Thermal and sound performance of lightweight constructions

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Abstract: A high-performance building envelope is synonymous with healthy living. Lightweight steel constructions as significant technological development to make buildings sure and more comfortable. Knauf presents the own analysis of thermal and acoustic behavior of drywall elements: analyzing the contribution of the metal profiles to the linear thermal bridge and soundproofing level. The range thickness of the metal stud analyzed (0,5÷2,5mm) could be used for load-bearing and non-load bearing elements: according with European directive 2010/31/UE-EPBD2 and UNI 11367 – UNI 11444.

Keywords: Drywall, Thermal bridge, Soundproofing, Metal profiles thickness.

Search Object

Steel lightweight constructions are typically characterized by a cold formed C-shaped steel structure collaborating with gypsum boards on each C-wing side.

Thickness of the cold formed C-shaped profile identifies the drywall systems for non-load bearing applications or light steel systems for load bearing applications. At the same time thermal and sound insulation performance are insure by a high performance gypsum board (with a high density of core and coating cardboard) and by the therno-pysical characteristics of the insulation material installed between the C-vertical stud. The main goal of this research is it to identify the correct correlation between thermal/sound insulation and steel sheet thickness, in order to develop a simple drywall system with own properties performance level in optimized light steel system: considering the effect of the linear thermal bridge (ψ [W/mK]) and soundproof insulation produced by the thickness variation of the C-profile.

Thermal analyzes were conducted using F.E.M software while the acoustic results are based on experimental tests.

Linear Thermal Bridging

Linear thermal bridging, represents the extra heat flow occurring at building junctions, which is over and above that through the adjoining planar elements. Linear thermal transmittance is measured in W/m.K, referred to as a 'psi-value' and expressed as a 'ψ–value'. The lower the ψ–value, the better the performance of a junction detail.

Linear thermal bridging are not taken into account in U–value calculations, but, instead, they are taken into account separately in the calculation methodologies used to assess the operational CO2 emissions of buildings.

The thermal resistance R is the resistance, a material counters a heat flow with at 1 °K for one m² and is based on the conductivity K. R is calculated as the thickness of the material divided by its thermal conductivity

$$R = \frac{l}{k}$$

k = thermal conductivity (W/mK)

l = material thickness (m)

This calculation of the R-value can also be performed for multilayer components, named as R_T:

$$R = \frac{l_1}{k_1} + \frac{l_2}{k_2} + \ldots + \frac{l_n}{k_n}$$

Based on the R-value the U-value thermal transmission coefficients, describe the amount of heat flow of an assembly. It is calculated as the reciprocal value of the sum of the thermal resistance and the surface resistances $1/h_0$ and $1/h_i$:on the conductivity K. R is calculated as the thickness of the material divided by its thermal conductivity.

$$U = \frac{1}{\frac{1}{h_0} + R_T + \frac{1}{hi}}$$

So the U-value describes the heat flow in a one dimensional way, which is needed to describe the energy loss of areas of the same assembly. This is not applicable to areas of thermal bridges. Heat flow through building assemblies was typically calculated using one dimensional, parallel path heat calculations. The general equation is:

$$Q = \left(U_1 \cdot A_1 + U_2 \cdot A_2 + U_3 \cdot A_3 + \ldots\right) \cdot \Delta T$$

Where:

- Q is the heat flow through a defined area of a building enclosure with multiple adjacent assemblies;
- U_x is the Thermal Transmission Coefficient in BTU/ h/ m^2/K for assembly x including the effect of the interior and exterior surface films;
- A_x is the Area of assembly x, in m^2;
- ΔT is the difference between the indoor air temperature and the outdoor air temperature.

It would be more comfortable working with the concept of thermal resistance (R) than its inverse thermal transmission (U). Using thermal resistance, equation 1 then becomes.

$$Q = \left(\frac{A_1}{R_{T1}} + \frac{A_2}{R_{T2}} + \frac{A_3}{R_{T3}} + \ldots\right) \cdot \Delta T$$

where:

R_{Tx} is the thermal resistance for assembly x, generally obtained by summing the resistance of each layer of material in the assembly including inner and outer air films and:

$$R_{effective} = \frac{\left(\frac{A_1}{R_1} + \frac{A_2}{R_2} + \frac{A_3}{R_3} + \ldots\right)}{A_{TOT}}$$

$$U_{effective} = \frac{1}{R_{effective}}$$

Q and $R_{effective}$ are useful to illustrate some important aspects of material thermal bridges.

Consider a wall with R 20 insulation; if 4% of its area is penetrated by a concrete slab and 0.07 % of its area by steel connectors, about the same amount of heat would go through each of the slab, the steel, and the rest of the wall. The Effective R-Value of the wall assembly would be about one third of the insulation value (i.e. about 4.2). Clearly, if one does not take into account the impact of thermal bridging, this can result in major errors in calculating heat flows through building assemblies and the purchased energy required to make them up.

In reality, the equations only hold true if heat flow is one dimensional and parallel or, in other words, there is little lateral heat flow so that heat does not move sideways and around thermally resistant elements. This has proven to be a reasonable approximation in wood frame construction, where even the structural materials have significant thermal resistance (wood is about R1 per inch). In buildings constructed of highly conductive materials such as concrete, steel, aluminum, and glass, the assumption of parallel heat flow is much less likely to be valid.

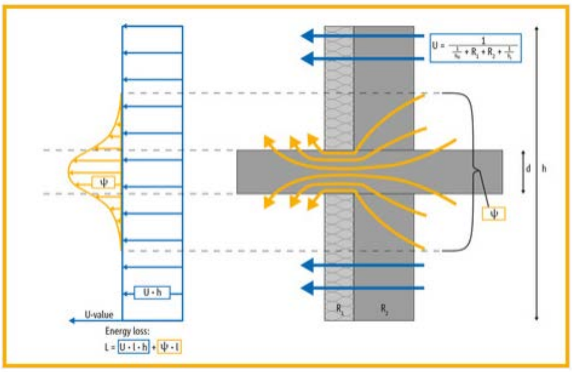

Fig. 1 Pattern of heat flow through a building enclosure with materials that allow lateral heat flow to a thermal bridge

Figure 1 illustrates several important concepts using the example of a slab, such as a balcony, penetrating a wall and therefore the insulation layer:

- Heat will flow laterally to the easiest path through the assembly (i.e. the slab).
- The clear field heat flow (U_0) is the heat flow through an assembly without thermal anomalies. The linear transmittance is the additional heat flow with the thermal anomaly due to lateral heat flow as shown in Figure 1.
- One can view the influence of the thermal bridge as being an additional heat loss due to the slab (the yellow area under curve on the graph) that is added to the heat loss of the wall without the slab (the blue area of the graph).

Recognizing that the heat flow through a thermal bridge can be added to the heat flow through a "clear field" building assembly provides a method of accounting for thermal bridges that cannot really be addressed by the "parallel path" method.. This is particularly true when the power of computer modeling can be used to determine the heat flow attributable to specific types of thermal bridges. It has proven useful to classify thermal bridges by how one would add them up:

- The impact of small, frequent and distributed bridging elements (e.g. brick ties or Z-girts carrying cladding) (see the girts in Figure 16 below) are generally best handled by adding their thermal influence to Clear Field Effective U-value (BTU/ft^2/ºF) for the assembly. The term U_0 is used to represent this.
- The heat transfer associated with linear element (e.g. slab edges, corners, roof/wall intersections, window wall interfaces etc.) can be handled by determining the Linear Heat Transmittance coefficient (BTU/h/ft^2/ºF). The Greek letter Psi (Ψ) is conventionally used to represent a linear transmittance.
- The heat transfer associated with intermittent or singular elements (e.g. beams or other projecting structural elements) can be handled by determining the Point Heat Transmission coefficient BTU/h/oF). The Greek letter Chi (χ) is conventionally used to represent a point transmittance.

Figure 2 illustrates an example of using computer modeling to determine the Ψ value of a linear thermal bridge, in this example a slab penetrating a wall. One creates two "models" with the same width and height:

The wall without the slab but with the frequent and distributed bridging elements (the Z-girts in this case) that one would want to include in U_0. The program provides the heat flow per unit time for the assembly (Q_0).

The assembly including the slab. The program provides the heat flow per unit time for the combined assembly (Q).

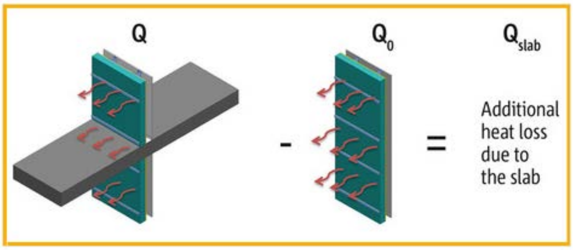

Fig.2 Example of process of determining the linear transmittance of a slab penetrating a wall

The difference in heat flow between the two models divided by the width of the modeled sections is the linear transmittance or Ψ for slab. This value is effectively the area under the yellow curve in Figure 1.

A similar process can be used to calculate the point transmittance of something such as a beam penetrating a wall. Linear and point transmittances can be determined by two or three dimensional thermal modeling for specific details. For example, a commonly used software package developed and routinely used to evaluate glazing systems called THERM can also be used to evaluate the thermal performance of any wall detail. Moreover, generic transmittance values becoming more readily available for use by industry (ASHRAE 1365-RP, Building Envelope Thermal Bridging Guide, ISO 14683).

Using this concept, the total heat flow through a building assembly with linear and point thermal bridges is calculated by adding the heat flow through the thermal bridges to that through the clear field of the assembly.

$$Q = \left\lfloor U_0 \cdot A + \Sigma(\Psi_i \cdot L_i) + \Sigma\chi_j \cdot n_{j)} \right\rfloor \cdot \Delta T$$

Where:

U_o is the "clear wall" assembly heat transmittance (including the impact of frequent and distributed bridging elements);
A is the area of the assembly, including all details in the analysis area;
Ψ_i is the linear heat transmittance value of detail "i";
L_i is the total length of the linear detail "i" in the analysis area;
χ_j is the point heat transmittance value of detail "j";
n is the number of point thermal bridges of type "j" in the analysis area.

To include the effects of thermal bridging transmittances to whole building energy simulation, the overall wall or roof assembly U-value inputs into the energy model should be modified by using the appropriate Ψ and χ factors. An equivalent total U-value can be entered into the models as:

$$U_{effective} = \frac{U_0 + [\Sigma(\Psi_i \cdot L_i) + \Sigma(\chi_j \cdot n_j)]}{A}$$

where $U_{effective}$ is the corrected U-value and all other terms have been previously defined.

If the energy model requires R-values, the surface transfer coefficients ("surface films") should be:

$$R_{effective} = \frac{1}{U_{effective}} - \frac{1}{h_0} - \frac{1}{h_i}$$

where h_o and h_i are the interior and exterior surface transfer coefficients respectively.