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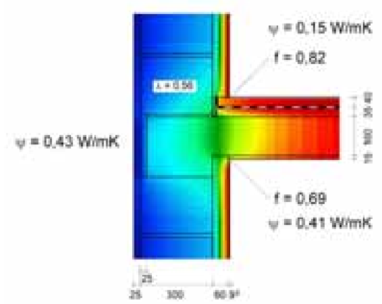

Example of a thermal bridge effect at a concrete ceiling embedded in the external wall.
Calculation of the thermal bridge loss coefficient and the dimensionless temperature coefficient. The colours illustrate the temperature distribution within the construction.
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Impact of thermal bridges on the energy performance of buildings

Thermal bridges have influence on the surface temperature of building components, but also on the energy performance of buildings. The ratio of losses due to thermal bridges to the total transmission losses is small in existing, non-retrofitted buildings but can become quite considerable in new and especially in high performance buildings. This paper summarizes studies on the impact of thermal bridges on the energy performance of buildings in different European Member States and gives therefore an indication on the relevance of including detailed thermal bridge assessments in the EPBD calculation methods.

1 > Questions to be answered

Thermal bridges in building structures and component joints have impact on the surface temperature of the relevant building components. Due to the lower thermal resistance, the internal surface temperature on components with thermal bridges is reduced in winter and can in many cases lead to problems with moisture and mould. Additionally thermal bridges have an impact on the energy performance of buildings as they increase the heat transfer through the building envelope, meaning they cause additional transmission losses in summer and winter. Yet:

- How big are these transmission losses due to thermal bridge effects in absolute and relative values?
- What is the influence on the total final or primary energy consumption of a building?
- Should an energy performance assessment method for buildings include a possibility for a detailed calculation of the impact of thermal bridges?

The Intelligent Energy Europe project ASIEPI has collected studies dealing with the influence of thermal bridges on the energy performance of buildings which have been performed in different European Member States. They are summarised here and a conclusion concerning the importance of a detailed assessment method within the energy performance calculation of buildings is drawn.

2 > International studies on the quantification of thermal bridge effect on the energy performance

As presented in Information Paper 64 “Thermal bridges in the EPBD context: overview on MS approaches in regulations” [1] not all analysed countries consider the influence of thermal bridges in their regulations for

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new buildings and even less for the renovation of existing buildings. In the case of new buildings an explicit calculation of thermal bridges is used in 35 % of the countries in North Europe, 100 % in Central Europe and 50 % in South Europe. Most countries use a simplified approach, e.g. default values for including the increased thermal losses due to thermal bridges. Even in countries where a detailed calculation method for thermal bridges is part of the energy performance calculation standard, a simplified alternative method is often offered. Then the simplified method is applied more frequently than the detailed method.

In some Member States studies on the influence of thermal bridges have been carried out, often in order to see if this impact can be either neglected or substituted by default values. The ASIEPI project has collected studies from the following countries: Germany, France, Denmark, The Netherlands, Czech Republic, Poland, Belgium and Greece. The studies were either made with typical buildings, with a collection of up to 200 buildings, or with pilot projects for high performance buildings. Also the results are expressed in different ways: as additional transmission losses, as additional net heat energy demand or as additional primary energy demand.

Germany: Demonstration project 3-liter-houses Celle - Thermal bridge influence on the energy performance of the Ziegel-Aktiv-Haus [2]

Photo of the double house used for the German study on the impact of thermal bridges on the energy performance of buildings.

Main results of the German study on the impact of thermal bridges:

- Improved joints can reduce the energy need for heating by 11.4 kWh/m²a (compared to standard constructions) and 4.4 kWh/m²a (compared to state of the art constructions)
- At high performance buildings the primary energy for heating can be reduced by 4 to 5 kWh/m²a. This is 15 % of the allowed demand for a 3-liter house.
- Thermal bridges can have the same influence as solar thermal hot water generation.

In this demonstration project concepts for high performance houses have been developed and some of the concepts have been built. The aim was to achieve a primary energy demand of less than 34 kWh/m²a which can be recalculated to less than 3 liter oil per m² and year for space heating, ventilation and auxiliary energy. The concepts included different technologies and strategies, one of them being the reduction of energy losses due to thermal bridges. To this end, not only have advanced building joints been developed, but also a study on the comparison of the default values for thermal bridges that are used in the German energy performance code with the explicitly calculated values has been carried out. The German standard DIN V 4108-6 foresees default values for standard joints (ΔU=0,10 W/m²K) and for state of the art joints (ΔU=0,05 W/m²K) according to a leaflet with example joints.

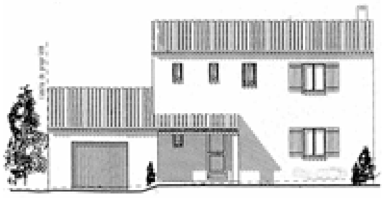
The double house consists of an advanced brick construction with low thermal conductivity of the bricks, highly insulated roof and basement slabs and triple glazed low-E-coated windows. The heating system of each unit is a gas condensing boiler combined with solar collectors feeding into the heat storage and ventilation by window opening in one, and a mechanical ventilation system with heat recovery in the other.

There have been 16 linear joints analysed and improved starting from the external wall corners, window and door frame connections, roof-wall joints, dormer constructions, to connections between wall and slab. The results of the study are presented in the following table:

Savings of Ziegel-Aktiv-Haus compared to	Standard	State of the art
ΔU [W/m²K]	- 0.081	-0.031
Energy need for heating [kWh/m²a]	-11.4	-4.4
Primary energy for heating [kWh/m²a]	-9.9 / -12.6*	-3.8 / 4.8*

* two different heating systems in the double house units.

Compared to the standard values for joints the net energy demand for heating can be reduced by 11.4 kWh/m²a if all joints are well designed and explicitly calculated. Compared to state of the art joints 4.4 kWh/m²a can be saved. For the building systems used in the two units of the double house, the primary energy for heating can be reduced by 9.9 kWh/m²a respectively 12.6 kWh/m²a referred to standard constructions and still about 4 to 5 kWh/m²a referred to state of the art constructions. As 34 kWh/m²a primary energy for heating and ventilation is the limit for such a high performance building, a reduction of 5 kWh/m²a (=15 %) is an important part of the energy concept. The necessary reduction of the wall U-value compared to state of the art to compensate for not improved joints would be 0.1 W/m²K (with a 90 m² wall). Thermal bridges (and airtightness) have the same influence as solar thermal hot water generation if compared with standard joints (>10 kWh/m²a primary energy reduction).



Example building used for the French study on the impact of thermal bridges on the energy consumption of buildings.

Main results of the French study on the impact of thermal bridges:

- Improved joints can reduce the primary energy for heating by more than 18 kWh/m²a (compared to standard constructions)
- This is a reduction of 15% of the primary energy for heating.

France: Thermal bridge influence on the primary energy [3]

The French project partners have conducted a study for a new single family house with concrete construction and a gas condensing boiler as heat generator. The house has a suspended ground floor and attic. The climate zone H1A (Paris) was chosen for the study. Nine different thermal bridges were analysed in detail including the connections of basement slab to walls, of ceilings to walls, doors, etc. Then followed an analysis of corrective techniques such as thermal bridge rupture as an isolated measure or in combination with other measures such as the insulation of ceiling and floor.

The results are presented in the following table for the mean U-value of the building ($U_{bât}$ in W/m²K), the difference to the original mean U-value of the buildings and the primary energy demand for heating. The standard realisation resulted in a mean U-value of 0.56 W/m²K, an energy use for heating of 75.92 kWh/m²a and a primary energy for heating of 117.76 kWh/m²a.

Corrective technique	$U_{bât}$ [W/m²K]	$\Delta U_{bât}$ [W/m²K]	Saved primary energy for heating [kWh_{PE}/m²/a]
Thermal bridge rupture	0.50	-0.06	-8.45
Thermal bridge rupture + insulated drop ceiling	0.48	-0.08	-11.34
Thermal bridge rupture + floating screed	0.45	-0.11	-15.37
Thermal bridge rupture + insulated drop ceiling + floating screed	0.43	-0.13	-18.14
External insulation	0.45	-0.11	-15.37

The French study showed that the improvement of joints can result in a primary energy saving of more than 18 kWh/m²a, that is more than 15 % of the primary energy for heating.

Example building used for the Danish study on the impact of thermal bridges on the energy consumption of buildings.

Denmark: Low energy class 1 typehouses according to the Danish building regulations [4]

The low energy class 1 type house is a new highly insulated building with lightweight wooden external walls with a brick facing, a wooden roof construction, a concrete slab floor and joints optimised to reduce thermal bridge effects. The three analysed thermal bridges are those that have specific demands (standard requirements) in the Danish building code. The Danish building code contains stricter requirements for thermal bridges at extensions to an existing house than for new buildings. The following table shows the thermal bridge loss coefficients for the optimised building and

Main results of the Danish study on the impact of thermal bridges:

- The saved primary energy compared to new buildings according to the requirements in the building code is 5.2 kWh/m²a.
- To compensate for this the original U-value of the low energy building of 0.105 W/m²K had to be improved by 0.03 W/m²K.

the requirements in the building code:

Type of detail	Thermal bridge loss coefficient [W/mK]		
	Requirement for new buildings	Requirement for additions to a house	Calculated for the low energy class 1 type house
Slab with floor heating - external wall	0.20	0.12	0.063
Slab with floor heating - doors/high windows	0.20	0.12	0.093
Window reveal including window wall joint	0.06	0.03	0.059

The saved primary energy due to improved joints compared to the requirements for new buildings is 5.2 kWh/m²a; compared to an addition to an existing house 1.6 kWh/m²a. If instead of improved joints the same impact should have been reached by a higher insulation of the 154 m² wall, the reduction of the U-value had to be 0.03 W/m²K for the new building. With an original wall U-value of 0.105 W/m²K this is not easy to achieve.

Main result of the Dutch study on the impact of thermal bridges:

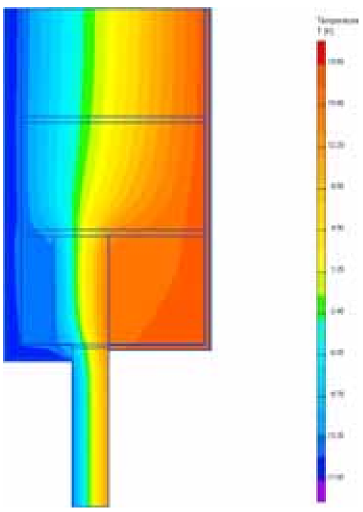
- The detailed calculation of thermal bridges compared to the nationally used default values can lead to reductions in the EP value between 3.75% and 11.25 % depending on the house type.

The Netherlands: Effects of using default values for thermal bridges in the EP calculation versus using detailed calculations [5]

A consulting office was contracted by an insulation manufacturer in 2005 to perform a study to compare the effect of using the Dutch default values for thermal bridges in the energy performance calculation with detailed calculations. The exemplary buildings used for this study were 5 reference new residential buildings with brick construction: an end house, a terrace house, a semi-detached house, a gallery flat and a detached house. For all the houses the lengths and the thermal bridge loss coefficients of all joints have been calculated. The result of the study was the difference in the energy performance between the calculation based on the default value for thermal bridges (U-value + 0.1 W/m²K) and based on detailed calculations which resulted in a lower energy performance value EP:

Reference house	∆ EP/EP value of 0.8 [%]
End house	7.5
Terraced house	3.75
Semi-detached house	7.5
Gallery flat	3.75
Detached house	11.25

The study showed that a detailed calculation of the thermal bridge effect can lead to up to an 11% lower EP value.



Exemplary result of the detailed calculation of thermal bridges in the Czech study. Here: window lintel.

Czech Republic: Influence of thermal bridge details on the energy performance of houses with different energy quality [6]

This study analysed the growing impact of thermal bridges with the improved energy quality of houses. The example building used for this study was a residential building with brick construction and wooden frame windows. The following graphic presents the impact of the thermal bridges on the energy need balance of 4 similar houses. At typical houses of the 1970s (bar on the left) the relative impact of thermal bridges is 7 % while with improving quality, the impact can get as high as 28 % (bar on the right for the currently recommended technical standard).

Main result of the Czech study on the impact of thermal bridges:

- With an improved technical standard of the house, the relative influence of thermal bridges on the energy need balance increases from 7% (regular house of the 1970s) to 28% (currently recommended standard).

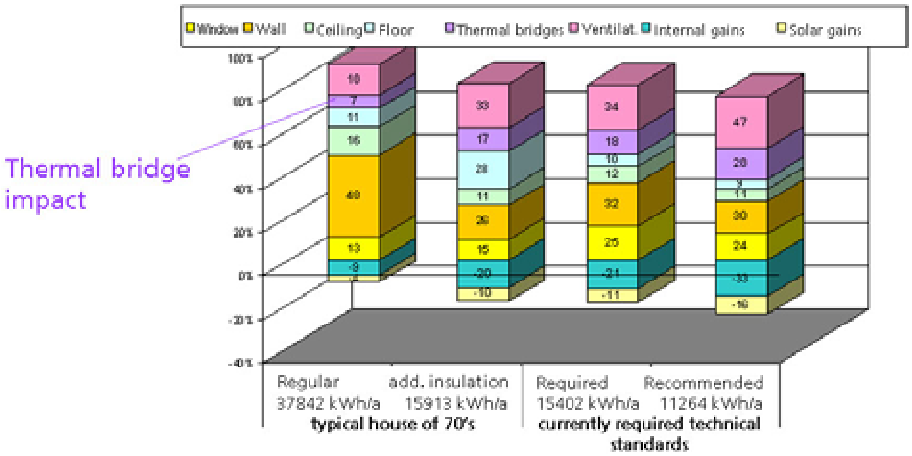


Photo of the example building used for the Polish study on the impact of thermal bridges on the energy performance of buildlings.

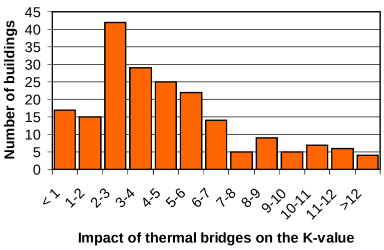
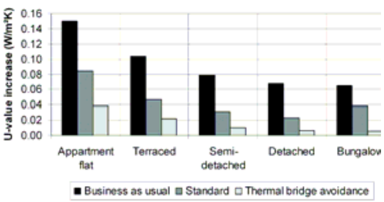


Diagram showing the impact of thermal bridges on the K-value of 200 different houses in Flanders.



U-value increase due to the impact of thermal bridges in different types of cavity wall dwellings in the 2nd Belgian study.

Poland: Quantitative study of thermal bridges in residential buildings [7]

A typical design of a two-storey single-family house with aerated concrete construction and a wooden roof was analysed by the Polish partners in ASIEPI. Thirteen different thermal bridges were calculated in detail. The main result was the difference between the default value for the impact of thermal bridges on the energy performance and the detailed calculation expressed by an addition to the thermal transmittance losses (Δ U * building surface area). The Δ U-value according to the detailed calculation was 0.036 W/m²K, whereas the standard Δ U-value for thermal bridges is 0.1 W/m²K and the value for state of the art joints 0.05 W/m²K. When calculating with the detailed results, the thermal bridges are responsible for 5.9 % of the thermal loss through the building envelope (transmission and ventilation).

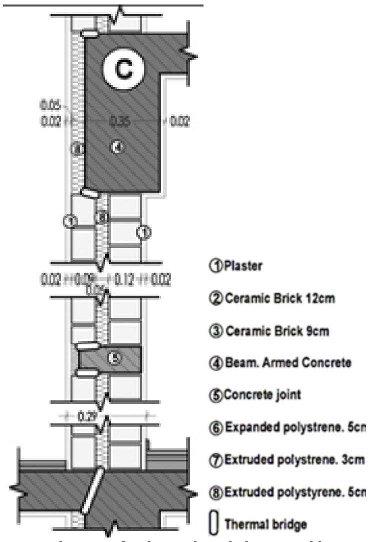
Belgium: Study of the energy aspects of new dwellings in Flanders: insulation, ventilation, heating [8]

200 residential buildings that were constructed between 1990 and 1996 have been analysed in a simplified manner concerning various thermal bridges. In Flanders, the thermal quality of the building envelope is expressed through a so-called K-value: a dimensionless area-weighted average thermal transmittance value. The current requirement for the building envelope is K45. According to the study the average impact of the thermal bridges is approximately 5 K-points. With 45 K-points as the maximum, the thermal bridges have about 10 % impact on this value. The study only analysed the impact on the thermal transmittance. The Belgian partners in ASIEPI estimated the average energy impact of the thermal bridges (compared to zero net thermal bridges) based on the energy performance calculation method as:

- ~ 8 kWh/m²a energy needs for space heating
- ~ 11 kWh/m²a energy use
- ~ 10 kWh/m²a primary energy

The reduced primary energy compared to the energy use is due to increased consumption for (fictitious) cooling.

In another Belgian study [9], cavity wall dwellings with 20 cm wall insulation have been analysed. Three scenarios (little attention to thermal bridges, standard attention and thermal bridge avoidance) have been compared regarding the increase of the U-value based on the thermal bridge effects of 23 different joints. The main results were:



Section of the double wall construction analysed in the Greek study.

- When insufficient attention is paid to the avoidance of thermal bridges the increase of the average thermal transmittance can be as high as 0.06 - 0.15 W/m²K.
- When attention is paid to thermal bridge avoidance the increase of the average thermal transmittance can be as low as 0.01 – 0.04 W/m²K.

Greece: The impact of thermal bridges on the energy demand of buildings with double brick wall constructions [10]

The paper presents a study on representative configurations of thermal insulation at external walls in order to investigate the impact of the thermal bridges on the energy consumption in both summer and winter conditions. A three-storey apartment building equipped with heating and cooling systems was calculated with a dynamic simulation program under the climate of Thessaloniki. While the study assesses 4 different insulation scenarios from typical application to external insulation it also calculates the (total) impact of thermal bridges on the heating and cooling demand. For this information paper the results of the thermal insulation scenario according to the minimum requirements for the coldest zone in Greece (5 cm insulation thickness) are summarised in the following table.

Characteristic value	Unit	Excluding thermal bridges	Including thermal bridges
Specific annual energy use for heating	kWh/m²a	71	92
Maximum heating load	kW	24.8	30.4
Specific annual energy use for cooling	kWh/m²a	30	31
Maximum cooling load	kW	15.4	17

The impact of the thermal bridges on the annual energy need for heating is 30 % or 21 kWh/m²a. The specific energy need for cooling difference is much lower with 1 kWh/m²a or 3 %. On the other hand, the calculations show that also the summer influence of thermal bridges shouldn’t be neglected as the difference of the maximum cooling load is more than 10 %. It can be assumed that if the climate region would have been warmer, the impact on the cooling load and cooling energy need would have been higher.

3 > Summary and conclusions

It is advised to read the presented results of national studies regarding the impact of thermal bridges on the energy demand of buildings with care. Most of the studies compare existing default values for thermal bridge impacts in national standards with detailed thermal bridge calculations of improved joints such as the German, the French, the Danish, the Dutch and the Polish study. Other analyses including the Czech, Belgian and Greek studies presented here have as results the (total) impact of the thermal bridges on the energy performance without comparing it to default values. Also the amount of analysed joints, the building geometry, the climate, etc. vary between the studies. Still the results can be summarised as follows:

- The total impact of thermal bridges on the heating energy need is in general considerable and can be as high as 30 %.
- The impact on the cooling energy need is significantly lower. There is however still a significant summer influence regarding the maximum cooling load.
- Countries with national default values for thermal bridges have mostly set those values in order to be on the “safe side” meaning that they result in slightly higher impact than if the joints are analysed in detail

with 3D-simulation programs.

- If national default values are compared with improved joints regarding the energy quality, the difference of the heating energy can be as high as 11 kWh/m²a energy need or 13 kWh/m²a primary energy. Another study showed an influence of 18 kWh/m²a primary energy.
- The relative impact of improved joints compared to national default values on the primary energy for heating can amount to 15 %.

The following conclusions can be drawn:

- The impact of thermal bridges in both winter (heating energy demand and heating load) and summer performance of buildings (cooling load) can't be neglected and should be included in the national calculation methods by default values and/or detailed calculations.
- In order to motivate for improvements of joints it should be offered to use lower values than the default value for thermal bridges according to the result of detailed calculations. Due to that improved joints can be used as method to improve the energy performance of buildings similar to better insulation, more efficient systems, etc.
- Better joints do not only reduce thermal bridge losses but also improve the airtightness of the building.

4 > References

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* to be available at the end of the project.

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