complex details like curtain wall detailings.

DOCUMENTATION APPROACH III

- This approach has been tested and used to conduct the thermal bridging analysis for all the details presented in this report. While this workflow requires different platforms, it helps automate some of the manual procedures, such as reading data from excel, applying thermal material properties, and generating thermal images with high resolution etc. Once the workflow settings are properly established at the beginning of the process, this approach delivers a result in an expected manner. Hence, we would strongly recommend using this method when analyzing details.

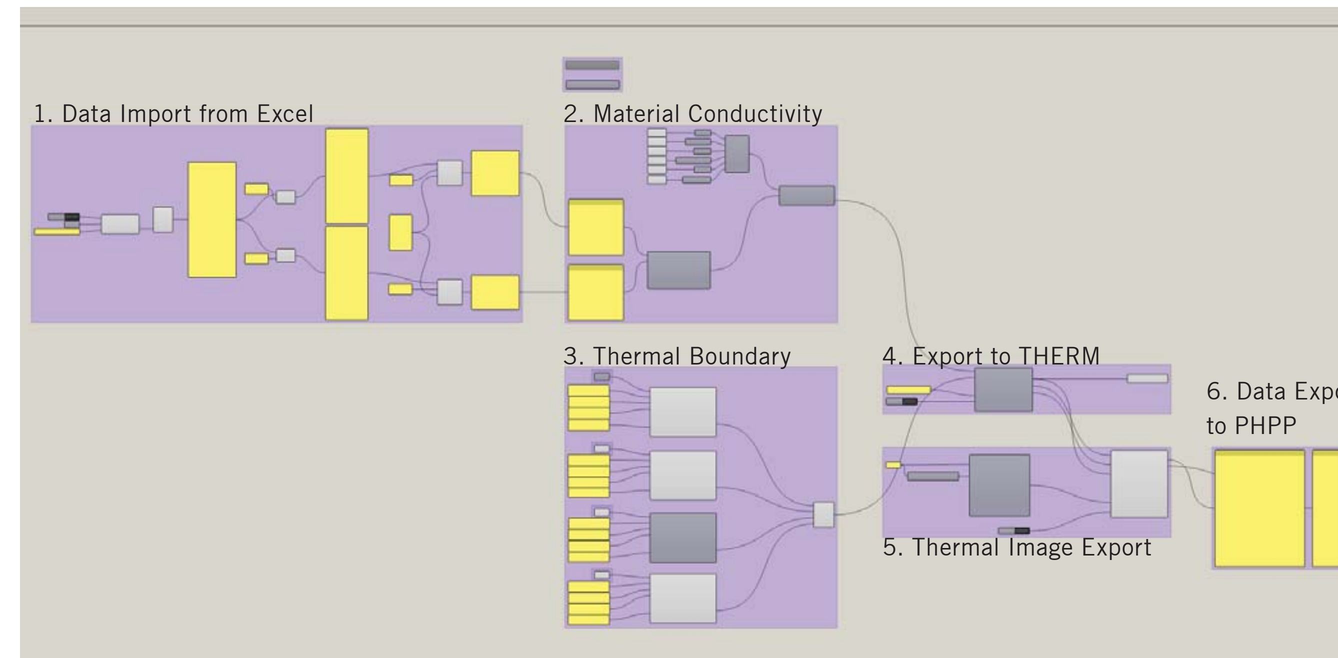
4.2 Documentation Approach III Example:

As a demonstration, the graphs below show general workflow of how one of the typical revit plan details from the Passive House project could be analyzed and calculated to generate heat flow diagrams and determine PSI (Ψ) values required for PHPP.

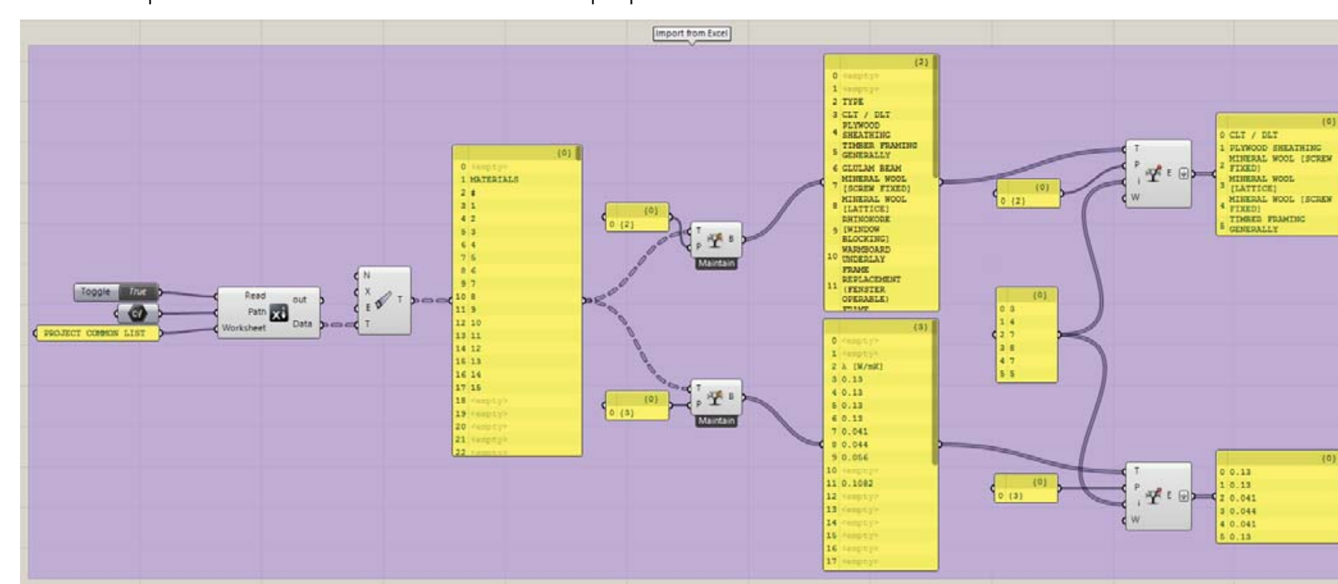


4.3 Rhino/Grasshopper Script:

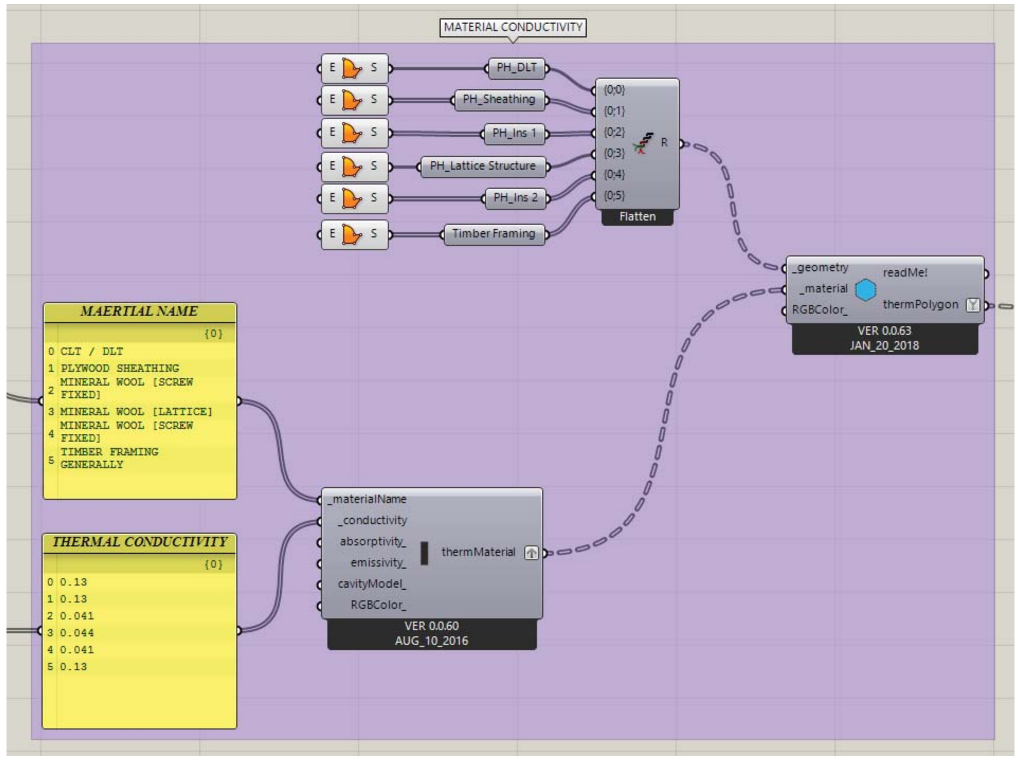
Based on the existing Rhino/Grasshopper script, the new version has been developed to simplify and partially automate the thermal bridge modeling process. It consists of five parts - data import, material conductivity, thermal boundary, THERM export, and thermal image export. Data export to PHPP is still under investigation as it is detail-based and requires constant manual adjustments in the script.

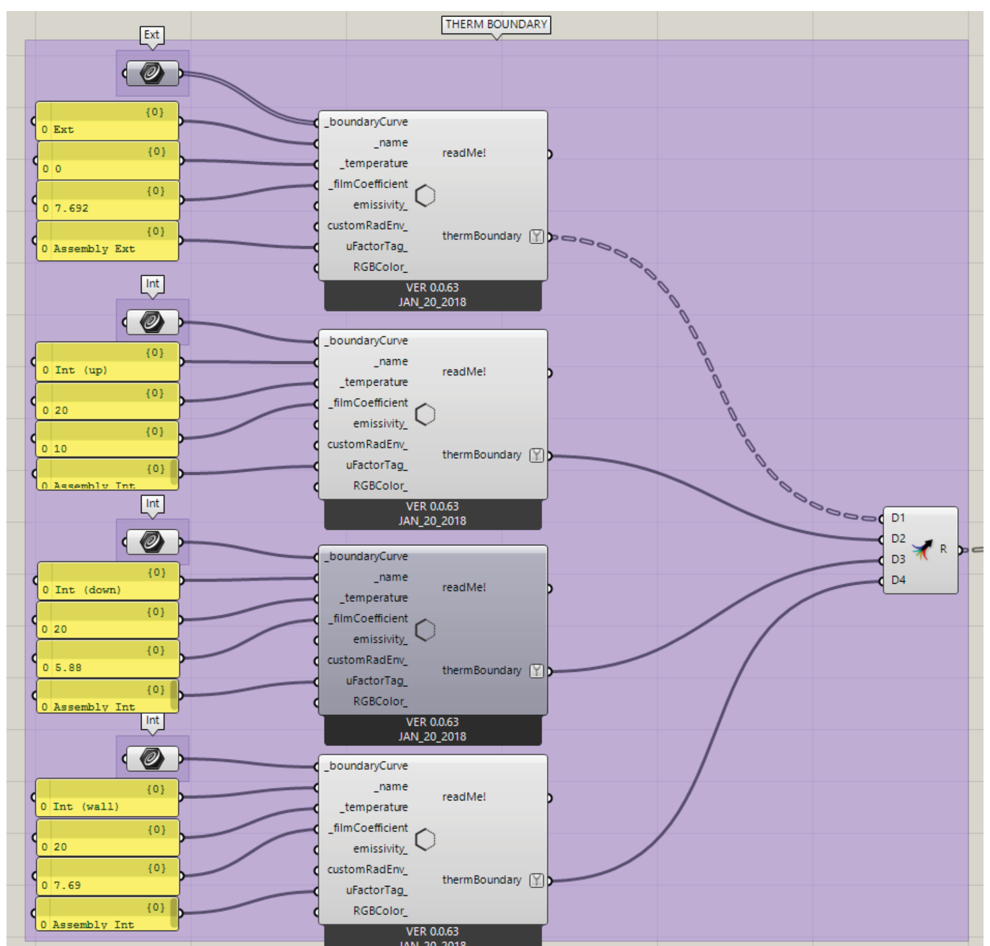


1. Data Import from PHPP for thermal material properties

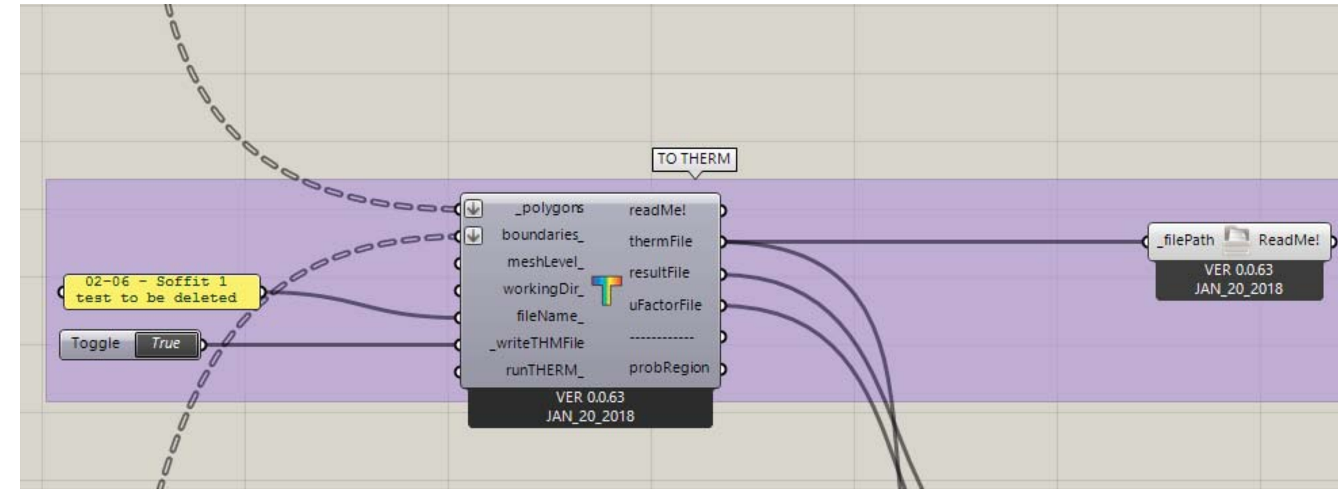


2. This section generates closed surface and assigns thermal conductivity to respective materials.



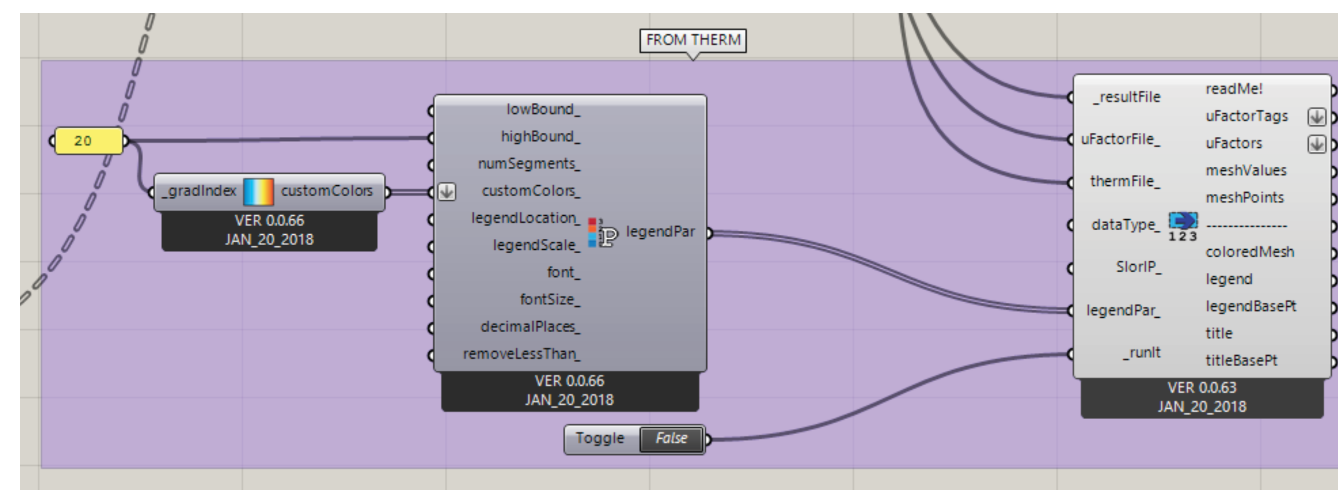


3. This is where THERM boundary conditions are assigned. There are four different parts based on interior and exterior pressure directions, and it should be selected according to a specific detail prepared for thermal bridging analysis.



4. Geometry export to THERM to perform thermal bridge analysis.

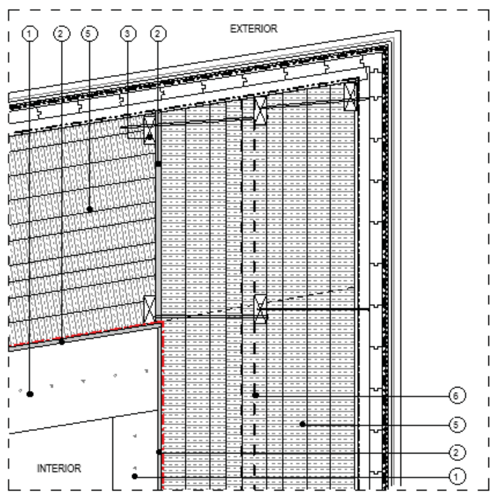
5. Instead of screen capturing the thermal image, this component extracts data from THERM and generates printable high resolution images in Rhino.



4.4 Lessons Learnt:

- Creating a closed and non-overlapping polysurface is a critical step towards successfully bringing geometries into THERM. If this step is not done properly, it would complicate the process and create a situation where troubleshooting can be time-consuming and exhausting.
- Keeping the list management organized is equally important when it comes to dealing with a complex detail. There is a definition in Rhino/Grasshopper added to organize the lists in the way we want and correctly assigns thermal material properties.

TB 02-02: RIDGE
ψ value: 0.0XX W/mK



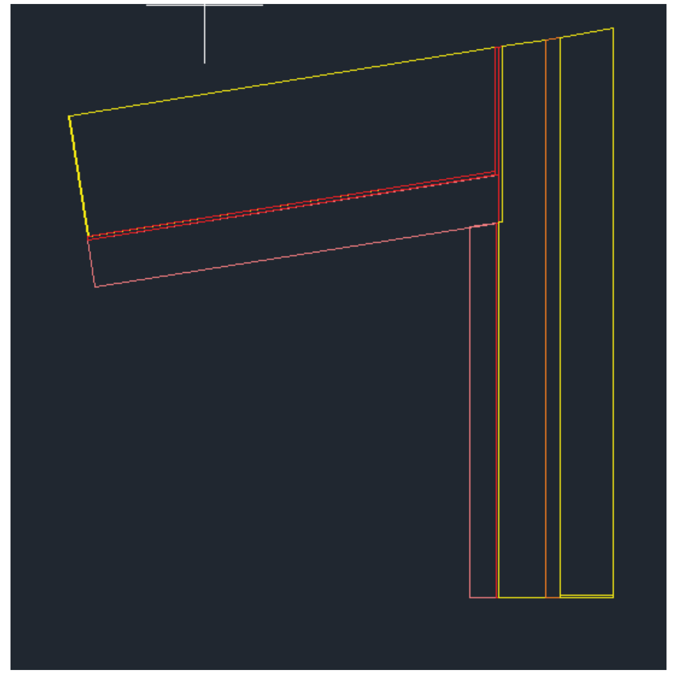


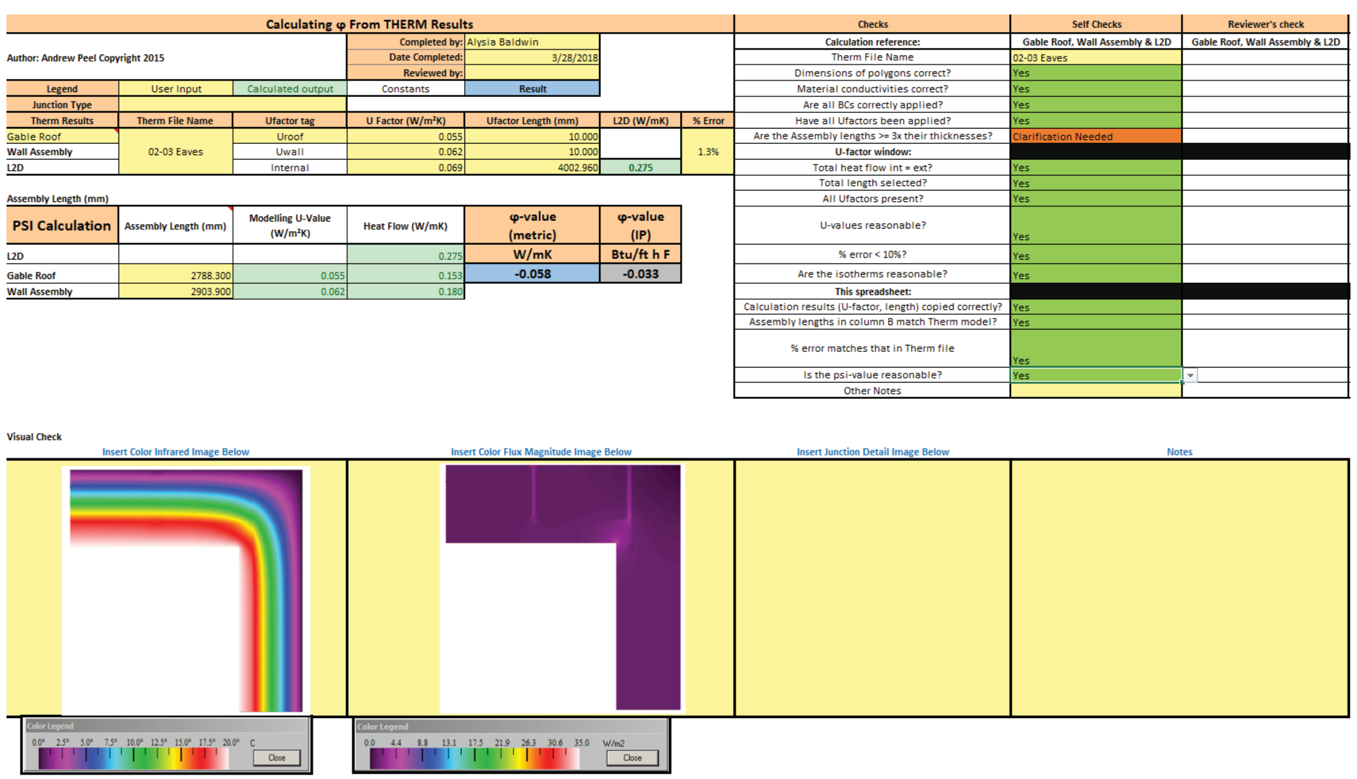
Image: Detail transfered from Revit to CAD and Rhino

4.5 Revit to Rhino:

While Rhino can easily read CAD exports from Revit there is still a process to clean and prepare the file and make it suitable for thermal bridge calculation. The detail should encapsulate a certain distance (minimum 2m) beyond the intersection itself meaning the detail may need to be abstracted or modified from its actual state in Revit.

4.6 Therm to PHPP

Once the Therm file is generated there is still a supplementary process to generate the PSI vlaue (other programs such as Flixo calculate this automatically). This is calculated value which can be completed using an excel calculator by transfering U-Factor values from Therm into the appropriate section. The PSI value is then given which can be inputed into the energy model.



Calculating φ From THERM Results

Author: Andrew Peel Copyright 2015

Completed by:	Alysia Baldwin
Date Completed:	3/28/2018
Reviewed by:	

Legend	User Input	Calculated output	Constants	Result		
Junction Type						
Therm Results	Therm File Name	Ufactor tag	U Factor (W/m²K)	Ufactor Length (mm)	L2D (W/mK)	% Error
Gable Roof	02-03 Eaves	Uroof	0.055	10.000		1.3%
Wall Assembly		Uwall	0.062	10.000		
L2D		Internal	0.069	4002.960	0.275	

Assembly Length (mm)

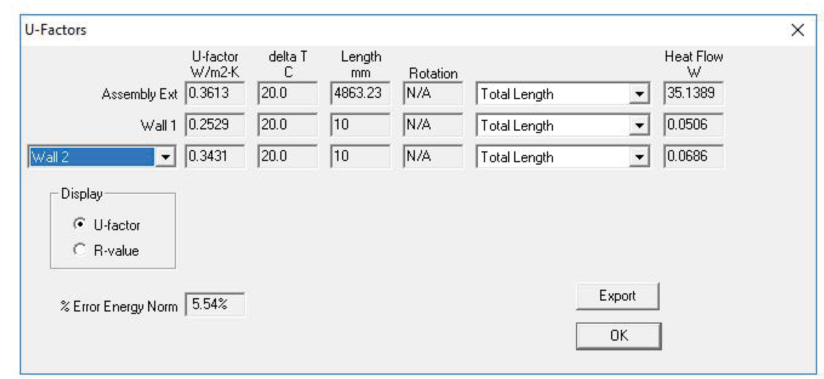
PSI Calculation	Assembly Length (mm)	Modelling U-Value (W/m²K)	Heat Flow (W/mK)	φ-value (metric)	φ-value (IP)
L2D			0.275	W/mK	Btu/ft h F
Gable Roof	2788.300	0.055	0.153	-0.058	-0.033
Wall Assembly	2903.900	0.062	0.180		

Checks	Self Checks	Reviewer's check
Calculation reference:	Gable Roof, Wall Assembly & L2D	Gable Roof, Wall Assembly & L2D
Therm File Name	02-03 Eaves	
Dimensions of polygons correct?	Yes	
Material conductivities correct?	Yes	
Are all BCs correctly applied?	Yes	
Have all Ufactors been applied?	Yes	
Are the Assembly lengths >= 3x their thicknesses?	Clarification Needed	
U-factor window:		
Total heat flow int = ext?	Yes	
Total length selected?	Yes	
All Ufactors present?	Yes	
U-values reasonable?	Yes	
% error < 10%?	Yes	
Are the isotherms reasonable?	Yes	
This spreadsheet:		
Calculation results (U-factor, length) copied correctly?	Yes	
Assembly lengths in column B match Therm model?	Yes	
% error matches that in Therm file	Yes	
Is the psi-value reasonable?	Yes	
Other Notes		

Visual Check

Insert Color Infrared Image Below	Insert Color Flux Magnitude Image Below	Insert Junction Detail Image Below	Notes

Image: PSI value calculator, authored by Andrew Peel, Peel Passive House Consulting, Passive House Certifier



U-Factors

	U-factor W/m2-K	delta T C	Length mm	Rotation		Heat Flow W
Assembly Ext	0.3613	20.0	4863.23	N/A	Total Length	35.1389
Wall 1	0.2529	20.0	10	N/A	Total Length	0.0506
Wall 2	0.3431	20.0	10	N/A	Total Length	0.0686

Display: U-factor / R-value

% Error Energy Norm: 5.54%

Export | OK

Image: Thermal data generated in THERM

5.0 CONCLUSION / participants' thoughts / further research

Designing to higher performance standards such as the Passive House standard and more rigorous modelling methodologies such as that demanded by PHPP that takes into account all thermal bridging does raise some design challenges for architects and pose some questions that can otherwise be ignored e.g. how to design a beautiful eaves/overhang/parapet detail or introduce a level access balcony threshold which maintain continuity of insulation and are thermal bridge free? The disconnect between the design and performance is what leads to the performance gap. For meaningful contribution to reduction of buildings' ecological footprint the two need to be considered in concert. It should not be a choice between a building that is excellent in design/aesthetic or one that is excellent in performance. Equipping the architect with the understanding of the processes and tools involved is an important first step.

5.1 Impact on design process:

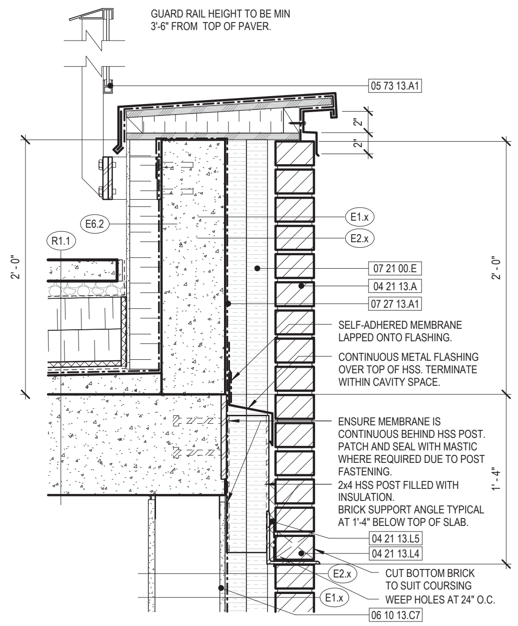
Thermal bridging analysis is normally completed at the later stage of the design process when the details are completed. There should be consideration given at early design stage of potential thermal bridging due to massing, assemblies choice and articulation as to its impact. Proceeding to Design Development Work stage the aim is careful design and detailing – eliminating if possible, if not minimize and mitigating elsewhere. Unavoidable thermal bridges need to be calculated and included in the energy model.

If seeking certification or a high performance target then tender documentation should include provision for thermal bridging in detail drawing and specification. Thermal conductivities of insulation materials should be provided. Careful monitoring is required on site with contractor education and workshops on methodology, constructability and sequencing.

5.2 Lessons learned - software

Design is an iterative process, when aiming for a performance based metric it is important to have a seamless feedback loop that validates design decisions. The primary detailing and documentation software of the design process is Revit. The validation software in the case of Passive House certification is an excel based energy model (PHPP). In order to do the appropriate thermal modeling a third software is required, in this case THERM, a free software from Lawrence Berkeley Labs. This innovation Incubator investigated a process that linked these three platforms together.

While THERM performs the requisite calculations it is outdated and not very user friendly, either when using it as a standalone software or trying to import outside files. In order to just use it as a calculation tool and have the drawing portion done in a more controlled environment this Innovation Incubator leveraged (and sought to optimize)a process involving Rhino and Grasshopper that took a CAD export from Revit (requiring cleanup) and assigned thermal properties. This results in multiple platforms to achieve the desired result. This troubleshooting is tedious and time-consuming and also requires an understanding of the grasshopper script, THERM's idiosyncrasies' and how PSI values are calculated. A more user friendly program (e.g. Flixo) might be beneficial if multiple details are being looked at. In order to simplify and streamline, it may require additional research and funding for commercial software tools.



13 PARAPET AT ROOF TERRACE - MASONRY (BRICK OR STONE)
1 1/2" = 1'-0"

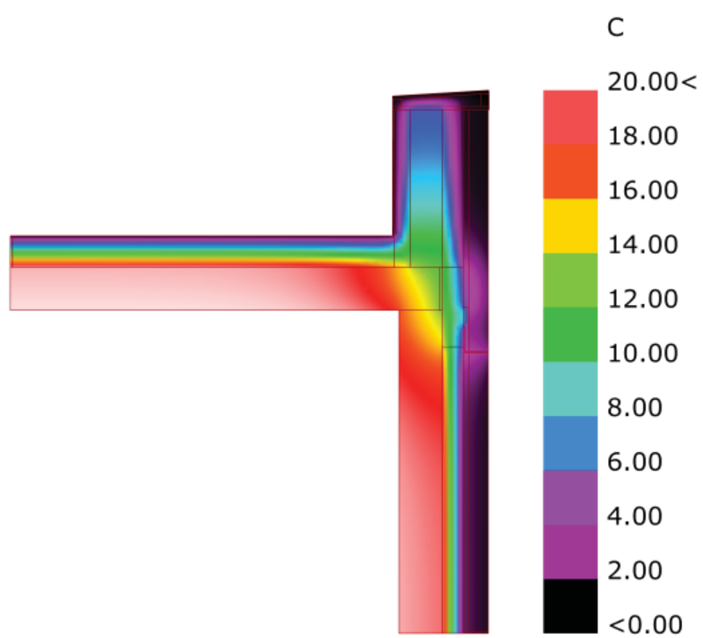


Image: Typical parapet detail

5.3 Lessons Learned- understanding Thermal bridging

Typically definitive thermal bridge analysis is done using a special software e.g. Therm, Flixo, Heat 3d etc. This is generally a specialist service offered by a building envelope engineer or mechanical engineer if required. Simple linear thermal bridges (see Types of Thermal Bridging) can be done for a fee of approximately $200 - $500 per detail once the detail is established and the thermal conductivities for all components are known. More complex details such as 3d thermal bridges or details involving windows may take longer and be more expensive. The aim of the Innovation Incubator was to investigate a in-house methodology for quickly analyzing our simpler details not only saves on these costs but also brings the benefits as outlined in the Summary section.

The calculation itself may still remain as a specialist endeavour (e.g. by the building envelope consultant) but early design decisions and assumptions can influence the result. Improving the architects understanding of how thermal bridging works and what related technical terminologies, such as boundary conditions, thermal conductivities, and Psi values etc. mean in the context of modeling and detailing to facilitate integrating performance requirements into the design process.

In the course of this Innovation Incubator the goal was to expose two additional Perkins+Will staff who were working on a Passive House Project to the processes involved. Both staff members were highly skilled in Revit and Grasshopper and were able to identify additional workflow improvements. One undergone Passive House training and certification so had some background knowledge on thermal bridging, the other had not. This was quite a hands on process so more time could have been spent learning the theory behind the process, how the analysis is performed and what makes a good versus a bad detail. This report seeks to give some of the is background guidance but further in-house training from a specialist would be required.

5.4 Further Research & Next Steps

With the trend towards performance based standards and the inclusion of thermal bridging in EUI calculations the calculation of thermal bridging is growing in importance. Use of standardized details and reference manuals is one avenue for optimization - this suggests that Perkins+Will SEED file Revit typical details should be assessed. This may be the scope of a future Innovation Incubator.

There is also scope for research into the overlap and communication between the design software (Revit in this case) and energy modeling software (PHPP in the case of Passive House certification) in order to ensure an iterative process is possible and that design changes can be quickly validated in order to further close the performance gap.

	Performance Metric	Comment
Space Heating & Cooling Demand	15 kWh/m2 (4.8 kBtu/ft2)	A limit to the annual energy consumption per area for heating and cooling the building. For comparison, ASHRAE 90.1-2010 has space heating demand requirement of 85.4 kWh/m2 (27 kBtu/ft2 a) for Education Buildings in Vancouver The cooling demand limit has an additional, climate-dependent allowance for dehumidification..
Max Heat/ Cooling Load	10 W/m2	Alternative means of compliance to the Thermal Demand figure. This is a limit on the peak power output of system on the coldest day of the year. Compliance can allow the small heat load to be supplied via the fresh air ventilation system – reducing heating distribution system required.
Primary Energy Demand [Site Energy]	120 kWh/m² (38.1 kBtu/ft2) [30-60 kWh/m²] (9.5 - 19 kBtu/ft2)	A conversion/generation factor is applied to the total site energy (including heating, HW, plug loads etc.) to give an overall primary energy demand limit. This limit was set at 120 kWh/m² (38.1 kBtu/ft2). These limits are being recalibrated with 3 new stepped certification targets to allow for a renewable energy generation – making it easier to achieve in BC where 97 percent of energy comes from renewable sources. The reality is that this limits the EUI of the building to 30-60 kWh/m² (9.5-19 kBtu/ft2), depending on fuel source. e.g. Architecture 2030 Challenge Targets for K12 buildings10. 2015 ~ 73 kWh/m² (23.1 kBtu/ft2) 2020 ~ 37 kWh/m²a (11.7 kBtu/ft2
Airtightness	0.6 ACH@50Pa	The City of Vancouver residential code calls for 3.5 ACH@50Pa. The Zero Emissions Plan (active as of May 2017) requires 2.0 L/s*m² @75 Pa if not complying through achieving Passive House. The average airtightness for large buildings in Canada is approximately 2.15 L/s*m² @75 Pa11. Note that there are two differing metrics for airtightness testing: -Relative to volume of air in the building - dividing the airflow by the volumeof the building. This gives a result as air changes per hour (ACH or h-1), andresults are usually reported at 50Pascals. -Relative to the area of the building envelope - dividing the airflow (V75) by thearea of the building enclosure. This gives a result of flow per unit area (L/s·m2 orcfm/ft2). Results are reported at 75Pascals (0.3 inch water column (wc)). The test result is reported is in L/s·m2@75Pa or cfm/ft2@0.3 in wc. For larger buildings (over 1500 m2 / 16145 ft2), both values must be reported for facilities seeking certification. The airtightness metric is verified with an onsite pressure test in both pressurized and depressurized states for Passive House certification.

APPENDIX A - THE PASSIVE HOUSE STANDARD

The Passive House Standard internationally recognized, performance-based energy standard in construction. The primary aim is to achieve exceptional energy efficiency while maintaining superior inhabitant comfort. A building can be certified as a Passive House building if it meets a series of technical requirements as outlined below[1].

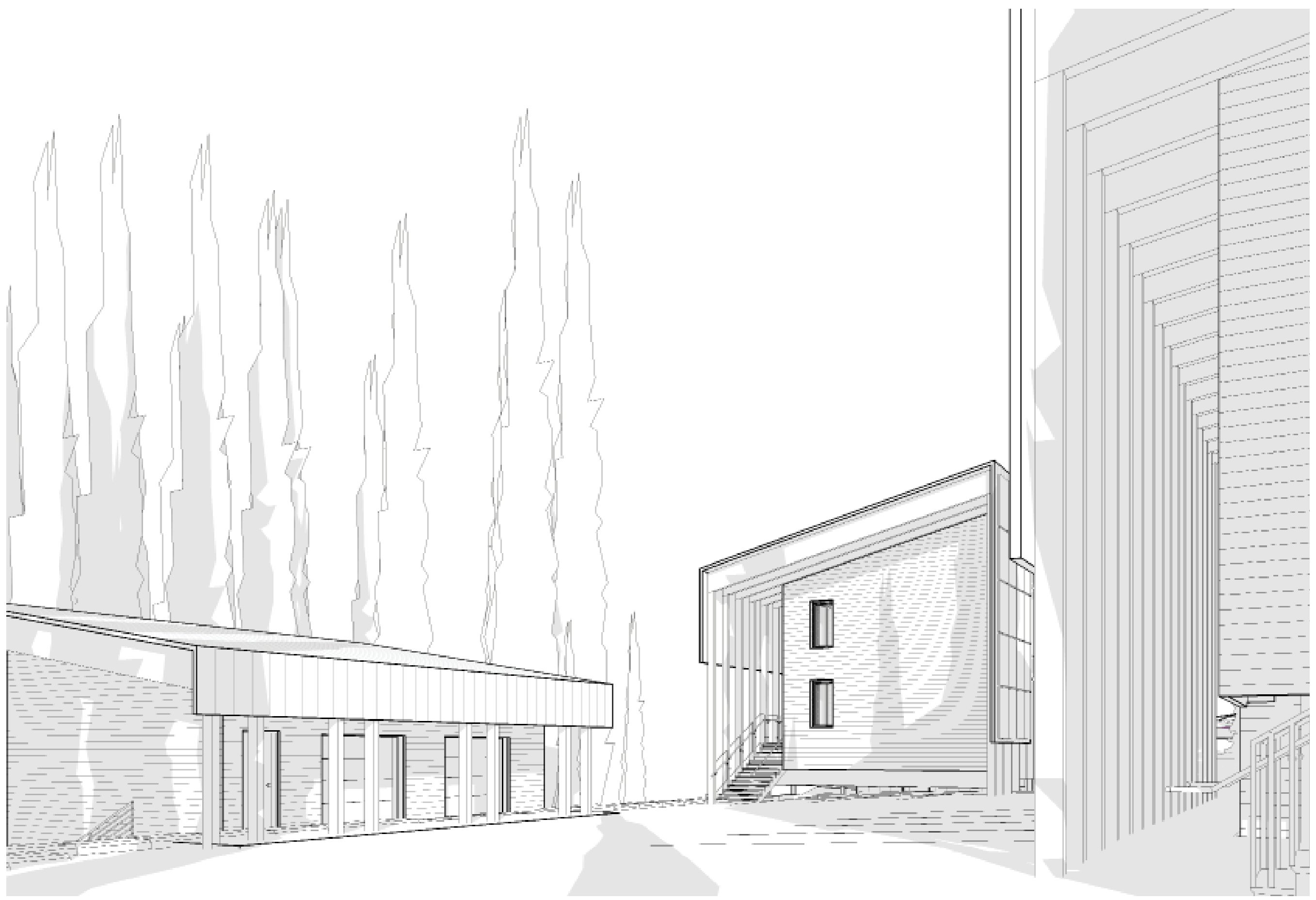
It is performance based as opposed to prescriptive; design teams can develop their own design strategies as long as the requirements are met and validated. The focus is on 'passive' measures that are inherent in the design of the building to achieve these performance levels as opposed to conventional 'active' systems that require energy use. The result is a building that uses over 75% less energy for heating and cooling, and over 50% less overall energy than a typical building in North America.

There are five performance metrics that need to be met for a project to be certified according to the Passive House Standard, as defined by the Passive House Institute, which are outlined in Table 1. It demands a rigorous methodology with increased focus on the building envelope.

The core principles are:
1. Reducing demand:
   - Reducing heat loss or gain though super-insulation, reducing air Infiltration and thermal bridges
   - Limiting the overall energy use through a primary (source) energy limit
2. Maximizing gains
   - Capitalizing on solar heat gain and
   - Accurately measuring and optimizing internal gains
3. Ensuring occupant comfort
   - Controlling gains and overheating in the summer
   - Providing fresh air and using a heat/energy recovery ventilator to recover waste heat.
   - Ensuring all thermal comfort criteria are met

The Passive House standard has been applied globally to a wide variety of building types and scales including multi-family residential, schools and offices.

1 Canadian projects typically follow the International Passive House Standard as administered by the Passivehaus Institute (PHI). There also exists a US based set of performance requirements as set out by PHIUS (Passive House Institute US).



Thermal Bridge Free Design

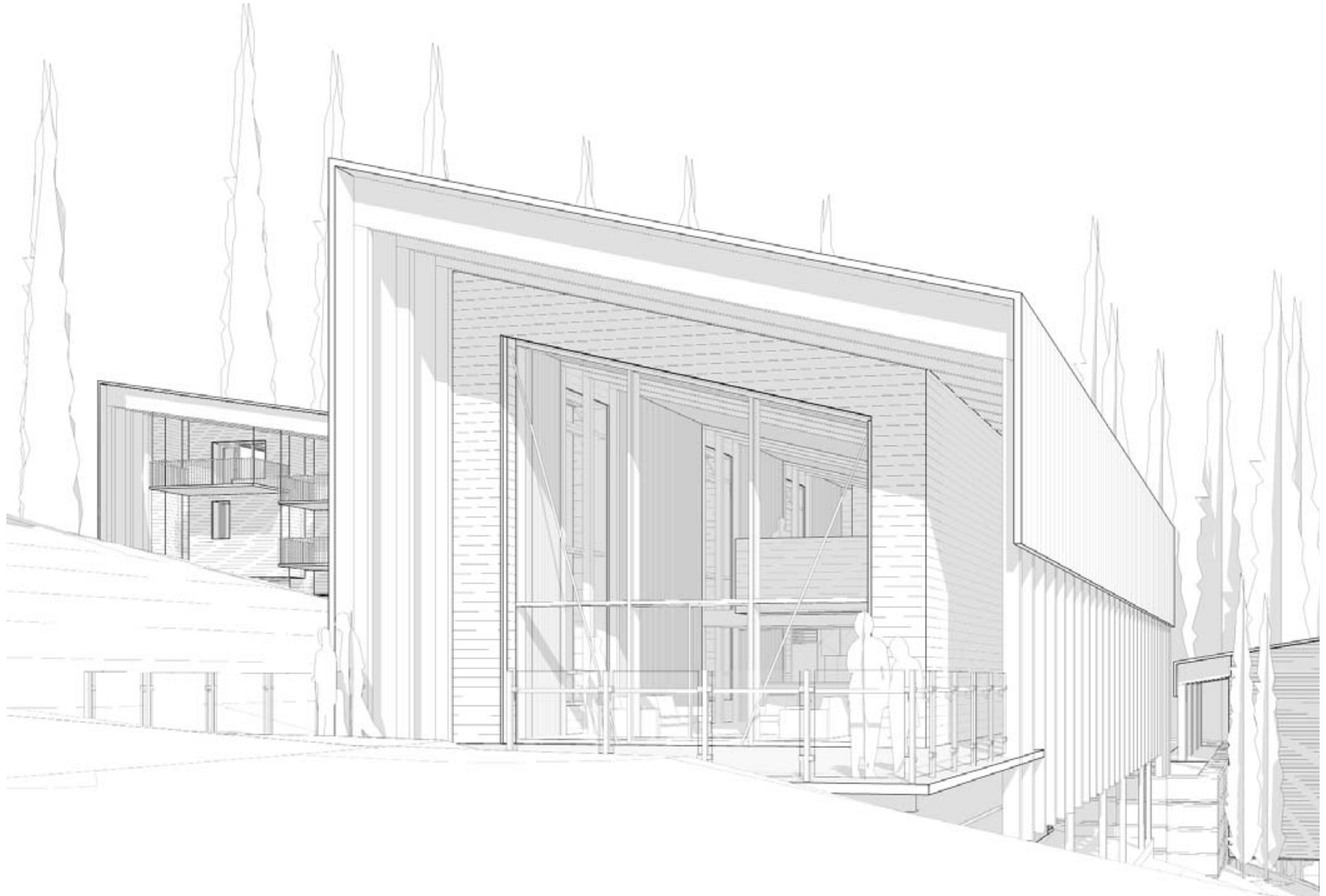
This is defined as the sum of all linear and point thermal bridges being less than zero ($\sum(\Psi) + \sum(\chi) = 0$). Repeating thermal bridges are accounted for in the effective U-Values. To avoid having to calculate every detail a simplified criterion has been defined, $\Psi < 0.01$W/mK for all linear thermal bridges. (This also presumes all point thermal bridges have been designed out). The designer can ignore any thermal bridges that meet this criteria and only input those that exceed it, or if they wish to input negative Ψ values must then calculate and input all thermal bridge values, positive and negative.

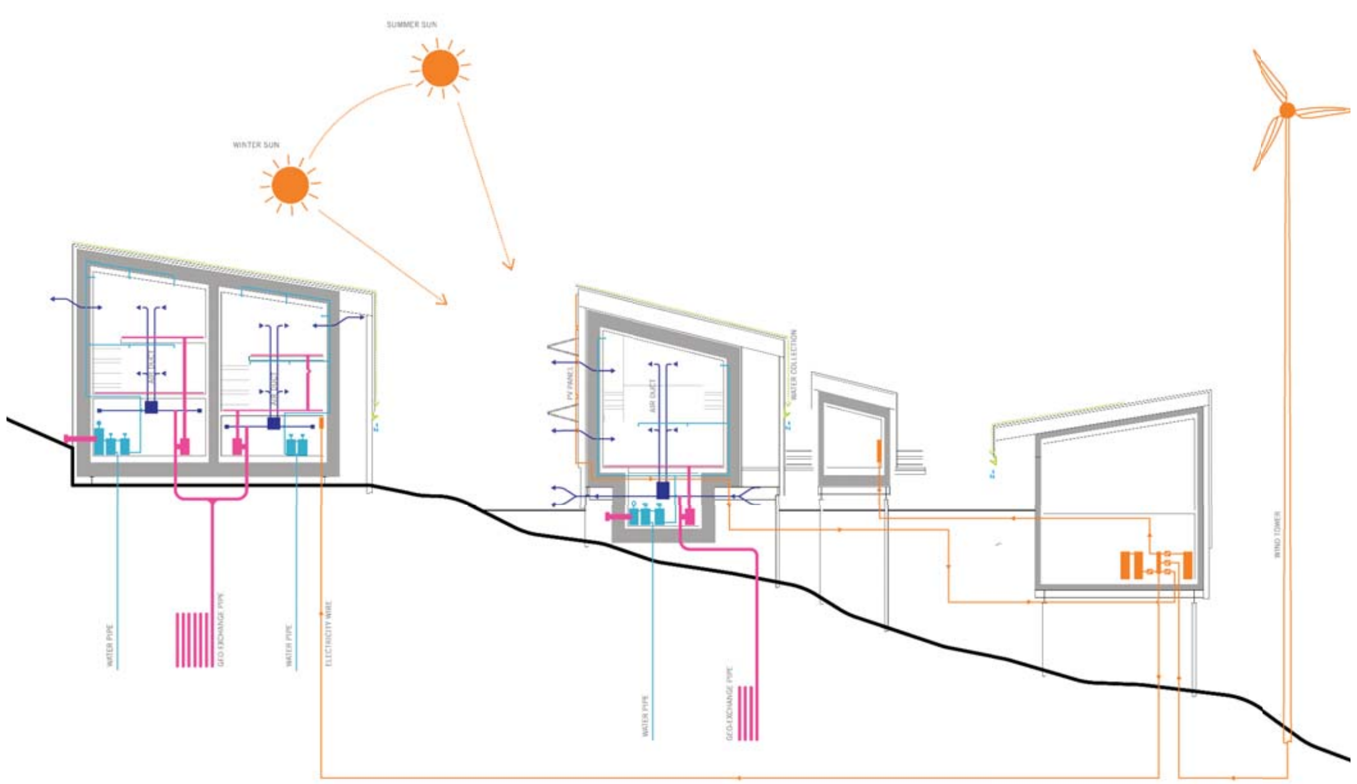
PHPP Modelling and Certification Documentation

Passive House projects use an excel based energy modelling software Passive House Planning Package (PHPP) as both a design tool and submission for third party verification under the certification process. In addition there is a comprehensive submission of supporting documentation required to back-up the inputs into the PHPP energy model, including but not limited to: as built drawings, spec sheets, material data sheets and proof of installation, comprehensive site photographs, thermal bridge calculations, airtightness test result, commissioning report.

Thermal bridging is a subset of building envelope heat loss (grouped under transmission losses). As well as inputting the Ψ values in the PHPP energy model the certification submission includes the calculation files and product data (insulation specification sheets etc).

APPENDIX B - PROJECT CASE STUDY /





Perkins+Will Vancouver are engaged to design prototype homes on a confidential site located north of Whistler, British Columbia. The site, rich in natural beauty and stimulating topography, does not have any infrastructure apart from a gravel Forest Service Road that cuts across the property and a river passes nearby. This particular situation demands prototype homes to be 'off the grid', requiring facilities to make electricity, provide potable water, and manage human waste.

The project consists of three buildings, one of which is being designed to achieve the Passive House standard, the second is being designed to meet the PHI Low Energy Standard (the third is an ancillary building).

There are a number of factors that make achieving both standards more difficult than normal. To begin with the climate is demanding, Climate Zone 5 with cold winters being as low as -29°C and hot summers being as much as +35°C. The mountain range to the south limits the amount of solar radiation available throughout the year. The design decision to raise the buildings out of the ground is due to several ecologically inspired reasons, among them eliminating the need for concrete on-site, touching the ground lightly and allowing the buildings be removed in future if necessary and making prefabrication easier. As a result however another heat loss surface is exposed to outdoor air (the soffit) and more consideration needs to be given to how thermal bridging is avoided when transferring loads to the ground.

Because of these constraints, the assemblies become very thick requiring over ~18" of mineral wool insulation. When these thick assemblies wrap around the building the external corners will likely result in negative Psi values (as explained in section 2.4). As discussed under the Passive House Certification (Appendix A) the design team can decide to include these values in the energy model but then must include all thermal bridges. It means more work in terms of modelling and calculation but all thermal bridges are minimized generally then these negative values are of benefit and can help towards achieving certification by calibrating the model and removing the overestimation of heat loss.