Research Project

Analysis of the quality of restoration of buildings with regard to remaining and new thermal bridges

Condensed Report

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Statement of task

Rising energy costs and a higher level of standards regarding admissible energy consumption, recently aggravated by the introduction of the Energy Economy Ordinance (EnEV) in 2007, necessitate dealings which are both long-lasting and protective of finite sources of energy. This is increasingly becoming a central political and economic subject. Above all, an efficiently insulated building envelope contributes to a reduction of heating energy needs in the construction field. This can at least be assumed from the undisturbed regulation construction parts in the case of new buildings. Considerable optimisation potential is the result when the connection details are executed in a manner which will minimise thermal bridges.

At present, efforts made in the energetic restoration of existing buildings through the KfW-programme are being further intensified.
Energy losses via thermal bridges continue to gain significance in the result of the renovations.
In case of insufficient quality in executing restorative measures, it is not only the energetic efficiency that is limited, but there is also the danger of consequential damage in and on the building. Thermal bridges are one of the main causes of mildew formation.
There is still a need for clarification concerning the influence of thermal bridges on heating energy consumption and, deriving from this, suggestions for the avoidance of thermal bridges in building restoration must be processed.

With the research project “Analysis of the Quality of the Restoration of Buildings with regard to Remaining and New Thermal Bridges,” priority statements are to be delivered concerning the extent of thermal bridges – both those not rectified during restoration and those which have been newly created through restoration.

Alongside insights concerning the actual extent of thermal bridges, the research project intends to consider their economical significance as well. Results concerning the economic efficiency of the prevention of thermal bridges in the planning and execution of renovatory measures will be compiled.

Execution of the research task

The research project “Analysis of the Quality of the Restoration of Buildings with regard to Remaining and New Thermal Bridges” is one of a series of investigations of existing buildings in Germany.
At the present time, scientific investigations in existing buildings are increasingly concerned with questions of energy, especially under the aspect of the necessity of modernisation and renovation of old existing buildings. These investigations deal with the quality and energy efficiency of the renovations. Thus, within the framework of considerations of quality, the significance of thermal bridges has increasingly come to the fore in recent years. New regulatory bodies have been part of the result, as for example the EnEV and thermal bridge catalogues.

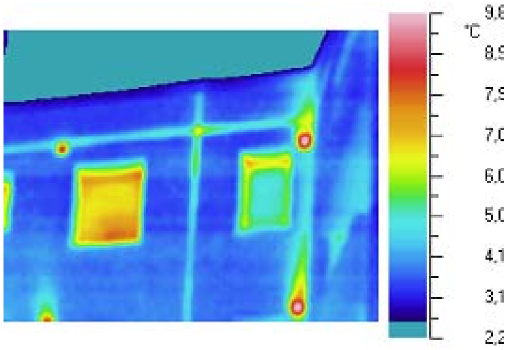
The present research project is profoundly concerned with the influence of thermal bridges on the energy efficiency of the building envelope after renovation. It especially focuses on older multiple dwelling units.

The results were gained by means of a field study. For this, contact was made with apartment construction companies, owners and planning bureaus, and possible multiple dwelling units probed in accordance with prescribed criteria.

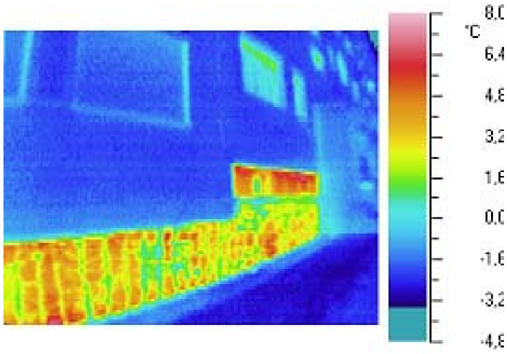
15 representative typical multiple dwelling units built according to the industrial building method and 15 multi-family buildings built according to the customary building method in Berlin und Brandenburg were available for the field study.
The industrially constructed multiple dwelling units were built from the early 1970s until the 1980s and renovated in terms of energy during the period from 2000 to 2006.These are different types of panelised structures. The multiple dwelling units built in the customary manner are masonry buildings out of hollow-chamber and sand-lime brick or solid brick, and were built between 1892 and 1975. The renovation in terms of energy took place from 2002 to 2007 (Illustration 1).

Illustration 1: Selection of representative housing areas and thermograms of a typical thermal bridge


Masonry construction out of hollow-chamber brick


Upper end of building


Panelised structure WBS 70


Lower end of building

After the evaluation of the building damage reports and other research projects, an initial checklist was prepared for the ascertainment and evaluation of thermal bridges of renovated multiple dwelling units. The construction documents of the multiple dwelling units of the filed study were viewed with this checklist as the starting point. This work was supported by the inquiries made of the building owners, planners and building companies. Extensive infrared thermographical investigations (external thermography with a total of 740 thermograms, a selection shown in Illustration1) of all buildings during the heating period of 2006/2007 completed the results, especially in the identification of thermal bridges through possible defects/errors in execution of the construction.

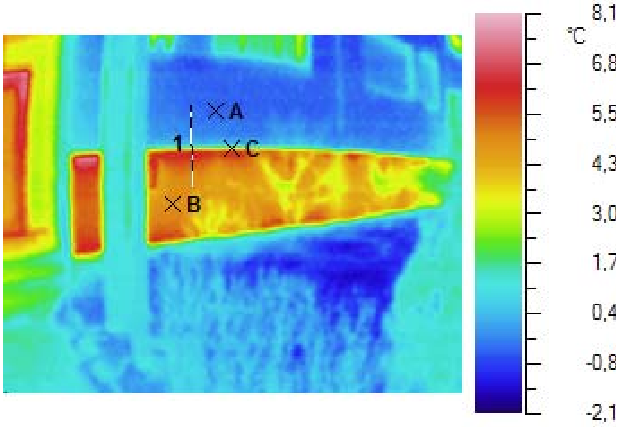
A checklist for the assignment of thermal bridges to building parts/buildings for approx. 300 possible thermal bridges of the multiple dwelling units under investigation was derived from the investigations.

The ascertainment of the effect of thermal bridges after the renovation was the next step in the project. To begin with, a typical multiple dwelling unit (WBS 70) was selected for this, for which all 57 thermal bridges found were calculated by means of acknowledged software (ARGOS). The energy-relevant thermal bridges were probed from the result of these calculations and the comparison with the literature research for this building (10 thermal bridges altogether). All thermal bridges whose percentage of overall thermal-bridge loss was > 3% were recorded, including overhanging balcony panels, upper and lower building ends and, in addition, under consideration of the window junctions. Deriving from this, 90 comparative calculations were carried out for the remaining multiple dwelling units, only for these energy-relevant thermal bridges.
With the software named above, the linear thermal-bridge loss coefficient Ψ (W/mK) and also the temperature factor f for the engineering physical evaluation (mildew formation) were calculated for each individual thermal bridge (Illustration 2).

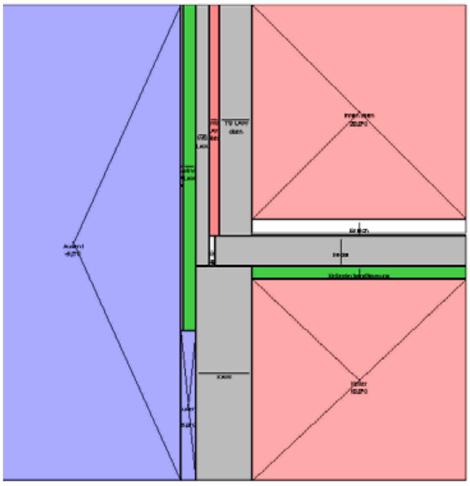
Illustration 2: Thermal bridge with a marked linear thermal-bridge loss coefficient Ψ and relevant conductance L (thermal-bridge loss)

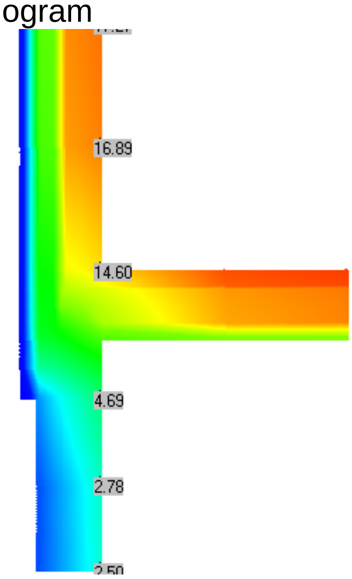
Lower end of building


Photo

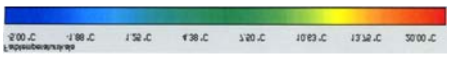


Thermogram


Construction



Isotherms



Calculation results f = 0,764

Ψ = 0,219 W/(mK)

L = 8,14 W/K

Through the ascertainment of the proportionate lengths, it was then possible to determine the corresponding thermal-bridge loss of all thermal bridges and the specific transmission heat loss of the thermal bridges of each building (thermal-bridge surcharge). With the thermal-bridge surcharge calculated for each multiple dwelling unit, a comparative qualitative evaluation of the energy losses via the examined thermal bridges is possible after the renovation of the individual buildings.

Solutions for the continued decrease of energy losses were developed for selected thermal bridges within the framework of economic considerations.
For this, the thermal bridges with the greatest heat losses (percentage of total thermal-bridge loss > 75 %) were selected for this, from the relevant 10 thermal bridges of the WBS 70 named above. Further relevant thermal bridges from a conventionally constructed building were brought into the calculations for comparative observations.
The possible energy-loss reduction was quantified under the assumption that the thermal bridge would be minimised or completely eliminated with the selected renovation (maximum saved energy costs). The calculation of the energy losses was made of the annual heating energy need [kWh/(m²a)] with the help of the EnEV calculation programme (EnEV-XL von IWU). In addition, the costs of the renovation variant (chargeable investments) were calculated by means of the software LEGEP cost planning.
The basis of the calculation of the annuity profit (calculated by means of the IWU economic-efficiency tool) and the costs of the saved energy include the ascertainment of the lifelong energy costs with consideration of the increase in energy prices as well as the ascertainment of the costs of the renovation variant.

Summary of the results

The goal of the investigation of 15 conventionally and industrially constructed renovated multiple dwelling units in Berlin/Brandenburg is the effect of thermal bridges which remain after the renovation, with regard to aspects of energy and economics.
With this aim in mind, thermographical investigations were carried and systematically evaluated, the effects on the energy of the thermal bridges found were quantified; the costs required for the avoidance of thermal bridges were estimated as well.

With the thermographical external investigations, it was possible to establish relevant thermal bridges in all the renovated multiple dwelling units in the area of the overhanging building parts, with the exception of one residential block with thermal bridges at certain points in the area of the non-decoupled fasteners. In addition, the lower ends of the buildings in the foundation area and the window areas were conspicuous. The upper ends of the buildings are particularly conspicuous, if at all, in the area of the horizontal expansion joints and in the eaves of a residential block. The thermographical conspicuousness of these eaves is probably caused by a thermal pile-up (convective heat stream via windows) under the roof and/or defects in the execution of the construction.

Basically, only statements concerning the quality of the thermal bridges are possible with the IR thermography. Calculation of the thermal-bridge coefficients, temperature factors and the conductances were necessary for the quantitative evaluation of the thermal bridges.

It is possible to evaluate the energy relevance of each individual thermal bridge from its percentage proportion of overall thermal-bridge loss (total conductance). It becomes clear, in the model calculation of the selected typical multiple dwelling unit of the type WBS 70 with a total of 57 established thermal bridges, that 10 thermal bridges amount to a proportion of approx. 90% of the total thermal-bridge loss and must therefore be designated as relevant thermal bridges (Table 1). The thermal bridges in the overhanging building parts and in the upper and lower ends of the building belong to these. The windows which are conspicuous due to the thermography are also included in the calculations, as required in the standards and in the literature. Thus, for this multiple dwelling unit, there was a proportion of thermal bridges in the window area and the thermal bridges relevant for overall thermal-bridge loss of approx. 80%. This decrease in percentage resulted from the negative conductances for the window embrasures and lintels. Deriving from these results, it is shown that thermal bridges with relatively small thermal-bridge coefficients and/or slight operating longitudes of the thermal bridges are negligible. In this investigated WBS 70, the remaining 47 thermal bridges have only a proportion of < 3% in the overall thermal-bridge loss. The vertical building corners/edges and protrusions, building entrance areas and curtain wall are included in these thermal bridges.

Table 1: Calculation results for Ψ, f and conductance of the relevant thermal bridges according to building area

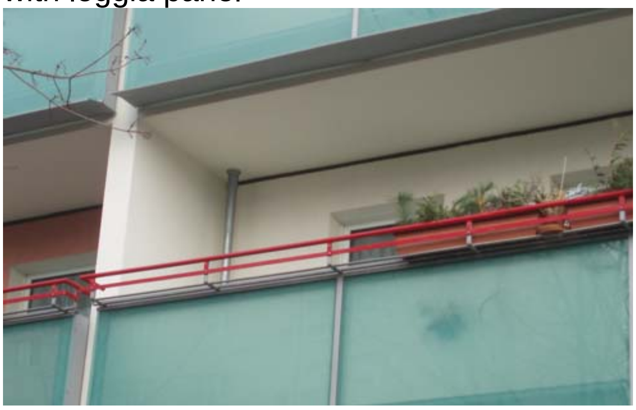
Building areas	**f-value**	**Ψ-value**	**Conductance**	**Proportion**
		W/(mK)	**W/K**	**%**
Roof above housing unit				
Trough base at double position	0,696	1,330	6,81	3,9
Upper end of building, exterior				
Longitudinal exterior wall / jamb wall ceiling to attic area (without loggia)	0,656	0,574	21,42	12,2
Longitudinal exterior wall-ceiling to attic area (with loggia)	0,628	0,688	27,43	15,7
Gable exterior wall/ jamb wall	0,660	0,579	7,16	4,1
Gable exterior wall/ jamb wall on parting line	0,708	0,734	9,08	5,2
Lower end of building, exterior				
Longitudinal exterior wall-basement exterior wall-basement ceiling (without loggia)	0,764	0,219	8,14	4,7
Gable exterior wall / basement exterior wall on parting line	0,720	0,731	9,04	5,2
Basement under housing unit				
Basement ceiling / basement interior wall	0,790	0,624	25,67	14,1
Overhanging building parts				
Longitudinal exterior wall / storey ceiling with loggia ceiling	0,896	0,213	35,28	20,2
Longitudinal exterior wall / interior wall with loggia shaft	0,916	0,075	8,47	4,8
Thermal-bridge loss without windows			**158,5**	**90,6**
Windows, upper storey				
Window balustrade, upper storey	0,916	-0,037	-5,36	-3,1
Window embrasure, upper storey	0,892	-0,044	-15,82	-9,0
Window lintel, upper storey	0,908	0,014	2,60	1,5
Thermal-bridge loss with windows			**139,9**	**80,0**
Overall thermal-bridge (57 thermal bridges)			**175,0**	
Heat-transferring building envelope	**2631,01 m^2**			
Thermal-bridge surcharge	**0,067 $W/(m^2K)$.**			

The results of the extensive calculations of all thermal bridges on this selected building led to the recognition that it is sufficient (for the continued procedure in the investigation of the remaining multiple dwelling units) to calculate only the relevant thermal bridges of the above-named building areas and the thermal bridges of the windows.
This is essentially confirmed by the calculations of the thermal bridges of the remaining industrially built and conventionally built housing blocks.

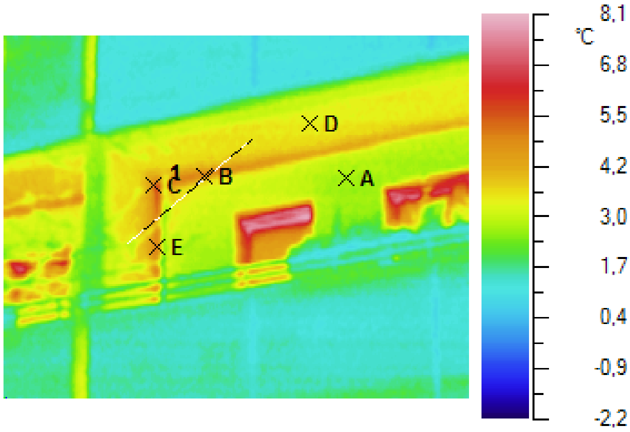
The overhanging parts of the existing building represent the most conspicuous thermal-bridge losses in both construction types (Illustration 3). The proportion of the total thermal-bridge loss can be as high as 66 %. When the balconies are newly constructed, thermal-bridge losses via the building parts are present at certain points or are considerably less compared to the remaining housing blocks.

Illustration 3: Thermal bridge with conspicuous linear thermal-bridge loss coefficient Ψ and relevant conductance L (thermal-bridge losses)

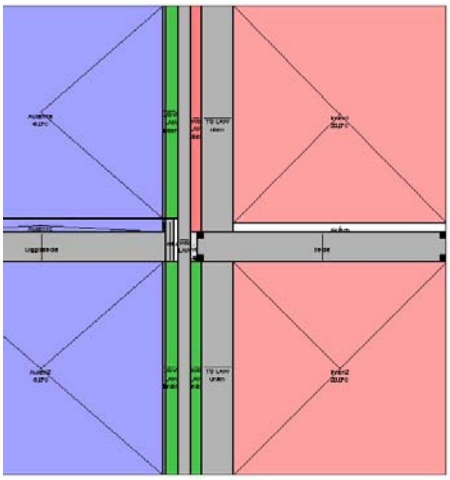
Longitudinal exterior wall – storey ceiling with loggia panel



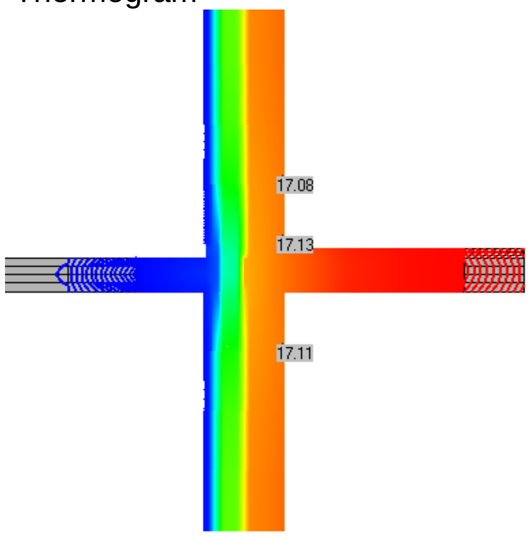
Photo



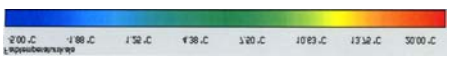
Thermogram



Construction



Isotherms



Calculation results

f = 0,896

Ψ = 0,213 W/(mK)

L = 35,28 W/K

In all buildings, conspicuous thermal bridges can be found in the area ranging from the basement interior walls to the basement ceiling and/or to the walls under the living area.

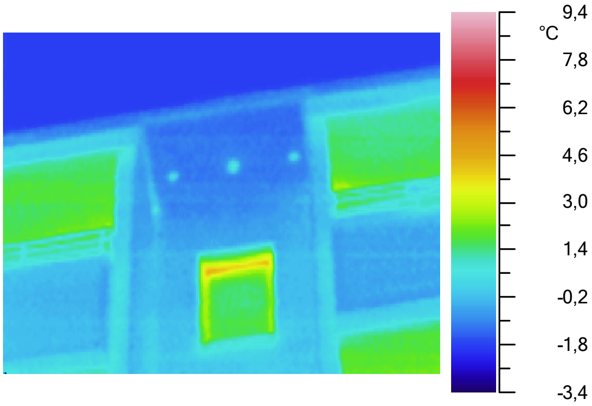
In the top ends of the multiple dwelling units investigated, the thermal bridges are only particularly conspicuous when there are ventilated roofs with jamb walls that are not insulated on the inside.
The windows are also generally inconspicuous in the case of a variety of methods of assembly (behind the insulation level and/or placed behind the rabbets. Exceptions to this are the window balustrades, especially with conventionally constructed housing blocks. It becomes clear in such cases that the results documented with the help of thermography are to be evaluated in greater detail as regards conspicuous features. It can be assumed that the influence of convection via the window leads to conspicuous thermal features in the adjoining areas (lintel, embrasure and balustrade).

As far as the engineering physics are concerned regarding falling short of the thawing point and the formation of mildew, the adherence to the threshold value for the temperature factor f of 0.7 is to be tested. Both with industrially constructed and conventionally constructed multiple dwelling units, with the exception of one conventionally constructed building, 7 thermal bridges were found which fall short of the threshold value. These thermal bridges occur in all building areas. The lowest f-value of 0.520 was ascertained in the area of the loggia panels with loggia windows in industrially constructed building WBS 70.
These thermal bridges must be regarded critically as regards falling short of the thawing point and the formation of mildew. They are found in all building areas (Illustration 4).

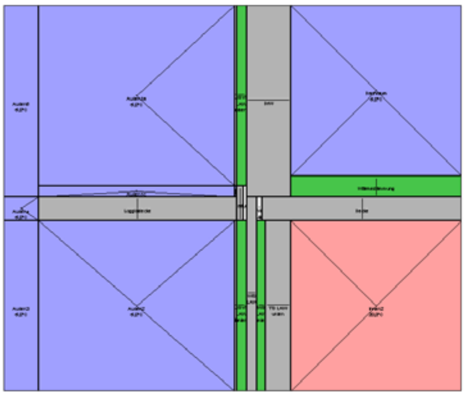
Illustration 4: Thermal bridge with temperature factor $f_{Rsi} < 0.7$ and conspicuous linear thermal-bridge loss coefficient Ψ

Longitudinal exterior wall - exterior jamb wall to the roof area with loggia ceiling

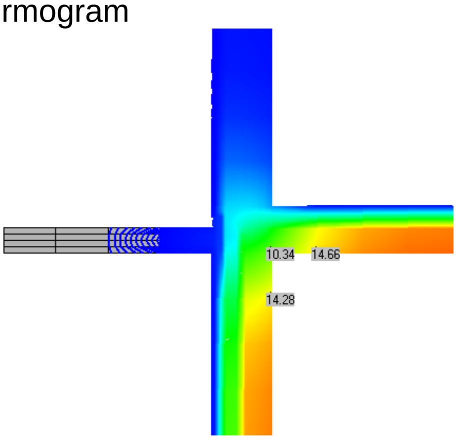
Photo



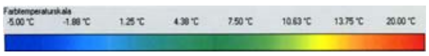
Thermogram



Construction



Isotherms



Calculation results

$f = 0{,}628$
$\Psi = 0{,}688$ W/(mK)
$L = 27{,}43$ W/K

In one housing block, the complete removal of the core of the building and adding on an additional storey made possible a high-quality plan regarding energy and the execution of the renovation in the low-energy building standard with the result that none of the thermal bridges investigated fell short of the threshold value of $f < 0.7$.

The consideration of the thermal-bridge losses via the detailed calculation of the Ψ- and L-values led to the result that thermal-bridge surcharges of < 0.1 W/(m^2K) were registered for all housing blocks. The thermal-bridge surcharges vary considerably here, however, lying between 0.014 and 0.092 W/ (m^2K). Only within a conventionally constructed housing block is this value exceeded by over 0.1 W/ (m^2K) in the case of individual buildings. This results from the relatively high proportion of overhanging building parts with similarly high conductances in these buildings.
The lump-sum surcharge prepared for the planning of renovations in accordance with EnEV for the thermal-bridge losses of 0.1 W/ (m^2K) was proven to have been adhered to with almost all the housing blocks under investigation. This means that one can assume that the valid energy standards are at least being adhered to in the buildings under investigation. The best renovation result was attained in the low-energy building.

Considerations of economic efficiency concerning thermal bridges with a high percentage of heat loss have been carried out from the knowledge gained about the extent of thermal bridges after renovation, both for an industrially constructed multiple dwelling unit and a conventionally constructed multiple dwelling unit.
It was investigated, with the further calculations, to what extent the executed renovations could be optimised through further renovatory measures or variants.
No differences were established between the industrially and conventionally built multiple dwelling units in the economic efficiency consideration thus carried out.
Renovations in the area of the jamb wall with exterior and interior insulation of the exterior jamb walls and of the interior basement walls with insulation to the basement ceiling are recommended; these should be part of a careful planning within the framework of the overall renovation.
The calculation was not able to prove any economic efficiency for the more comprehensive renovation of the overhanging building parts and windows. Especially for these building areas, it is essential to carry out the renovation in accordance with the highest possible economic and practical constructional standards, already in the planning of the calculation of these thermal bridges. Subsequent renovation is not recommended.

From the field study carried out, it is clear that the quality of renovation as regards energy meets the demands of the currently valid standards. The fluctuation range in the calculated thermal-bridge surcharges indicates an optimisation potential. To optimise the situation, detailed calculations of the relevant thermal bridges are necessary, including the windows, when planning the renovation. These should be accompanied by considerations of economical efficiency.
Thermographical interior and exterior investigations can provide information concerning relevant thermal bridges during the renovation preparations.