

## The Concept of Linear and Point Transmittance and its Value in Dealing with Thermal Bridges in Building Enclosures

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### ABSTRACT

Thermal bridging through insulating layers can greatly reduce the thermal performance of building assemblies. As such, determining the effects of thermal bridging is often of immense importance to building engineers, energy modelers and architects in accurately designing a building. This can be very difficult to accomplish, and as a result many building codes and standards do not comprehensively address this problem.

In North America, the common approach in calculating the area effects of thermal bridging is to use an area weighted average of U-values. For assemblies with easily definable geometry and U-values, such as walls with windows, the area weighted process is straightforward and has been well established. However, for many assemblies, identifying the effective area of a thermal anomaly used in calculations can become either too arbitrary or too complex, especially when dealing with three dimensional heat flow paths. The purpose of this paper is to introduce a simple methodology, incorporating the concepts of linear transmittance, in order to assist practitioners in overcoming these complexities for determining the heat flow through many types of details.

The proposed method involves modeling an assembly to find its heat flow, with and without the thermal anomalies, and attributing that difference to individual contributions of point or linear loads. Determining the area of influence of a thermal anomaly is not needed in the heat transfer calculations and only involves the number of point occurrences (i.e. # of steel beam penetrations through exterior insulation) or linear distances (i.e. slab length across a building face). In order to find the overall heat flow in a building assembly, all the linear and point loads can be simply added together with the clear field heat flow (the heat flow through the assembly without the thermal anomalies). With that total heat flow known, several other parameters, such as an overall U-Value, can be easily calculated. Included in this paper are examples showing where the area weighted average approach encounters drawbacks and why the linear transmittance method is better suited to quantify the effect of thermal bridging of opaque building envelope assemblies.

The idea of linear transmittance has been widely used in practice in various forms across Europe. This concept, however, has yet to gain wide acceptance in North American codes, standards and practices. This paper is intended to bridge the two continental approaches, and incorporate linear transmittance into current methods of assessing building enclosure performance in North America.

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## 1.0 INTRODUCTION

With growing environmental pressures and rising energy costs, the need for energy efficient buildings is increasing. A major use of energy in buildings is from continual heating and cooling due to heat flow through the building enclosure; however, improving the thermal performance of walls and roofs is not necessarily straightforward.

Thermal bridging through building envelope assemblies can significantly change the resultant thermal resistance of a wall structure. Adding more insulation into a wall assembly may, intuitively, seem like all that is needed to reduce the heat flow through the building envelope. However, if most of that heat is flowing through the slab edges, metal cladding attachments or other highly conductive features that bypass the insulating layer, then changing the amount of insulation may make little difference.

By knowing what the additional heat flow is as a result of various thermal bridges, designers can get a better understanding on how certain detail features affect the overall thermal transmittance. Additionally, from an economic perspective, showing the relative amounts of heat flow that each thermal bridge contributes gives more insight into where to get the most 'bang for your buck' in terms of improving the thermal performance.

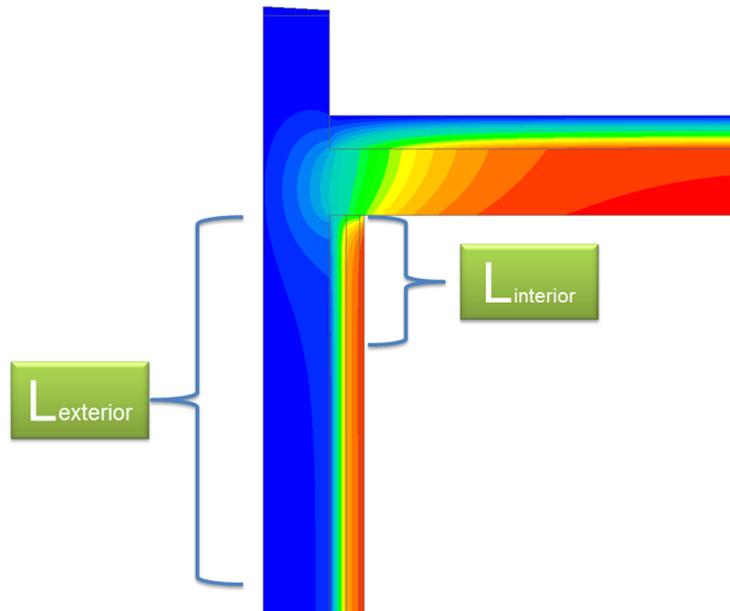
In practice, determining the effects of these thermal bridges can be quite difficult. Approaches such as the area-weighted method, discussed in more detail in the following section, involve finding 'zones of influence' of thermal bridges, and averaging the heat flow from these areas with the 'unaffected' clear field areas. With 3D conduction heat flow paths, defining the areas of these zones can be quite cumbersome to calculate, and in many cases assigning the areas is arbitrary. Furthermore, the area-weighted method averages the effect of a major thermal bridge with a portion of the clear field heat flow; therefore the absolute effect of detailing on thermal bridging is difficult to distinguish from the adjacent clear field heat flow. The complexity of this problem is likely why many codes and standards have yet to thoroughly address thermal bridging beyond simple parallel path flows. The linear transmittance method, detailed in section 3, greatly reduces the complexity in calculation of the overall thermal transmittance by removing the need for the area of effect of thermal bridges and makes the calculations a simple additive process. This is shown in an example building in section 4.

Being able to accurately (and easily) assess the effects of thermal bridging will give designers the tools to be able to make better informed decisions when it comes to designing thermally efficient buildings. By simplifying calculations and eliminating the need for areas and zones of influence, the method of linear transmittance outlined in this paper provides tools.

## 2.0 DRAWBACKS OF THE AREA WEIGHTED METHOD

In North America, it is common practice to calculate the overall thermal transmittance for the building envelope (walls, windows, roofs, etc.) by using an area weighted average approach. There are some variations used, one of which is featured in the ASHRAE Handbook of Fundamentals (2009). The overall thermal transmittance for a wall is determined by a weighted average of the heat flow over the area of the clear field, and heat flow over the area of the thermal anomalies. Overall this approach works reasonably well when dealing with building features that have easily definable areas, such as clear walls and windows. However, with other details such as intersections or pipe penetrations, the zone of influence of the thermal anomaly needs to be calculated, which can be complicated

The zone of influence of an anomaly is the area where the anomaly has an effect on the clear field heat flow. The effective width and height are the distances where the heat flow around the anomaly approaches the clear field heat flow. Determining these effective lengths through modeling requires the heat flow through surfaces to be analyzed at finite intervals away from the thermal anomaly. The heat flow through the surfaces is compared to the clear field heat flow without the anomaly. The analysis using this method can be cumbersome if trying to satisfy predetermined criteria and is often not consistent depending on the location of the insulation. As a simple example, take an effective length calculation for a concrete parapet with insulation inboard, as shown in Figure 1.



**FIGURE 1:** Effective lengths for parapet from exterior and interior

For this parapet thermal anomaly there is a significant amount of lateral heat through the concrete ceiling and exterior concrete wall due to the wall insulation inboard and the roof insulation outboard the concrete structure. Therefore, the heat flow through the interior and exterior surfaces do not converge at the same effective lengths. As a result the effective area cannot be effectively defined by only either the interior or exterior surface for both the portion of the roof and wall affected by the parapet thermal bridge. This procedure breaks down further when the adjacent assemblies have complex heat flow paths due to thermal bridging in three dimensions.

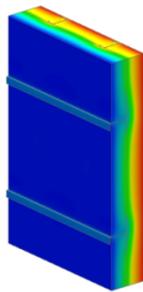
Finally, one of the major drawbacks is that with an area-weighted average, it is harder to quantify the individual contribution of a single thermal anomaly. The effects are averaged over the entire area, diluting the impact with the clear field heat flow, making it more difficult to appreciate the full impact of the thermal bridging and apply results to assemblies with varying insulation levels.

### 3.0 THE LINEAR TRANSMITTANCE METHOD

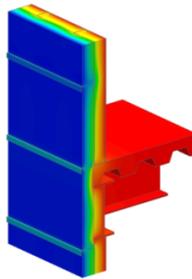
From the previous discussion, it can be seen that determining the area of effect of a thermal anomaly ranges from being too complicated to arbitrary. If this is the case, then *why not make that area zero?* This is how the linear transmittance method approaches thermal bridging. Instead of finding areas of influence, the absolute heat flow increase caused by the presence of an anomaly is found and prescribed to simple mathematical constructs of lines and points. Designers can simply add up the number of occurrences of these lines and points on a wall to find the overall heat flow caused by thermal bridges in their details.

#### 3.1. Linear Transmittance Types

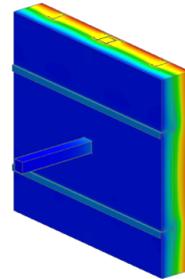
For this method there are three types of transmittances involved in calculations, the clear field, linear and point transmittance. The clear field is the general wall structure and the linear and point transmittances are the major thermal anomalies. Most typical building components will fall into these three categories. Examples of each are shown in Figures 2 a,b and c for a steel stud assembly with insulation outboard and horizontal z-girt cladding attachments.



**FIGURE 2a:** Example of a clear field



**FIGURE 2b:** Example of a linear anomaly



**FIGURE 2c:** Example of a point anomaly

The clear field is the typical wall structure away from major anomalies. Since, as a wall the clear field has an easily definable projected area, the transmittance can be treated the same as in standard practice and is presented as a clear field heat flow,  $Q_o$ , or easily converted back and forth to a U-Value,  $U_o$ . While multiple uniformly distributed features, such as steel studs, brick ties or cladding supports are thermal bridges, they usually occur so frequently that it is impractical to account for them individually and they can be assumed to modify the thermal transmittance of the assembly.

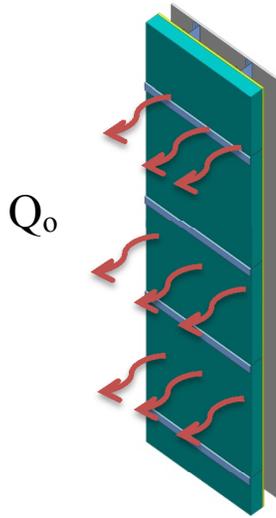
Linear anomalies are thermal anomalies that occur in a single linear direction across a building face. This includes floor slabs, corners, parapets, and transitions between assemblies or other anomalies whose characteristic lengths can be reduced to a line. Essentially, the linear transmittance is the additional heat flow to the assembly if a linear anomaly was present. The linear transmittance is a heat flow per length, and is represented by  $\psi$  ( $\Psi$ ).

Point anomalies are those thermal anomalies that occur only at single, infrequent locations. This is components such as a beam or pipe penetration, or intersections of perpendicular linear anomalies. The point transmittance is a single additive amount of heat flow if a point anomaly is present, represented by  $\chi$  ( $\chi$ ).

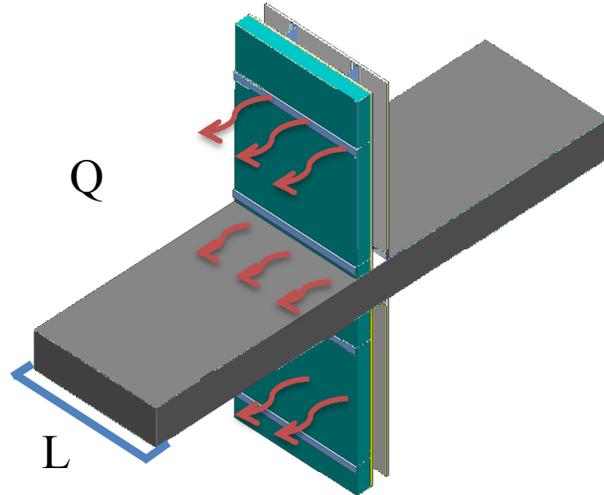
### **3.2. Determining Transmittance Values**

Part of the ease of this method is that each of these transmittances can be found through 2D or 3D thermal modeling, with programs which are already widely used in the industry. However, with the 3D nature of heat flow paths for most assemblies, 2D models would need many corrections and assumptions, so for the greatest accuracy 3D modeling is required. The clear field transmittance can be found by analyzing a characteristic section of the clear field assembly. For a steel stud assembly, this is a section at least two girt spacings wide. The heat flow,  $Q_o$ , can be found through this model and, since clear fields have an easily defined projected area, a  $U_o$  can be easily derived. Since the clear field contains uniformly distributed thermal bridges, different spacing of these components can produce different  $Q_o$  and  $U_o$  values.

The linear transmittance can be found by modeling a section of wall with the linear thermal anomaly and subtracting out the clear field heat flow. For example, an extended slab shown in Figures 3 a and b.



**FIGURE 3a:** Clear field assembly



**FIGURE 3b:** Assembly with slab

For a wall of a certain size,  $A_o$ , and  $U_o$  value, there is a certain amount of heat flow through the clear field assembly,  $Q_o$ , shown in Figure 3a. By adding a slab, the heat flow is increased, shown in Figure 3b. The total heat flow for the assembly with the slab is  $Q$ . Subtracting the heat flow through just the wall, from the heat flow through the wall and the slab gives the incremental increase from the slab,  $Q_{slab}$ . This  $Q_{slab}$  value includes not only the heat flow through the slab, but also any additional heat flow change in the surrounding wall (such as an increase in lateral flow) caused by having that slab in place.

In order for  $Q_{slab}$  to be applicable for different sizes of assemblies, this heat flow is prescribed as a line. This is done by dividing  $Q_{slab}$  by the modeled slab length, which gives the linear transmittance,  $\Psi_{slab}$ . The general mathematical approach for any linear anomaly is given in Equation 1.

$$\Psi = \frac{(Q - Q_o)}{L} \tag{1}$$

Where:

- $\Psi$  = linear transmittance of the anomaly (Btu/hr· ft·°F or W/m K)
- $Q$  = the heat flow through the assembly with the anomaly (Btu/hr· °F or W/K)
- $Q_o$  = the heat flow through the clear field assembly without the anomaly (Btu/hr· °F or W/K)
- $L$  = the characteristic length of the anomaly (ft or m)

Point transmittances are found using the same approach as the linear transmittance; however they are single points of heat flow and are not divided by any length. Therefore the heat flow from the assembly with the point anomaly subtract the heat flow from the clear field is the point transmittance,  $\chi$ . The mathematical approach is given in Equation 2.

$$\chi = (Q - Q_o) \quad (2)$$

Where:

$$\chi = \text{point transmittance of the anomaly (Btu/hr} \cdot \text{ }^\circ\text{F or W/K)}$$

For linear and point transmittances, note that no areas for the thermal anomalies were needed. Different sizes of anomalies will result in different linear and point transmittances, but areas are not explicitly used in calculations. For example, a larger diameter pipe penetration might have a larger point transmittance than a smaller diameter pipe, but the only difference in the calculation is the value of Q.

Attempts have been made, mostly in Europe, to apply this approach to windows and glazing units (Svendson (2005)). However, the process of using the area weighted average in North America for glazing assemblies is well established. Since windows, curtain wall and other glazings have easily definable areas, there is already a large amount of accurate data for these structures and it would be unnecessary to change that. Furthermore, glazing assemblies are typically treated separately in standards and energy modeling. Therefore, the best use of the linear transmittance method presented here is for opaque assemblies.

### 3.3. Overall Thermal Transmittance Calculations

It can be seen that the linear and point transmittance values were derived by separating the heat flow of the thermal bridge from the heat flow through the clear field in a modeled assembly. With this separation, each thermal bridge can be considered an individual heat flow contribution. Therefore, in order to find the overall thermal transmittance of a wall or roof with several thermal anomalies, all those individual heat flow contributions can be simply added together with the clear field heat flow. This is shown in Equation 3.

$$Q = \sum Q_{anomalies} + Q_o = \sum (\Psi \cdot L) + \sum (\chi) + Q_o \quad (3)$$

Where:

$$Q_{anomalies} = \text{the heat flow from the anomalies (Btu/hr} \cdot \text{ }^\circ\text{F or W/K)}$$

For the linear anomalies, L is the characteristic length. In general, L can be considered the length that the anomaly occurs across the face of the wall. For a slab this is, in most cases, the width of the wall, or for a corner it is the height of the building. This convention is quite accurate, but there are slight nuances and

correction factors to further increase this accuracy, some of which are discussed in Janssens et al (2007), however, in general, these are unnecessary.

For many applications, such as whole building energy modeling, it is much more useful to present Eq.3 as a U-value. Knowing  $U=Q/A$  produces the following equation:

$$U = \frac{\sum (\Psi \cdot L) + \sum (\chi)}{A_{Total}} + U_o \quad (4)$$

Where:

- U = overall effective wall thermal transmittance (Btu/hr·ft<sup>2</sup>·°F or W/m<sup>2</sup>K)
- U<sub>o</sub> = clear field thermal transmittance (Btu/hr·ft<sup>2</sup>·°F or W/m<sup>2</sup>K)
- A<sub>total</sub> = the total opaque wall area that includes anomalies (ft<sup>2</sup> or m<sup>2</sup>)

From these equations, again it can be seen that the area of the thermal anomaly is not needed. An example in using this linear transmittance method is shown in section 4.

#### 4.0 THE LINEAR TRANSMITTANCE METHOD IN PRACTICE

The following example demonstrates how to use the linear transmittance method in practice, and to show the relative contributions of different building details. For this example two wall types are compared; an exterior insulated steel stud assembly with horizontal z-girt cladding attachments and R-10 nominal insulation and a poured in place concrete mass wall with R-10 nominal insulation and steel stud backup wall. Both assemblies have no insulation in the stud cavity.

##### 4.1. Example Details

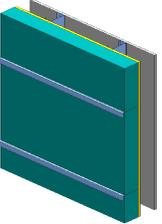
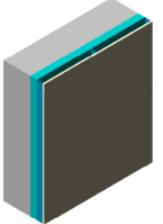
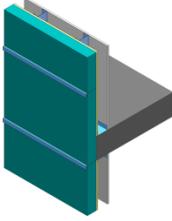
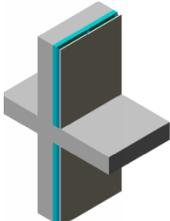
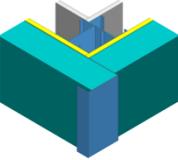
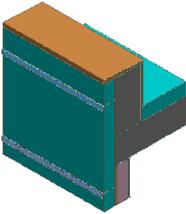
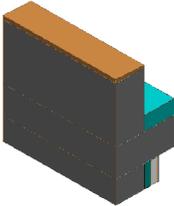
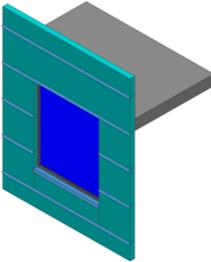
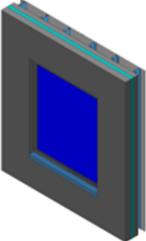
For this example, Q, U and R-values are found for a building, with the specifics shown in Table 1, based on the linear transmittance method.

**TABLE 1: Example building specifics**

Wall	Height	60 ft (18.3 m)
	Width	120 ft (36.6 m)
Total wall area		7200 sqft (669 m <sup>2</sup> )
# of floor s		12
# of windows		5 per floor, 60 in total
Window	Height	5 ft (1.5m)
	Width	4 ft (1.2m)
Total opaque wall area		6000
Total window area		1200 sqft (111.5 m <sup>2</sup> )
Window to wall ratio		20% glazing

The following clear field and linear transmittances, shown in Table 2, are taken directly or interpolated from ASHRAE 1365-RP (2011), which contains thermal values for a catalogue of common building details. Also included is a brief description of the detail. For more information, see ASHRAE 1365-RP (2011).

**TABLE 2: Thermal Transmittance Summary for Example Building**

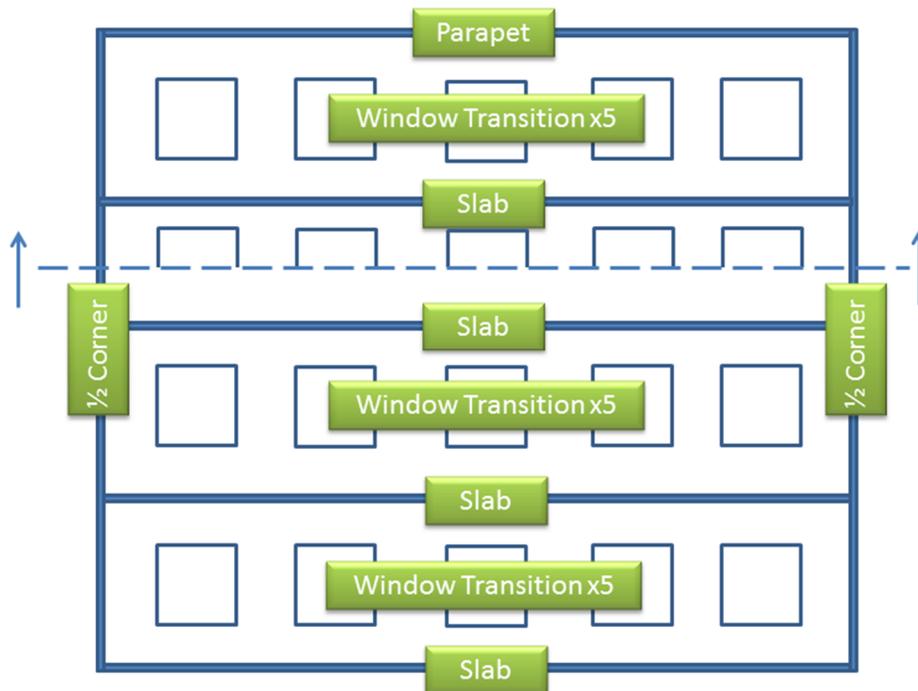
Exterior Insulated Steel Stud Assembly		Poured In Place Concrete Assembly	
	$U_o$ 0.106 Btu/hr-ft <sup>2</sup> -°F (0.60 W/m <sup>2</sup> K) The clear field assembly is an exterior insulated steel stud (16" o.c.) assembly with horizontal z-girt cladding attachments (24" o.c.) and R-10 nominal insulation.		$U_o$ 0.080 Btu/hr-ft <sup>2</sup> -°F (0.46 W/m <sup>2</sup> K) The clear field assembly is a poured in place concrete wall with an R-10 nominal insulation outboard of a stud cavity (16" o.c.)
	$\Psi_{slab}$ 0.043 Btu/hr-ft-°F (0.075 W/m K) The floor slab is flush with the interior stud wall, with exterior insulation outboard of the slab face		$\Psi_{slab}$ 0.465 Btu/hr-ft-°F (0.805 W/m K) The slab is an extended balcony slab with a concrete to concrete intersection
	$\Psi_{corner}$ 0.091 Btu/hr-ft-°F (0.158 W/m K) The corner joint is a typical parallel stud arrangement with butted insulation	-	$\Psi_{corner}$ - The corners have continuous insulation and can be considered negligible
	$\Psi_{parapet}$ 0.284 Btu/hr-ft-°F (0.491 W/m K) The parapet is a simple concrete curb with an R-5 insulation		$\Psi_{parapet}$ 0.449 Btu/hr-ft-°F (0.777 W/m K) The parapet is an un-insulated curb
	$\Psi_{window\ transition}$ 0.053 Btu/hr-ft-°F (0.093 W/m K) The window transition is a typical steel framing and full flashing at the jambs, head and sill, broken at the window thermal break		$\Psi_{window\ transition}$ 0.028 Btu/hr-ft-°F (0.048 W/m K) The window transition is a typical steel framing with flashing only at the sill, broken at the window thermal break

## 4.2. Example Assumptions

- 1) The building is square, so all 4 walls are the same
- 2) The slab, at grade, is similar to those above grade
- 3) Doors and glazing calculations are treated separately

## 4.3. Example Calculations

In order to more easily visualize the building specifics in terms of linear transmittances, a simplified building view for the top and bottom floors is shown in Figure 4.



**FIGURE 4:** Simplified building view

For the clear field  $Q_o$ , the opaque wall area is the total wall area subtract the glazing area. The calculation is shown below:

$$Q_o = U_o \cdot A_o = U_o \cdot (A_{Total} - A_{windows})$$

The calculation of  $Q_{slab}$  and  $Q_{parapet}$  for both wall types is fairly straightforward. They are found by multiplying the linear transmittance,  $\Psi$ , by the wall width. For the slab, this occurs 12 times, while the parapet only once. The calculation for both these values are:

$$Q_{slab} = 12 \cdot \Psi_{slab} \cdot L_{width}$$

$$Q_{parapet} = \Psi_{parapet} \cdot L_{width}$$

The corner of the exterior insulated steel stud assembly is shared by the adjacent wall, which is why they are labeled  $\frac{1}{2}$  corner in Figure 5. In this example, each corner height is the same, so this wall in essence contains one full corner. Therefore the calculation is as follows:

$$Q_{corner} = \Psi_{corner} \cdot L_{height}$$

For the window transition, the characteristic length is the perimeter of the punched window. This occurs 5 times per floor and 60 times overall for the wall. The calculation process for the windows is shown below:

$$Q_{window\ transition} = 60 \cdot \Psi_{window\ transition} \cdot L_{window\ perimeter}$$

#### 4.4. Example Results and Discussion

Using the lengths given in Table 1 and the thermal values given in Table 2, the total heat flow for the opaque wall can be calculated using Equation 3. The values for the individual contributions and the totals are shown in Table 3.

**TABLE 3: Heat Flow Contributions for Both Wall Types**

Transmittance Type	Exterior Insulated Steel Stud Assembly		Poured In Place Concrete Assembly	
	Q Btu/hr°F (W/K)	%	Q Btu/hr°F (W/K)	%
Clear Field	638.6 (337.1)	<b>84.6</b>	484.2 (255.6)	<b>55.3</b>
Floor Slab	31.2 (16.5)	<b>4.1</b>	334.9 (176.8)	<b>38.3</b>
Corner Joint	11.0 (5.8)	<b>1.5</b>	-	-
Parapet	17.0 (9.0)	<b>2.3</b>	26.9 (14.2)	<b>3.1</b>
Window Transition	56.8 (30.0)	<b>7.5</b>	29.5 (15.6)	<b>3.4</b>
<b>Total</b>	<b>754.5 (398.3)</b>	<b>100</b>	<b>875.5 (462.2)</b>	<b>100</b>

Using Equation 4, the overall thermal transmittance for the opaque wall can be found. Knowing  $R=1/U$ , the R-value can also be found. These values are shown in Table 4.

**TABLE 4:** Overall U- and R-Values for Opaque Wall

Assembly Type	Exterior Insulated Steel Stud Assembly	Poured In Place Concrete Assembly
<b>U</b> Btu/hr-ft <sup>2</sup> ·°F (W/m <sup>2</sup> K)	0.125 (0.71)	0.145 (0.82)
<b>R</b> hr-ft <sup>2</sup> ·°F/Btu (m <sup>2</sup> K/W)	R-8.0 (1.41)	R-6.9 (1.22)

From this example, there are several things to note:

*Thermal anomalies can greatly affect the thermal efficiency of a building, regardless of the clear field assembly.* Both these building types have similar 1D nominal insulation value for their clear field assemblies (about R-13). With all the thermal anomalies accounted for, the actual effectiveness of the entire wall is equivalent to only about 60% of that.

*Separating out thermal anomalies gives a better understanding of their heat flow contribution.* From the percentages in Table 3, for the exterior insulated steel stud assembly, it can be seen that the details are fairly thermally efficient. The floor slab and the window transition add a slight amount to the overall thermal transmittance of the opaque wall; however the clear field contributes the most. For the concrete assembly, while the clear field is still the largest contribution of heat flow, the transmittance from the slab is significant.

*The quality of the details counts.* Looking at the differences of clear field Q and U-values between these two wall types, the poured in place concrete has a much more thermally efficient structure than the exterior insulated steel stud assemblies. From Table 3, it can be seen that the heat flow through the clear field is much lower for the poured in concrete. However, the slab details make a considerable difference in the overall heat flow of the building. Since, for the exterior insulated wall, the slab face is insulated, the slab transmittance is very low and only accounts for 4% of the total heat flow through the opaque wall. With the concrete building, the slab is un-insulated and extends out, acting like a fin. As such the slab linear transmittance is high, and accounts for almost 40% of the total opaque wall heat flow. The transmittance through the slab detail essentially negates the benefits that the clear field of the concrete assembly has over the exterior insulated steel stud assembly. By using this linear transmittance method and separating out the heat flows, a designer can see which details are major heat flow contributors and where improvements can make the best impact. Take two improvements for the concrete assembly. One could be to increase the insulation in the clear field by an R-5 (RSI-0.88); the other could be to improve the slab detail to reduce the linear transmittance to 0.144 Btu/hr-ft·°F (0.250 W/m K). With all other details remaining the same, the results are shown in Table 5.

**TABLE 3: Heat Flow Contributions for Improved Concrete Details**

Transmittance Type	Improved Clear Field		Improved Slab Detail	
	Q Btu/hr°F (W/K)	%	Q Btu/hr°F (W/K)	%
Clear Field	372.5 (196.6)	<b>48.8</b>	484.2 (255.6)	<b>75.1</b>
Floor Slab	334.9 (176.8)	<b>43.8</b>	104.0 (54.9)	<b>16.1</b>
Parapet	26.9 (14.2)	<b>3.5</b>	26.9 (14.2)	<b>4.2</b>
Window Transition	29.5 (15.6)	<b>3.9</b>	29.5 (15.6)	<b>4.6</b>
<b>Total</b>	<b>763.8 (403.2)</b>	<b>100</b>	<b>644.6 (340.3)</b>	<b>100</b>

From the totals in Table 3, it can be seen that if the slab detail could be improved, then it can have more of an impact than improving the clear field. For designers, this will depend on how much it will cost to implement either improvement.

*This method can be applied to any building division. While the previous example was for a whole wall, since the thermal anomalies are all separated, the calculations in section 4.3 can be easily applied to find the thermal values of Q, U and R, for smaller divisions, such as floor by floor, or even room by room. This can be very useful for energy modeling, which usually requires a wall assembly R-value for every exterior wall in a zone as an input.*

*Do not forget about the windows. While these are considerations for improving the opaque wall, designers should never lose sight of the impacts of windows on the overall heat flow. With the previous example there was 20% glazing on the wall. Using a metal framed window U-value of 0.45 Btu/hr·ft<sup>2</sup>·°F (2.56 W/m<sup>2</sup>K) and the glazing area given in Table 1, the estimated heat flow through the windows for both walls is 523.8 Btu/hr°F (276.5 W/K). Compared to the opaque wall heat flow, this is almost 40% of the total heat flow through the entire wall. With a larger glazing ratio, the windows alone could easily be the largest heat flow contributor and the heat flow through additional framing at glazing transitions will be more significant. In many cases, improving the windows should take precedent over improving the opaque wall structure. Using this approach with linear transmittance makes it much easier to make that judgment call by being able to calculate the overall heat flow through the opaque walls and comparing it to window calculations.*

## 4.5. Incorporating Linear Transmittance into Codes and Standards

The difficulty in establishing a consistent approach for accounting for and minimizing thermal inefficiencies has likely restrained the full impact of thermal bridging from being thoroughly addressed in North American energy standards. For example, in ASHRAE 90.1 (2007), the compliance paths are largely silent on major thermal bridges, like slab edges, shelf angles, parapets, etc<sup>4</sup> and do not provide a consistent approach to consider their effects. Unfortunately, this leads to confusion with designers on the intent of the requirements and often results these features being ignored in design. The poured in concrete, from the example earlier in section 4, can be considered to have continuous insulation and has a thermally efficient clear field U-value, while the exterior insulated steel stud assembly has z-girts penetrating the insulation and a much higher clear field U-value. It can be seen from Table 3 that the slab detail accounts for almost half the heat flow through the concrete mass wall and as a result, the continuous insulation assembly is worse thermally than the non-continuous assembly for the same building setup.

With the linear transmittance method, the importance of the details is emphasized. By having a listing of typical details and transmittances integrated into the standards, designers can easily select their building components, or make reasonable interpolations for their particular details. Then, following the calculation steps shown in this paper, they can determine the transmittance values for their buildings. This would provide direction and consistency in determining the effects of different details, such as slab edge conditions, and wall types on their building. With this information, designers will have insight on how they can more accurately meet the codes.

Additionally, by integrating this methodology into codes and standards, the codes themselves will be able to more comprehensively address their own intent, which is to maintain a minimum level of thermal efficiency in buildings. This can be achieved by a few different approaches using the concept of linear and point transmittances:

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<sup>4</sup> The nominal insulation minimum R-value and corresponding maximum U-value that are required for the prescriptive path in ASHRAE 90.1 (2007) appear to be based on clear wall assemblies that do not include the effect of slab edges or other major thermal bridges. We believe these values are derived from hand calculations or guarded hotbox measurements for assemblies without consideration of typical thermal bridging outside the clear field. Values in Appendix A for walls with continuous insulation are for clear field assemblies and, again, do not include major anomalies. This can be difficult to interpret and enforce in practice. For mass walls, there is no distinction between insulation inboard or outboard; but slab effects can be significant for typical construction, especially for insulation installed inboard a mass wall. Additionally, in modeling requirements for the energy cost and energy cost budget method suggests that if the thermal bridge is less than 5% of the total area, its area can be included with the adjacent assembly with the same thermal properties as the adjacent assembly. The ambiguity of these definitions allows for a wide variety of interpretations, which can have major lasting effects on the built environment.

**Performance Approach:** limit overall U-value for all thermal bridging. Provide information in the form of clear field transmittance ( $U_0$ ), linear transmittance ( $\Psi$ ) and point transmittance ( $\chi$ ) and guidance to users to thoroughly consider the effects of thermal bridging.

**Prescriptive Approach:** limit the clear field assembly U-value ( $U_0$ ) and transmittances for details ( $\chi$ - and  $\Psi$ -factors) for different types of construction. For example as proposed by Janssens et al (2007).

**Solution Approach:** provide acceptable solutions, including details and assemblies, which considers all thermal bridging for typical construction.

Ultimately a combination of all these approaches can be applied incorporated in standards. Different building constructions will then have a more even means of comparison when all their details are taken into account and thermal efficiency can be looked at objectively and consistently. This will allow standards to be more enforceable (and therefore likely more widely adoptable) and greatly encourage minimizing thermal inefficiencies due to thermal bridging in building design.

## 5.0 CONCLUSIONS

The challenge of comprehensively accounting for the effect of thermal bridges has restrained a consistent approach for considering thermal bridging in building design, simply because of the complexities and available information for North American construction. Using linear transmittance can provide that simplicity without sacrificing accuracy since the heat flow can be quantified using calibrated 3D thermal models, and the results can be analyzed with an uncomplicated and reliable approach of all types of construction. The linear transmittance method gives the flexibility to find the heat flow for a single level, an entire wall or even a whole building by separating the major thermal bridges from the clear field assembly. Additionally, by being able to easily analyze the individual contributions of details, this method gives a better appreciation of the impacts that details have on the building envelope. This allows more informed decisions to be made when looking at improving the overall thermal performance.

Integrating the linear transmittance method into codes and standards, while requiring a definite shift in thinking about thermal bridges in North America, will in the long term, greatly benefit the industry. This will give much needed guidance to designers who are likely more to design efficient buildings if requirements are straightforward and easy to implement and consistent to all types of construction.

Overall, the method of linear transmittance is an easy and straightforward approach that will help clarify much of the confusion involved with analyzing thermal bridges in assemblies and their part in overall building thermal transmittance.

## 6.0 REFERENCES

ASHRAE, 2009. ASHRAE Handbook – Fundamentals, Atlanta, GA: American Society of Heating, Refrigeration and Air-conditioning Engineers, Inc.

ASHRAE, 2007. *ASHRAE Standard 90.1, Energy Standard for Buildings Except Low-Rise Residential Buildings*. Atlanta, GA: American Society of Heating, Refrigeration and Air-conditioning Engineers, Inc.

Roppel, P., Lawton, M., 2011. Thermal Performance of Building Envelope Details for Mid- and High-Rise Buildings. ASHRAE Research Project 1365-RP Final Report.

Janssens, A, E. V. Landersele, B. Vandermarcke, S. Roels, P. Standaert, P. Wouters, 2007. Development of Limits for the Linear Thermal Transmittance of Thermal Bridges in Buildings. Proceedings of the IX International Conference on the Performance of Whole Buildings, Clearwater, FL.

Svendsen, S., Laustsen, J.B., Jesper, K. 2005. Linear thermal transmittance of the assembly of the glazing and the frame in windows. Proceedings of the 7th Symposium on Building Physics in the Nordic ,pages: 995-1002, 2005, IBRI, Keldnaholti, IS-112, Reykjavik Iceland, Raykjavik, Iceland