HEAT TRANSFER PROBLEMS IN AN ENERGY EFFICIENT BUILDING

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Abstract - Two-dimensional heat-transfer problems are important in passive house buildings because thermal bridges in walls, windows, and other components can have significant effects on energy performance and occupant comfort. Thermal bridges significantly lower effective insulation values and create unanticipated temperature gradients that can lead to thermal stress, condensation, and other effects. Three examples are considered in this paper. For each case, we perform computer simulations of the thermal transmittance, ψ. The results appear to be good with relative errors less than 5%

Keywords: passive house, thermal bridge, insulation, isotherms, heat flow

1. INTRODUCTION

The Passive House is the world's leading standard in energy efficient construction: Energy saved on heating is 80% compared to conventional standards of new buildings. The energy requirement for heating is lower than 10 to 20 kWh/(m²a) (depending on climate), adding up to a low cost of 10 to 25 € per month. Therefore high energy prices are no longer a threat to Passive House occupants. Exceptionally efficient components and a state of the art ventilation system, achieve these huge savings without compromising comfort, but rather increasing it. The Passive House concept is a comprehensive approach to cost-efficient, high quality, healthy and sustainable construction. The concept is easy to understand:

A passive house (PH) is a building in which the heat requirement is so low that a separate heating system is not necessary and there is no loss of comfort; in Germany, this is the case if the annual heat requirement is below 15 kWh/(m²a). The decisive idea to develop cost efficient passive houses was, that to dispense with a heating system the heat requirement need not be zero: If the maximum heat load is less than 10 W/m², then the extremely low required heat load can be provided without additional effort via the supply air. The characteristic figures of Passive houses are: very good thermal insulation (U-values < 0.15 W/(m²K)), avoidance of thermal bridges, high air tightness (n50-values < 0.6 h^{-1}), super-glassing (U-values < 0.8 W/(m²K) with solar transmittance factor g > 50 %) and ventilation systems with highly efficient heat recovery.

For the solar utilization the 'concept' can be described with following examples: the potential of the south side is used differently according to the single solar strategies. For instance the same south orientated surfaces, which gain the winter sun in a passive way, are available for the electricity generation in summer. The solar windows are largely arranged vertical – orientated to the low winter sun – because they shall deliver only the warmth of the winter sun. The fanlight windows in the south and the windows bring the light from the highest points of the building in the interior and make the best use of the daylight. In summer this fanlights deliver only diffuse sunlight, because they are lying in the North respectively are shaded completely. To build Passive Houses, highly efficient windows have to be used. The type of glazing and frames will depend on climate, however. In the Central European climate there are three essentials: Triple glazing with two low-e-coatings (or another combination of panes giving a comparable low heat loss),"Warm Edge" – spacers and Super-insulated frames.

These components harmonize in a way that the total heat loss of such a window is only half as high as compared to a conventional new window. But direct and indirect solar gains are collected through the glazing, too. Therefore, it has been demonstrated that by using these highly efficient windows, the result will be a positive energy balance even in the Central European winter period, as long as the orientation is suitable and the shading not excessive. The thermal loss coefficients, Uw, of such Passive House windows are lower than 0.8 W/(m²K) according to the new European standard (EN 10077). One consequence of such a low heat loss is that the interior surface temperature of such a window, even in cold European winter nights, will exceed 17 °C. This results in excellent thermal comfort even near the window: There will be neither trouble with "cold radiation" from the window nor an unpleasant lake of cold air at the floor. The 17 °C condition for minimum internal surface temperatures of windows in a Passive House is the defining requirement for Passive House windows in any given climate.

Through the chosen alignment (architecture) of the PV elements and the south glazing the building concept uses the changing stand of winter and summer sun without having to move itself or it's elements: the winter sun reaches into the building and the direct summer sun is entirely absorbed by the PV elements.

The Passive House vision defines highly ambitious long term goals for the future building stock. Passive Houses can be new-build or renovation. They can be homes, offices or public buildings. Passive House proposes a target framework for how to design and renovate such buildings that contribute positively to human health and well- being by focusing on the indoor and outdoor environment and the use of renewable energy.

A Passive House interacts positively with the environment by means of an optimised relationship with the local context, focused use of resources, and on its overall environmental impact throughout its life cycle. [1];[2] ;[3]

2. THERMAL BRIDGES

A thermal bridge is a localized area of the building envelope where the heat flow is different (usually increased) in comparison with adjacent areas (if there is a difference in temperature between the inside and the outside). The effects of thermal bridges are:

- Altered**,** usually decreased, interior surface temperatures; in the worst case this can lead to moisture penetration in building components and mould growth.
- Altered, usually increased, heat losses**.**

Both effects of thermal bridges can be avoided in Passive Houses: the interior surface temperatures are then so high everywhere that critical levels of moisture cannot occur any longer – and the additional heat losses become insignificant. If the thermal bridge losses are smaller than a limit value (set at 0.01 W/(mK)), the detail meets the criteria for "thermal bridge free design". If the criteria for thermal bridge free design are adhered to everywhere, the planners and construction manager don't have to worry about cold and damp spots any more – and less effort will have to be made for calculating the heat energy balance.Thermal bridge free design leads to substantially improved details; the durability of the construction is increased and heating energy is saved. A building envelope is considered to be thermal bridge free if the transmission losses under consideration of all thermal bridges are not greater than the result calculated using the external surfaces and regular U-values of the standard building elements alone. This is summarised using formulas as follows. The overall temperature-specific heat loss is characterised by the transmission conductance H_T. It comprises the regular losses of all areas A with their regular heat transfer coefficient U - $\mathbf{U \cdot A}$ .This regular loss does not include the thermal bridge contributions ($\Psi \cdot l$) and neither the punctiform contributions χ (Ψ is the linear, χ the punctiform thermal bridge loss coefficient). As the punctiform contributions are generally insignificant, they will not be discussed in detail here. "Thermal bridge free design" can be defined as follows: the contributions provided by the thermal bridge contributions are smaller than or equal to zero:

$$\sum \Psi \cdot l + \sum x \leq 0 \text{ [defined as thermal bridge free]} \qquad (1)$$

It will then be admissible to omit the thermal bridge effects, thus simplifying the calculation quite considerably. This is equivalent to the following statement $\mathbf{\Delta\ U_{WB} \leq\ 0}$, where $\Delta\ U_{WB}$ is the thermal bridge correction addend (as used in the German energy saving regulation for example). Reviewal using this definition of thermal bridge free design would imply that all details would have to be calculated in a multi-dimensional way. Therefore, simplified criteria for "thermal bridge free design" should be devised. It was found that for ordinary building geometries, the "thermal bridge free" requirement was almost always sufficiently fulfilled for all linear disturbances only if

$$\Psi \leq 0.01 \text{ W/(Mk) } \textit{[TbCrit]}. \qquad (2)$$

Thermal bridges which comply with *[TbCrit]* can still lead to positive contributions to a certain extent, which would be considered as "negligibly small" even within the context of Passive Houses. Besides, the remaining contributions are compensated to a certain extent by other connections where there are negative thermal bridge loss coefficients. The *[TbCrit]* requirement is enough for all structures which affect connections, edges, and individual interruptions in consistent areas. Recurring interruptions in consistent areas must already be taken into account when giving the regular heat transfer coefficient U_{reg}. With the simplified criterion, planning and construction become significantly easier: for a particular category of connection details, it only has to be verified once in advance that the*[TbCrit]* criterion has been met. This can be done, for example, by calculating all the relevant details for building envelopes. [4]

There are two types of thermal bridges. The linear or 2D ones are situated at the junction of two or more building elements and they are characterised by a linear thermal transmittance (or ψ-value in W/m K). The point or 3D ones lie where an insulated wall is perforated by an element with high thermal conductivity or where there are threedimensional corners and they are characterised by a point thermal transmittance (or χ-value in W/K). In most cases evaluations will be limited to linear thermal bridges, most common; 3D calculations will be exceptional. The evaluation of thermal bridges can be done experimentally by using standardised test methods on two identical building elements, the first one with and the second one without a thermal bridge. This method is limited to those building elements that can be so tested. Thus, the accuracy of the assessment is rather uncertain, it is time-consuming, expensive and laborious, only applicable for important projects or for checking the reliability of simulation calculations [5]. Thermal bridges can therefore be evaluated by using numerical methods. A lot of software helps for it [6-8]. However they need minimum skills and some care for defining the boundary conditions. Catalogues [9] give several examples of thermal bridges for fixed parameters (e.g. dimensions and kind of material). So they are less flexible than calculations[11]. In Romania, like in many European

countries, tabulated values of ψ are given for typical cases. But they often do not match with the actual details of any building project.
In this paper, we simulate the thermal transmittance of three different 2D thermal bridges. We begin with a numerical computerization of the thermal transmittance for a limited number of values for the most important variables that influence the ψ-value.
Numerical calculations of the heat transfer through a thermal bridge require the use of methods with numerical resolution like finite element or finite difference methods. The European Standard EN ISO 10211-2 [10] describes the calculus method for linear thermal bridges and superficial temperatures. The software used here, THERM refers to the finite difference method in order to calculate the global heat flows through the thermal bridge and the adjacent walls under steady-state conditions. Fig. 1 shows a geometrical model of 2D thermal bridge.

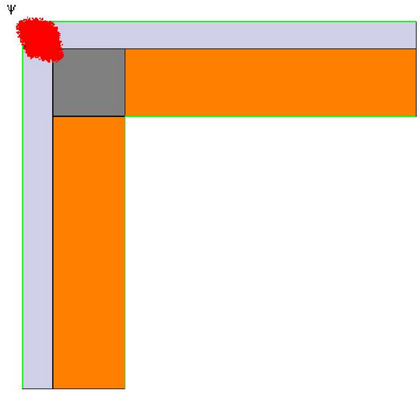

Fig. 1. Geometrical model of a 2D thermal bridge

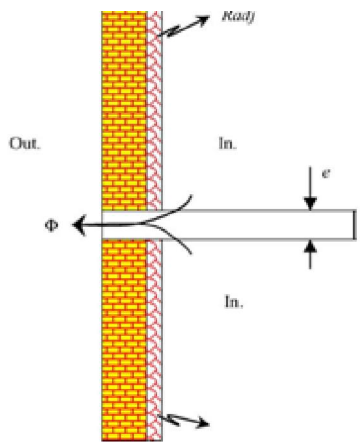

Fig. 2. Modelling of heat transfer through a 2D thermal bridge

The linear thermal transmittance is given by:

$$\Psi = \frac{\Phi g}{\Delta T} - \sum_{i=1}^{N} UiLi \quad (3)$$

where Φ_g is the global heat flow per unit of length (W/m), Ui the thermal transmittance of the 1D component i separating the two environments (W/m^2 K), Li the length within the 2D geometrical model over which the value Ui applies (m), ΔT the temperature difference between the inside and outside environment (K) and N the number of 1D components. [11]
The calculation hypotheses are given in the following tables for the boundary conditions (Table 1) and the thermal conductivities (Table 2).

Table 1. Boundary conditions

	Surface heat transfer coefficient (W/m^{2}K)			Temp(°C)
	Horizontal flow	Upward flow	Downward flow	
Internal	7.69	10	5.88	20
External	25	25	25	-10
	Surface thermal resistance (m^{2}K/W)			
	Horizontal flow	Upward flow	Downward flow	
Internal	0.13	0.10	0.17	20
External	0.04	0.04	0.04	-10

Table 2. Thermal conductivity of materials

Material	Conductivity (W/mK)
Insulation	0.04
Concrete	2.00
Masonry	0.7

The statistical model used to fit the values of a linear thermal transmittance obtained from the computer simulation is based on the heat flow per metre through the part of the wall that constitutes the thermal bridge (Fig. 2), given by the relation:

$$Q2Dim = eU\Delta T \quad \text{(W/m)} \quad (4)$$

where e is the width of the thermal bridge (m), U the thermal transmittance of the portion of the wall that constitutes the thermal bridge (W/m2 K), and ΔT the temperature difference between the inside and outside environment (K). However, the heat flow through the thermal bridge also depends on the insulation of the building envelope. Therm program provide realistic results using finite elements method and determine the total two-dimensional heat flow, Q_{2Dim} . The linear thermal bridge loss coefficient Ψ describes the difference between the actual heat flow Q_{2Dim} and the one-dimensional approximately calculated heat flow.
The linear Ψ value is calculating using:

$$\Psi = \frac{Q2Dim - Q1Dim}{l \cdot \Delta T} \quad \text{(W/mK)} \quad (5)$$

$$Q1Dim = \sum AiUi\Delta Ti \quad \text{(W/m)} \quad (6)$$

3. RESULTS AND DISCUSSION

This section presents numerical results for three thermal bridges, which amounts for the most of the overall envelope heat loss. For each one, we give on one side the thermal characteristics (flow lines) and on the other the ψ-value (W/ m K). For each thermal bridge three situations have been simulated; the exterior wall, with external insulation, of either 10cm, 15cm or 20cm.

3.1. Regular corner

Figure 3 and 4 show the isotherms of the 2D thermal bridge and the color flux magnitude, respectively. In this case the ψ value depend on the thickness of the insulation. As shown in Fig.3 the isotherms concentrate on the interior corner. This is a weak point which can cause condensation problems if the thermal insulation is low dimensioned.
The ψ -values for this situation are given in Table 3.

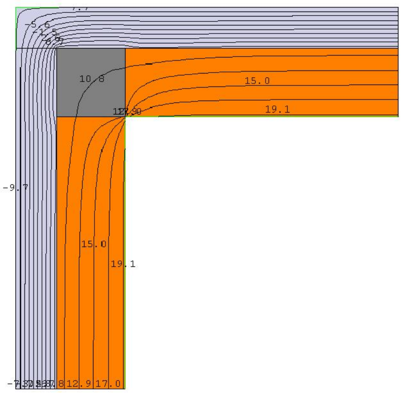

Fig. 3. Isotherms

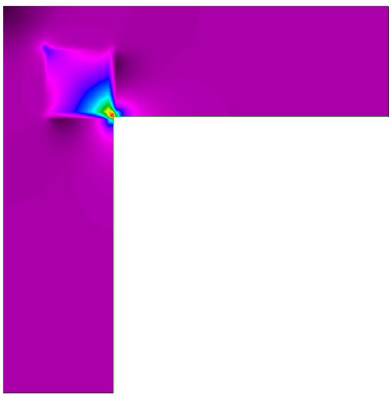

Fig. 4. Color flux magnitude

Table3. ψ –values for the corner

Regular Corner			
Composition: Insulation, Brick- 25cm, Concrete 25x25			
Thickness of insulation (d) cm	Q_{2Dim}	Q_{1Dim}	ψ
10	16.24	16.93	-0.023
15	12.81	13.78	-0.032
20	10.6	11.75	-0.038

With external dimension reference for a purely geometrical thermal bridge the actual total heat flow (2-dimensional flow calculation) is smaller than that for the one-dimensional calculation. Ψ_e therefore has a negative prefix and results in a ″credit" in the heat balance. For example for 20 m of external wall edge this would be about 104kWh/a (for standard climate G_t=84 kWh/a); for 150 m^2 living space at least 0.69 kWh/(m^{2}a). If this thermal bridge is ignored , the heating energy baance is on the safe side. With internal dimension reference the actual total heat flow (2-dimensional calculation) is greater than that for the one-dimensional calculation. Ψ_i therefore has a positive prefix and results in an additional transmission heat loss. When the interior dimension reference is used the thermal bridges are not to be ignored. For a passive house we always use external dimensions.

3.2. Terrace–wall junction

Figure 5 and 6 show the isotherms of the 2D thermal bridge and the color infrared, respectively. In this case the ψ value depend on the concrete slab thickness, the wall and slab insulations. The ψ -values for this situation are given in Table 4

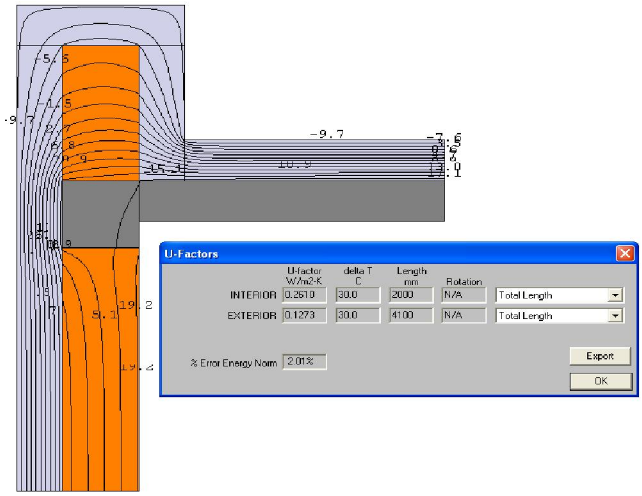

Fig. 5. Isotherms

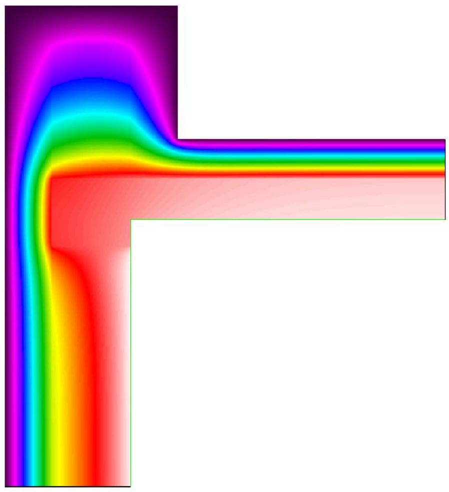

Fig. 6. Color infrared

Table 4. ψ –values terrace-wall junction

Terrace-wall junction
Composition: 1.Wall- Insulation, Brick- 25cm; 2. Terrace-Concrete slab-13cm, Insulation

Thickness of insulation (d) cm	Q_{2Dim}	Q_{1Dim}	ψ
10	27.06	25.11	0.064
15	19.46	17.77	0.056
20	15.22	14.11	0.037

3.3 Floor-wall junction

Figure 7, 8 and 9 show the isotherms of the 2D thermal bridge, the color infrared and color flux magnitude, respectively. In this case the ψ value depend on the floor thickness and the wall insulations. The ψ -values for this situation are given in Table 5.

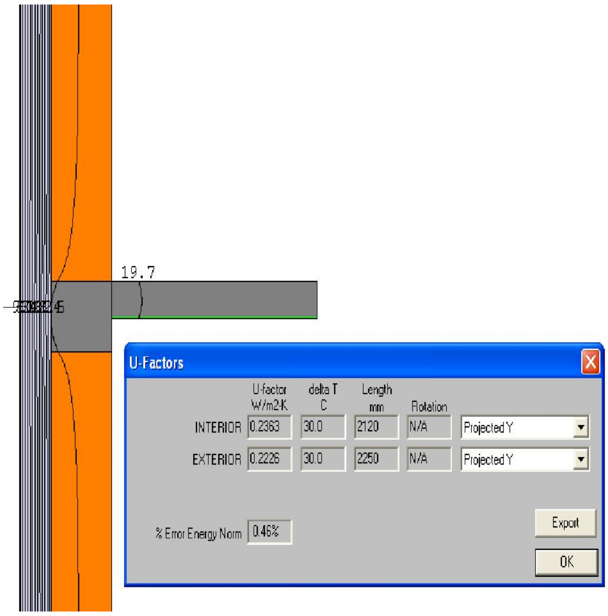

Fig. 7. Isotherms

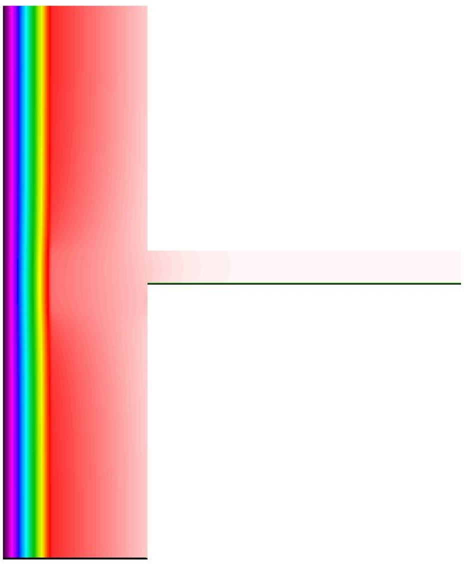

Fig. 8. Color infrared - 15cm insulation

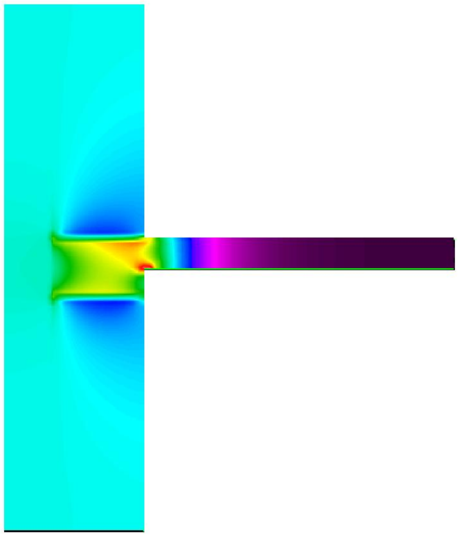

Fig. 9. Color flux magnitude

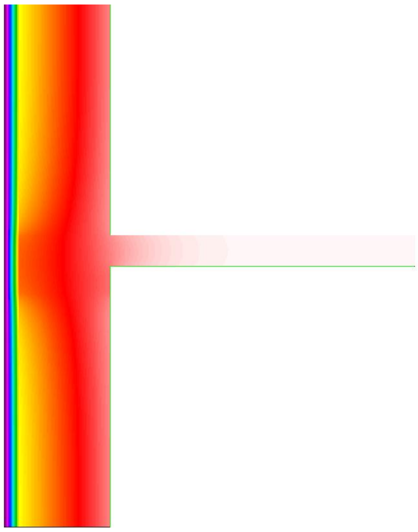

Fig. 10. Color infrared – 5cm insulation

Table 5. ψ –values floor-wall junction

Floor-wall junction			
Composition: 1.Wall- Insulation, Brick- 30cm; 2. Floor-Concrete slab-13cm			
Thickness of insulation (d) cm	Q_{2Dim}	Q_{1Dim}	ψ
5	36.31	35.23	0.036
10	21.26	20.86	0.013
15	15.03	14.85	0.006
20	11.62	11.54	0.002

4. CONCLUSION

In a passive house constructive thermal bridges should be avoided not only because of potential energy losses but also because of the increase of comfort in the home. This also prevents potential premature failure of the building substance due to condensation around thermal bridges. In general the goal should be to detail the connections between the different building envelope assemblies in such a way that an unterrupted insulation layer is created. If there are supports for reinforced concrete slabs, window lintels, or concrete columns in the exterior wall, then they need to be placed without interfering with the continuous layer of exterior envelope insulation. The exterior layer of insulation has to surround these elements in full thickness. The resulting thermal bridge heat losses can then be ignored. If all building elements are planned following these principles and constructed avoiding heat losses from thermal bridges, then "thermal bridge-free construction" is achieved. If it is not possible to avoid thermal bridges completely, the thermal bridge effects should be reduced as much as possible using thermal separation.

Acknowledgment: This work was partially supported by the strategic grant POSDRU/88/1.5/S/50783, Project ID50783 (2009), co-financed by the European Social Fund – Investing in People, within the Sectoral Operational Programme Human Resources Development 2007-2013.

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