DEEP ENERGY RETROFIT THERMAL BRIDGING ANALYSIS GUIDE

PREPARED FOR SUSTAINABLE BUILDINGS CANADA
DECEMBER 6, 2021

IMAGE OF LONDON TOWERS FROM GOOGLE EARTH

RDH BUILDING SCIENCE

EXECUTIVE SUMMARY

Thermal bridging is important to consider for all buildings as it can have a significant impact on a building's thermal enclosure performance. It is an especially important part of energy modelling retrofit projects as modelling typically requires calibration to utility bills or measured end-uses. For buildings considering a deep energy retrofit such as those participating in Enbridge's Savings by Design (SBD) program, consideration of thermal bridging is required to determine the enclosure performance upgrades and their relative impact on energy use. Thermal bridging in existing buildings can be particularly difficult to evaluate due to incomplete or incomprehensible drawing records and concealed conditions on site.

This document, referred to as the ***Deep Energy Retrofit (DER) Thermal Bridging Guide,*** is intended to address the complexities of predicting and mitigating thermal bridges in early design stage energy modelling for **existing buildings**. This Guide is supplementary to SBC's – *Part 3 Buildings Energy Modelling Guide* and *Deep Energy Retrofit Energy Modelling Guide* and should be read in tandem.

Section 1 of this Guide provides an overview of thermal bridging and R-values as they relate to heat flow through buildings.

Section 2 of this Guide provides common thermal bridges and associated psi-values for existing buildings and potential retrofit cases that may be used in energy modelling for a DER analysis including for projects participating in the SBD program. The values presented were evaluated for existing high-rise multi-unit residential buildings of mass construction. This typology and construction type has been identified as the most common typology of future DER projects within the SBD program.

Section 3 of this guide provides steps to incorporating the thermal bridge values from Section 2 into an SBD project, following the *Building Envelope Thermal Bridging Guide (BETBG) Chapter 5 – Example Utilization of the Catalogue*.

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SECTION 1: THERMAL BRIDGING

Thermal bridges are defined as localized areas of increased heat flow through walls, roofs, and other insulated building enclosure components. They are caused by interruptions in the thermal insulation that allow heat flow to bypass the insulation thereby reducing the overall thermal performance and potentially leading to comfort and durability problems that are common in older buildings.

The thermal performance of the building enclosure is measured by its U-value, the rate of heat flow through an assembly – a lower U-value means less heat transfer and better thermal resistance. R-value is the inverse of U-value and is the more common industry reference term for thermal performance. There are various ways to define an R-value, which depend on the assembly components included in the calculation and the extent of thermal bridging. Generally, including more components introduces more thermal bridges, which lowers the performance of the assembly, i.e., more heat moves through the enclosure. The example below provides several common R-value definitions and demonstrates how various components can affect the thermal resistance of an assembly.

→ Nominal (installed) R-value: rated R-value of the insulation times the thickness of the material in the assembly

Example: 4" of exterior mineral wool insulation (R-4/in) ≈ R-16

→ Assembly (centre of cavity) R-value: Nominal R-value + thermal resistance of other layers in the assembly, considered only in one-dimension across the wall assembly

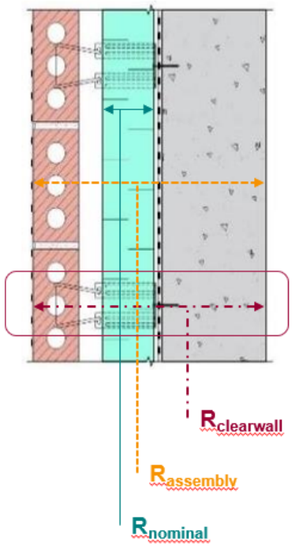
Example: exterior surface film + 4" brick cladding attached with brick ties + 1" air gap + 4" of exterior mineral wool insulation + water, air and vapour barrier + 8" concrete back-up wall + interior surface film ≈ R-19

→ Clear field R-value: Assembly R-value + 2D thermal bridging effects of repetitive structural elements

Example: same as above + fibreglass insulation clips spaced 2'x2' ≈ R-17

→ Whole wall R-value: Clear field R-value + thermal bridging effect due to junctions and penetrations throughout the enclosure assemblies, such as window perimeters, balcony slab edge, ventilation duct penetrations, etc.

Example: same as above + average window installation and parapet thermal bridges ≈ R-11



In energy modelling, it is typical that the *clear field R-values* are used (as is required by the Ontario Building Code, LEED, etc.), which includes the effects of uniformly distributed thermal bridging components like structural framing and cladding attachments.

Clear field R-values, although more accurate than nominal R-values, do not fully represent the building enclosure performance in energy models because they do not include thermal bridges that occur when walls, roofs, floors, and other structural elements intersect. These junctions can be classified as linear or point details where linear details occur along a length of the building and point details occur at a single element or point. Figure 1 and Figure 2 demonstrate the differences between linear and point details through thermal images.

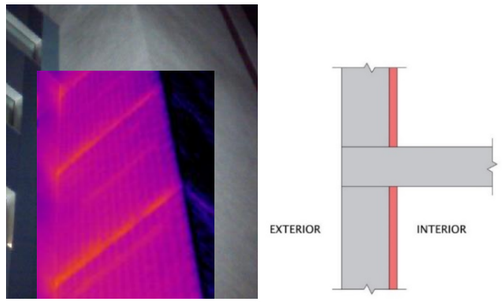


Figure 1: Thermal image of linear details. In this case, increased heat flow (i.e., a thermal bridge) occurs along the length of an intersection between an interior floor and the exterior wall. In this wall assembly, thermal insulation on the interior of the wall is interrupted where the floor structurally connects to the wall. The orange/yellow indicates areas of increased heat flow.

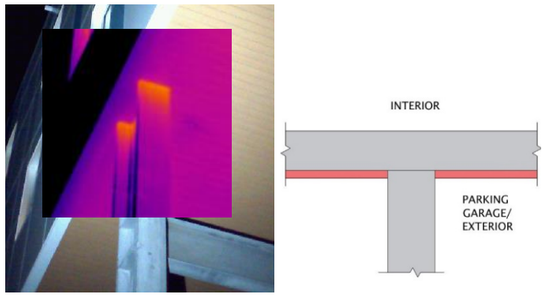


Figure 2: Thermal image of point details. In this case, increased heat flow (i.e., a thermal bridge) occurs at the point where the structural column passes through the exterior soffit. In this assembly, thermal insulation on the exterior of the soffit is interrupted where the column supports the building above. The orange/yellow indicates areas of increased heat flow.

Linear and point thermal bridges are typically measured in transmittance values. Linear transmittances are measured using a psi-value (ψ), which is the thermal transmittance per unit length of linear thermal bridge in Btu/hr.ft.°F or W/m.K.

→ Examples of linear interface details include intermediate floor junctions, balconies, and window to wall transitions.

Point transmittances are measured using a chi-value (χ), which is the thermal transmittance of a single point thermal bridge in Btu/hr.°F or W/K

→ Examples of point interface details include structural columns and beams that protrude from the building envelope.

To include the impact of thermal bridging in energy models, the whole wall assembly R-values are used. These are calculated by first determining the rate of heat flow through the assembly, which is the transmittance value (U-value) measured in W/m^2K or $BTU/hr \cdot ft^2°F$. The increased heat flow at the thermal bridges is then added to the heat flow through the assembly, resulting in a higher U-value and a lower R-value.

The methodology for determining the whole wall assembly R-values is described in Sections 2 and 3 below.

SECTION 2: EXISTING BUILDINGS

For new construction projects, thermal bridges are identified by the energy modeller in the architectural assemblies and detail drawings. The information provided in these drawings enables the energy modeller to determine thermal bridge transmittance values.

Existing buildings, however, may not have complete and comprehensible drawing records. Furthermore, assemblies and details may not be able to be confirmed on-site as they may be concealed by other building components. This makes identifying and quantifying thermal bridges for existing buildings challenging.

To simplify the process of calculating thermal bridging in existing buildings, this *DER Thermal Bridging Guide* presents a recommended list of thermal bridges that should be considered for DER existing building energy models. *Table 1: Common Thermal Bridges in Existing Buildings* lists nine of the most common thermal bridges in existing buildings and their associated transmittance values. Although this table is not a comprehensive list of thermal bridges, it provides the information required to reasonably evaluate thermal bridging in existing buildings. Consideration for additional thermal bridges could be given to develop a more accurate energy model. In this case, the energy modeller should consult an enclosure subject matter expert for further guidance on identifying and quantifying thermal bridges on a specific project (note that the SBD program facilitates access to thermal envelope experts as part of the energy modelling activity).

Each thermal bridge *in Table 1* is divided into three sections:

- → **Unmitigated**: describes the condition where no thermal bridge mitigation practices have been applied, appropriate for existing construction that has not been upgraded
- → **Mitigated**: describes the condition where some thermal bridge mitigation practices (e.g., some thermal insulation has been added to reduce thermal bridging) have been implemented to reduce the overall heat loss at that detail
- → **Prevented**: describes the condition where the thermal bridge has been mitigated to make the thermal bridge impact significantly lower or negligible

The transmittance values in Table 1 were determined using average values provided by the Building Envelope Thermal Bridging Guide (BETBG), ISO 14683:2017 Thermal Bridges in Building Construction, and the USACE Development of Thermal Bridging Factors for Use in Energy Models guides. Specifically, the thermal bridge transmittance values in Table 1 were evaluated for existing high-rise multi-unit residential buildings of mass construction (see example below). This typology was identified as the most typical and most prevalent of future projects participating in the SBD program. Although the thermal bridge values were evaluated for residential buildings, the values may be used for other existing buildings of similar construction types subject to discussion with an enclosure subject matter expert.

An example of an existing high-rise multi-unit residential building of mass construction is:

> *The project is a 1970s high-rise multi-unit residential building (MURB) retrofit project (see Figure 4). The 18-storey building consists of concrete construction with interior insulated concrete walls, exterior insulated concrete roof deck, and an uninsulated suspended concrete slab over two levels of below grade parking. A portion of the ground floor consists of an exterior insulated slab on grade. Balconies and aluminum-framed punched windows with sections of spandrel are present throughout the building. Figure 3 shows a section with the typical thermal bridges identified.*

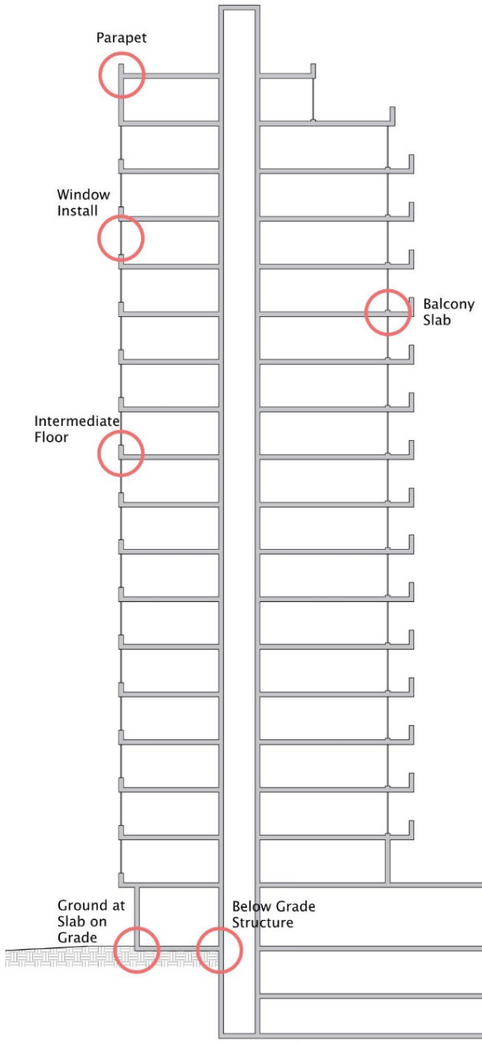
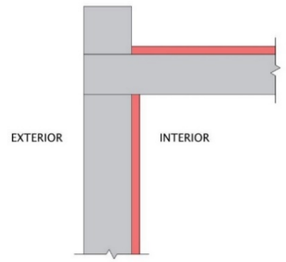
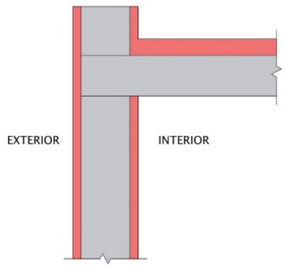
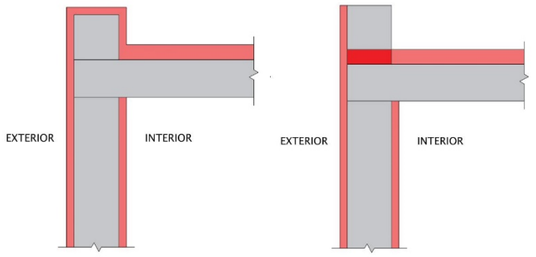
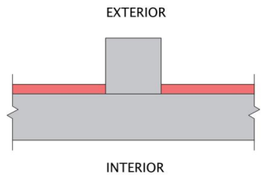
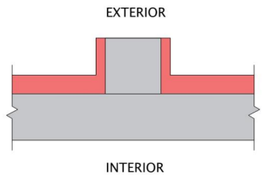
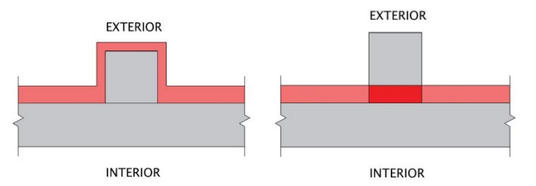
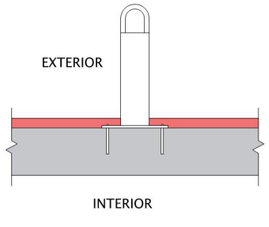
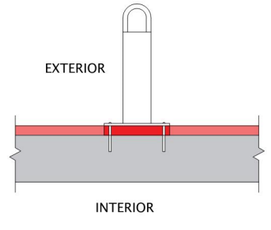
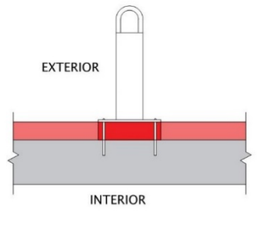


Figure 3 Building section identifying the major thermal bridges to be considered in the SBD program

Figure 4 Image of 1970s high-rise MURB

Table 1: Common Thermal Bridges in Existing Buildings

Thermal Bridge Type	Transmittance Values					
	Unmitigated		Mitigated		Prevented	
	Btu/ hr ft F	W/mK	Btu/ hr ft F	W/mK	Btu/ hr ft F	W/mK
Parapet	0.46	0.80	0.23	0.40	0.17	0.30
	- some interior wall insulation - some exterior roof insulation - uninsulated parapet		- partially insulated parapet - additional roof insulation - exterior wall insulation		- exterior wall insulation - additional roof insulation - insulation wrapped around parapet - thermally broken parapet	
Roof Curb	0.46	0.80	0.23	0.40	0.17	0.30
	- some exterior roof insulation - uninsulated roof curb		- additional roof insulation - partially insulated roof curb		- additional roof insulation - insulation wrapped around roof curb - thermally broken roof curb	
Roof Anchor	0.35	0.60	0.20	0.35	0.12	0.20
	- some exterior roof insulation - roof anchor connected directly to roof structure		- roof anchor thermally broken		- superior thermal break - additional roof insulation	

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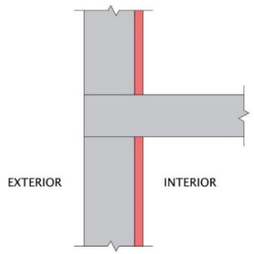
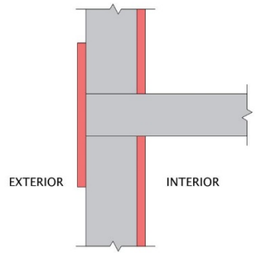
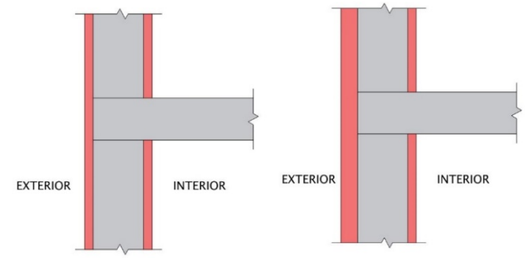
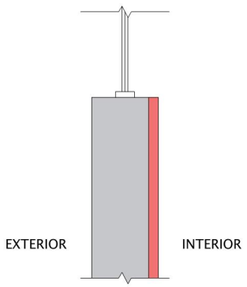
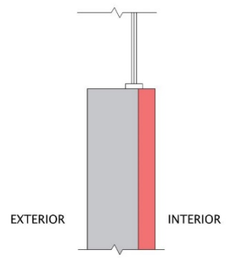
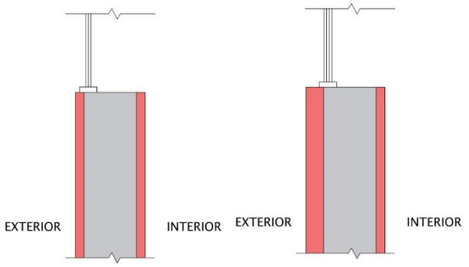
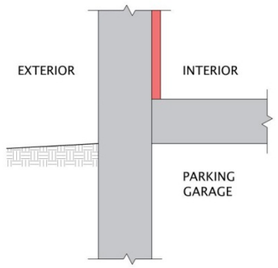
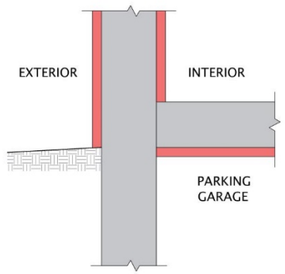
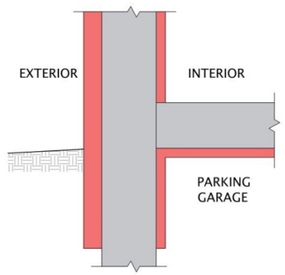
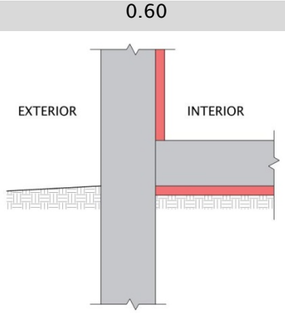
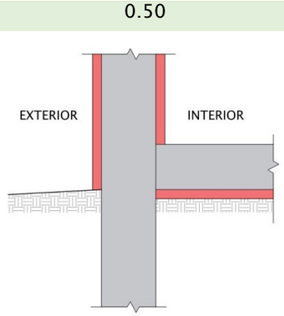
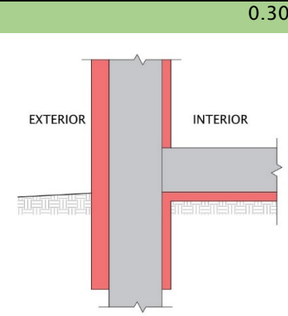
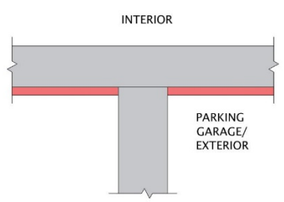
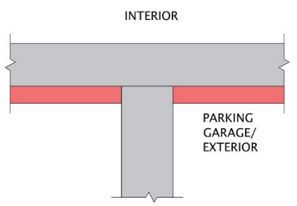
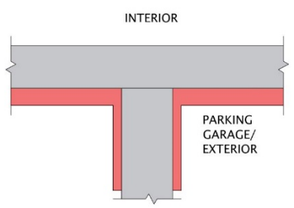
Thermal Bridge Type	Transmittance Values					
	Unmitigated		Mitigated		Prevented	
	Btu/ hr ft F	W/mK	Btu/ hr ft F	W/mK	Btu/ hr ft F	W/mK
Intermediate Floor	0.52	0.90	0.29	0.50	0.12	0.20
	- some interior wall insulation - uninsulated slab edge		- exterior wall insulation at slab edge with overlapping insulation layers		- continuous exterior wall insulation - additional exterior wall insulation	
Balcony Slab	0.52	0.90	0.41	0.70	0.29	0.50
	- some interior wall insulation - uninsulated balcony slab		- exterior wall insulation - uninsulated balcony slab		- continuous exterior wall insulation - insulation wrapped around balcony slab - thermally broken balcony slab	
Window Install	0.58	1.00	0.23	0.40	0.12	0.20
	- metal framed window - window aligned with wall structure - some interior wall insulation		- non-conductive window frame material - window aligned with wall insulation - additional interior or exterior wall insulation		- more insulative window frame material - window aligned with wall insulation - continuous exterior wall insulation	

Table 1: Common Thermal Bridges in Existing Buildings

Thermal Bridge Type	Transmittance Values					
	Unmitigated		Mitigated		Prevented	
	Btu/ hr ft F	W/mK	Btu/ hr ft F	W/mK	Btu/ hr ft F	W/mK
Ground at Parking Garage	0.41	0.70	0.35	0.60	0.29	0.50
	- some interior insulation at above grade walls - sub-slab insulation - uninsulated below grade walls and slab		- exterior insulation at above grade walls - sub-slab insulation - uninsulated below grade walls		- exterior insulation at above grade walls - sub-slab insulation - insulated below grade walls	
Ground at Slab on Grade	0.35	0.60	0.29	0.50	0.17	0.30
	- some interior insulation at above grade walls - sub-slab insulation - uninsulated below grade walls		- exterior insulation at above grade walls - sub-slab insulation - uninsulated below grade walls		- exterior insulation at above grade walls - sub-slab insulation - insulated below grade walls	
Below Grade Structure	0.46	0.80	0.29	0.50	0.17	0.30
	- sub-slab insulation - uninsulated below grade walls		- additional sub-slab insulation - uninsulated below grade walls		- additional sub-slab insulation - insulated below grade walls	

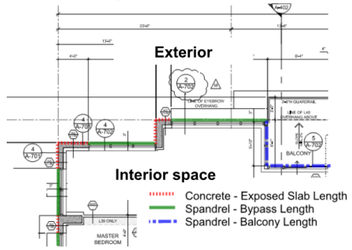
SECTION 3: APPLICATION

There are many ways to calculate overall assembly R- and U-values for advanced modelling of existing buildings. For projects participating in the SBD program, it is recommended that the BETBG Enhanced Thermal Performance Spread Sheet (BETBG Spreadsheet) be used to calculate overall assembly R- and U-values including the impact of interface (linear and point) thermal bridges. An example of this completed spreadsheet is included as an appendix to this guide. A blank spreadsheet can also be downloaded from https://www.bchydro.com/powersmart/business/programs/new-construction.html#thermal under the "Resources" section. For detailed instructions on how to use spreadsheet, consult the Instructions tab of the spreadsheet.

Generally, the BETBG guidelines for determining and modelling thermal bridging should be followed. Table 2 lists these steps in the left column with SBD specific methodology provided in the right column as it pertains to each step.

Table 2: Steps for SBD Modelling based on BETBG Guidelines

BETBG	DER/SBD Application
Step 1: Determine How to Divide Up the Building In calculating building envelope U-values, first it should be known how the U-values will be used. U-values can be calculated for different areas depending on how the U-value will be utilized or level of detail required. For example, the building envelope performance could be divided by zone to find specific zone heating loads, by construction type for whole building energy analysis or kept as one value for the whole building for preliminary design. The methodology to find the different U-values are the same and it is up to the judgment of the designer on what they require.	→ Use the "by construction type" methodology → Use separate tabs in the BETBG Spreadsheet (copies of "New Sheet 1") for each construction type → Use the following assembly identifications as applicable: • Above Grade Wall • Below Grade Wall • Roof • Basement Slab • Parkade Ceiling • Exposed Floors → Tabs can be added/modified as needed to suit each project
Step 2: Determine Clear Field Assemblies The construction types can be determined through the clear field assemblies, which can be found from wall/roof/floor schedules, as shown in Figure 13, but also by sorting through the elevations and detail drawings. There may be multiple clear field assemblies for a single construction type (i.e., several steel stud assemblies), but if they are similar enough in thermal transmittance, with good judgment they can be combined and considered one assembly. W2 EXTERIOR CONCRETE INSULATED WALL ACRYLIC ELASTOMERIC PAINT FINISH STRUCTURAL CONCRETE WALL 203 MM MIN EQUIVALENT CONCRETE R-11 RIGID INSULATION 3/8" AIR SPACE 1-5/8" STEEL STUDS @ 16" O.C. BRACED BACK TO CONCRETE WITH CLIPS AT 24" ON CENTER 1/2" GYPSUM BOARD VAPOUR RETARDANT PAINT PRIMER EXTERIOR FACE INTERIOR FACE 5" 5" **Figure 13:** Example concrete clear field wall assembly	→ Determine the clear field U-value of each assembly using: • Architectural Drawings • Subject matter expert • Manufacturers of proprietary systems • BETBG • ASHRAE 90.1 Appendix A → Whole window U-values are to be accounted for separately and not included in the whole wall U-value calculation → Determine glazing U-values from subject matter expert and/or architectural drawings → Spandrel assemblies shall be considered separate from glazing and shall be identified as an opaque assembly
Step 3: Determine Linear and Point Details After determining the clear field assemblies, the types of linear and point details need to be found. In architectural drawings, these can be found through elevations, plans and detail drawings, as shown in Figures 14 and 15. 3'-6"H GUARDRAIL BALCONY 2% SLOPE 4 A-701 LIVING 502 18-8 **Figure 14:** Exposed Floor Slab in Plan 4/A701 TYP. SLAB @ CONC. WALL **Figure 15:** Exposed Floor Slab detail 4/A701 When dividing by construction type, the interface details can also be divided in the same way and can be assigned to specific clear field assemblies. For each clear field assembly there will be a set of linear and/or point details associated with it. For transitions between different clear field assemblies (such as a parapet transition between wall and roof) it is up to the designer to choose which assembly to assign the heat loss to. Example interface details are shown in Figure 16. Concrete 1. Clear Wall 2. Slab - Exposed Edge 3. Partition Wall - Exposed Concrete Spandrel 4. Clear Wall 5. Slab - Spandrel Bypass 3. Slab - Balcony Projection **Figure 16:** Example building typical floor plan	→ Major thermal bridges to be considered for existing buildings and recommended associated psi- and chi-values are listed in Table 1 → Determine which thermal bridges in the list apply to the project → Additional thermal bridges may need to be considered if project has an atypical detail that hasn't been listed in Table 1 → Refer to SBD notes in Step 4 for where each thermal bridge should be accounted for

Step 4: Determine Area and Length Takeoffs With the types of transmittances (clear field, linear and point) found, the area, lengths and number of instances should be determined. **Information on takeoffs is given in section 3.4.1 of the BETBG.** Areas for the clear field can typically be easiest to determine from elevation drawings. Lengths for slabs, parapets and other horizontal linear details can be found through plans, while lengths for vertical linear details (such as corners) can be found in the elevations. An example takeoff for slab edges is shown in Figure 17.  **Figure 17:** Example slab length takeoff	→ Exterior dimensions should always be used to determine thermal bridge lengths → Input clear field assemblies and linear and point thermal bridges into the BETBG Spreadsheet using the blue cells; use as many lines and notes as needed to make tracking and project organization easier → Thermal bridges in table should be accounted for in the following locations: • Parapet in roof • Roof curb in roof • Roof anchor in roof • Intermediate floor in above-grade wall • Balcony slab in above-grade wall • Window installation in above-grade wall • Ground at parkade in above-grade wall • Ground at slab-on-grade in above-grade wall • Below-grade structure in parkade ceiling
Step 5: Determine Clear Field, Linear and Point Transmittances Thermal performance data for clear field, linear and point details can be found in the catalogue provided with this guide, or through other sources (outlined in section 4.3). The project specific interface details can be matched up with the catalogue details in Appendix A and the thermal values are given in Appendix B. If a specific project detail cannot be found in the catalogue, judgment will be required to estimate the thermal performance by comparing similar details or by using the ranges in section 4.2. If that cannot be done with certainty, then further modeling may be necessary.	→ Use Table 1 to determine the transmittance value for each thermal bridge → Quantifying existing building projects involves a certain degree of inaccuracy due to variations between existing documentation and as-built conditions, which can differ widely as they are influenced by the construction process, moisture, aging, etc. The purpose of thermal bridge modelling for the SBD program is not to predict energy usage but rather to compare mitigation options, therefore relative accuracy is more important than absolute accuracy and the modeller's best approximation should be used to determine the appropriate transmittance values.
	→ If additional thermal bridges not listed in Table 1 are identified, use other resources such as: • BETBG • ISO 14683:2017 • USACE Development of Thermal Bridging Factors for Use in Energy Models
Step 6: Calculate Individual Transmittance Heat Flow While not necessary to calculate the overall U-value, it may be advantageous for designers to calculate the individual heat flows associated with specific details to help make better design decisions and identify details that should be targeted. Recognizing components of the U-value equation given in section 3.4, the individual heat flows can be calculated using the following: → Clear Field Heat Flow = $U_o \cdot A$ → Linear Transmittance Heat Flow = $\psi \cdot L$ → Point Transmittance Heat Flow = $\chi \cdot$number of occurrences	→ The BETBG Spreadsheet will show individual heat flows associated with each thermal bridge
Step 7: Calculate Overall U-Value With all the transmittance values and takeoff areas/lengths known, the overall Wall/Roof U-values can be calculated using the equation: $$U_T = \frac{\Sigma(\Psi \cdot L) + \Sigma(\chi)}{A_{Total}} + U_o$$ If the individual heat flows have already been determined in Step 6, then all of the heat flows can be summed together and divided by the total opaque area (in this case, the clear field area) to get the overall U-value that includes the effects of thermal bridging at interface details.	→ The example BETBG Spreadsheet contains a tab that will calculate an overall U- and R-value for the building