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Step-by-step towards EnerPHit-Standard retrofit

Relevance of typical thermal bridges in a detached Franconian house from 1959

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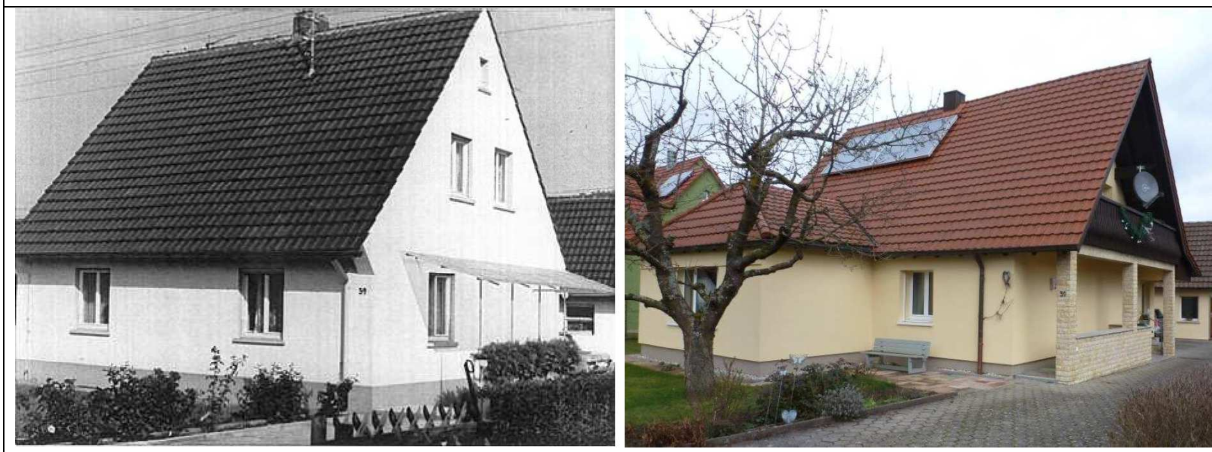

Figure 1: Photo of the original 1959 building "Sonnenstrasse 39, Zellingen", taken around 1970, and recent photo (2015) showing EnerPHit step 1 completed. Source: Karl Theumer

Table of contents

1 Eidesstattliche Erklärung / Statutory Declaration

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2 Abstract

Until recently, the Franconian village Zellingen/Main was mainly famous for carnival, but it is also being recognized for its sustainability image with a ‘green’ mayor, a Passive House new-build, a newly introduced funding scheme for energy retrofits and now, e first detached house refurbished with Passive House components.

However, the results achieved so far are intermediate because the renovation carried out was not a complete overhaul of the entire building. A step-by-step approach was used instead, due to earlier renovations in 1999 and 2004, when the roof was insulated, and windows, floor finishes and bathrooms were renewed without an overall refurbishment plan in place. The tasks now were to bring the house back on track by applying step 1 towards EnerPHit-Standard. This included insulation of the exterior walls as the facade needed repainting anyhow, insulation of the basement ceiling, improvement of building’s airtightness, installation of a ventilation system with heat recovery for fresh air and to reduce the risk of mold growth which had already been a problem, replacement of the inefficient, old heating system as well as two leaky attic windows.

Several possibilities for developing retrofit components were identified, which will be further explored within the EU project EuroPHit. Another revelation was the achieved PHPP interim result in light of the necessity of a long-term retrofit strategy for the whole house. Although the project is only half-way complete in terms of EnerPHit, the tenants are delighted due to high comfort paired with very low running costs, the investor is satisfied to have put the money into increasing the value and durability of the inherited family house. The only drawback at this stage is that the investor would actually prefer to move in himself after all the effort he had made and the successful end result.

This thesis focuses on the relevance of typical thermal bridges which occur in Franconian detached homes using the “Sonnenstrasse 39” project as an example. Four scenarios were analysed: before intervention, after step 1, a future step 2 when windows need to be replaced and a final stage in the EnerPHit-Standard. It can be derived that thermal bridges play a crucial role and should be addressed when the opportunity arises.

All in all, the retrofit was challenging but rewarding and is exemplary for the neighbouring Sonnenstrasse houses as well as for typical housing schemes from the 1950’s in Franconia.

3 Introduction

Until recently, the Franconian village Zellingen/Main was mainly famous for its carnival with traditions dating back to the middle age, but it is also being recognized for its sustainability image with a ‘green mayor’, a Passive House new-build, a newly introduced funding scheme for energy retrofits and now,the first detached house refurbished step-by-step towards the EnerPHit-Standard.

The energy standard for modernization of existing buildings, EnerPHit, can be achieved by applying Passive House components, such as thermal insulation with a U-value of 0.15 W/(m²a), to achieve warm surface temperatures on external walls, or highly efficient ventilation systems with heat recovery, known from Passive House new builds. Guidance values are listed in the EnerPHit certification criteria [EnerPHit_definition]. The need to focus on energy efficiency in sustainable retrofits as the target is becoming more well-known and there are many portals where EnerPHit projects are featured [Treehugger]. Wolfgang Feist, founder of the Passive House Institute (PHI) states this very clearly: “it must be said that energy is the most important and decisive factor regarding our civilisation’s progress towards sustainability.” [Passipedia_1]

Furthermore, [Schulze Darup_DBU 2004] gives the following ten reasons for highly-efficient refurbishments:

1) Resource preservation
2) Comfort and well-being
3) Structural protection
4) Indoor air quality and health
5) Future-proof building value
6) Good long-term rentability
7) Climate protection
8) Insurance against increasing energy costs
9) Qualification & job creation
10) Enhancement of urban development

The building owner of Sonnenstrasse 39 was aware of the advantages of deep retrofitting. Following an overall refurbishment plan, the building was modernized in winter 2013/2014 to the EnerPHit Standard following the principles outlined in [Bastian et al. 2012].

However, due to many factors, such as recently carried out retrofit steps without a master plan, see chapter 5, a step-by-step approach was followed. Therefore, the building acts as a case study within the EU project EroPHit, coordinated by PHI, which focuses on solutions for step-by-step retrofits using Passive House components.

EnerPHit – the Passive House Certificate for retrofits

It is not always possible to achieve the Passive House Standard (new constructions) for refurbishments of existing buildings, even with adequate funds. For this reason, the PHI has developed the "EnerPHit – Quality-Approved Energy Retrofit with Passive House Components" Certificate.

Significant energy savings of between 75 and 90 % can be achieved even in existing buildings, for which the following measures have proved to be particularly effective:

- improved thermal insulation (based on the principle: if it has to be done, do it right)
- reduction of thermal bridges
- considerably improved airtightness
- use of very good quality windows (there is no reason why Passive-House-suitable windows should not be used whenever the opportunity arises)
- ventilation with highly efficient heat recovery (again, Passive-House-suitable systems are very recommendable)
- efficient heat generation
- use of renewable energy sources

These are exactly the same measures that have proved to be successful in new constructions. A number of examples demonstrating the application of high-efficiency technology in existing buildings have become available in the meantime.

Figure 2: EnerPHit info box. Source: Passipedia, PHI

To be able to assess and evaluate the results of the project in terms of energy efficiency, the energy balance calculations were carried out with the Passive House Planning Package, [PHPP 8]. This allows for a comparison with other buildings on a national and international level and reflects the real building's energy performance very well, even for high-efficiency standards such as the Passive House Standard, see Figure 3.

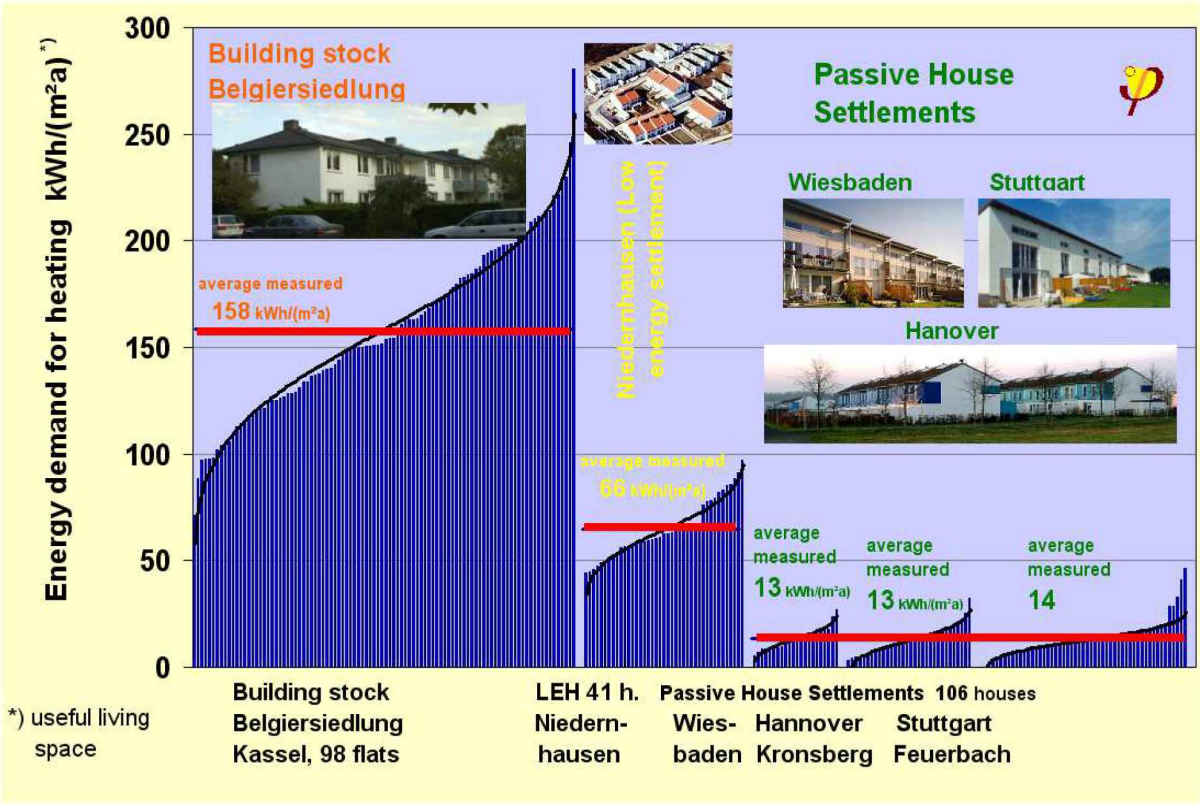

Figure 3: Comparison of measured buildings' energy consumption and calculated results with PHPP. Source: PHI

Various scenarios were examined which include the energy performance of the building before and after the improvements in the winter of 2013/2014.

Moreover, PHPP inputs such as thermal bridge effects were either estimated on the safe side or calculated with an additional software called Flixo,. Thus, the relevance of thermal bridges can be seen. In addition, the potential for further energy reduction is derived by explaining alternative solutions.

4 Building description

The single-family house Sonnenstrasse 39 in Zellingen/Main, Germany, was originally constructed in 1959. It is one of many detached homes built in new districts after the second world war for working-class families in Franconia, with a big garden to grow food and adjoining secondary buildings to house small animals, a washing room and a garage.

Figure 4: Street view. Source: Karl Theumer

Those districts provided electricity and later gas. In the unheated basement of each house, the building services consist of a domestic hot water (DHW) storage tank, gas boiler (in former times: oil tanks) and a chimney. A second chimney serves the living room where a wood stove could be installed as a back-up heating system. The main building is designed for four persons and has a treated floor area of 127 m² (according to PHPP). The latitude of the site is approx. 180m [Markt_Zellingen].

Although not a traditional lattice construction with eaves laths, known as “The Franconian construction style”, see Figure 5, the Sonnenstrasse building type was reproduced in nearly every Franconian settlement. Thus, demonstrating sustainable solutions for it will be beneficial for many other potential retrofits.

Figure 5: Typical Franconian buildings in lattice construction with and without render finish, Miltenberg, Germany. Source: Jose Alonso

It does feature a variety of Franconian details, typical for the time period and region. These include:

- Steep roof with an inclination of approx. 50 degrees
- Verge without roof overhang
- Stone window sills made of cast stone
- Cold basement without concrete floor slab
- Render finish of the facades
- Main entrance approx. 500 mm above ground level

All material descriptions including properties and thicknesses can be seen in the PHPPs, see Appendix PHPP_EN_V8.5_Sonnenstr39_Step0_2013. The walls are made of pumice stone. Assuming a weight of 800 kg/m³ the thermal conductivity of 0.465 W/mK was estimated based on DIN 4108 from 1952 [Bauexpertenforum].

Over time, the houses from this period were usually modernized and extended. Common features, which can all be observed in the Sonnenstrasse house, are

- Concrete balcony and access door as well as enlargement of the former window and use of glass bricks, see Figure 6
- Entrance porch added, see Figure 7
- Living room extension added with larger window areas, see Figure 8
- Wooden window frames and double-glazing replaced by PVC windows with double-glazing, new bathrooms, new floor finishes
- Bigger dormer windows added

Figure 6: Additions to the original design. Balcony and glass block element. Source: Karl Theumer

Figure 7: Additions to the original design. Entrance porch. Source: Karl Theumer

Figure 8: Additions to the original design. Living room extention. Source: Karl Theumer

In recent years, further changes can be noticed in some houses such as

- External wall insulation
- New double- or triple-glazed windows installed in the old position
- New heating system installed

All in all, the house in Sonnenstrasse 39 underwent the following interventions in chronological order:

1974: Concrete balcony and access door as well as enlargement of the former window and use of glass bricks, entrance porch added. Living room extension added with larger window areas (1974), see Figure 8.

1999: In addition to changes on the exterior (some windows replaced by PVC windows with double-glazing) the interior was modernized: new gas boiler, new floor finishes, new and bigger bathrooms.

2004: The rest of the house received new windows (with the exception of the attic windows)

2014: new gas boiler, solar DHW panels and storage tank, external wall insulation, new entrance door, new radio-controlled external blinds, new triple-glazed attic windows, ventilation system with heat recovery, basement ceiling insulation, internal basement access: insulation, airtightness improvements (named “step 1” of the EnerPHit requirements)

2050: In theory, as part of the overall refurbishment plan: New Passive House windows (named “step 2” of the EnerPHit requirements)

2070: In theory, as part of the overall refurbishment plan: Airtightness improvement along the eaves, additional roof insulation, better heat recovery efficiency of the ventilation unit (named “step 3”, achieving the EnerPHit requirements)

All interventions until 2009 were carried out without an independent energy consultant. In the year 2009, a mandatory energy label was being completed, combined with an intensive energy assessment by architect’s office Werner Haase, Karlstadt, see [Haase_2009, in German]. In 2013, this architect was hired to plan and supervise the next intervention (“step 1”, 2014), in close collaboration with the Passive House Institute. PHI assisted in developing the projects’ scope as well as details and carried out three airtightness tests as quality assurance in the course of the intervention.

The project was chosen as an “Observer project” for the European research project “EuroPHit” which deals with step-by-step retrofitting using Passive House components. A questionnaire compares the building’s performance before and after the intervention [EuroPHit_Q]. The various buildings’ energy balance calculations for step 0 (2013), step 1 (2014), step 2 (2050 – windows replacement) and step 3 (2070 – EnerPHit), see Appendix 3, are used to illustrate the potential energy savings.

The analysis and evaluation of the building's details in relation to its energy balance at various stages in time is the main focus of this master thesis.

Inspired by illustrations on page 37 and 38 of a step-by-step solution in [PHI-RG39], the windows from 1999/2004 were not replaced during the retrofit 2013/2014 but integrated into the new external wall insulation so that they can be uninstalled in the future, see detailed window drawings in Appendix 2.
The existing window frames are made of PVC and have three main air chambers, typical of windows from this time (1999). An U_f value of 1.845 W/(m²K), stainless steel spacers with a psi-value g for the glazing edge of 0.051 W/(mK) was assumed. The glazing u-value U_g of 1.1 W/(m²K) is a conventional double-glazing u-value and is taken from the window manufacturer's invoices from 1999 and 2004. Thus, the total u-value of a window with standard dimensions of 1.23m in width and 1.48m in height according to [DIN EN 10077-1] results in 1.45 W/(m²K).

According to [Haase_2009, in German] the primary energy demand of the building before the intervention was approx. 500 kWh/(m²a). The detailed PHPP calculation carried out with PHPP 8 shows a value of approx. 320 kWh/(m²a).
The gas costs for DHW and heating consumption are on average 1900 euros incl. 19% VAT. Electricity costs are not known because the tenants pay the energy supplier directly.

5 Challenges and goals

First and foremost, the scope of the project was defined. This was an iterative process, using the current EnerPHit certification criteria according to component quality as a guideline to define the long-term energy goal. It became clear that the financial restrictions and the recently replaced windows, along with no need for interior renovations, had to be respected for the success of this intervention.

Therefore, the measures were divided into

- Interventions that could be carried out at present, e.g. installation of a ventilation system.
- Interventions that could be carried out at present but with provisions for future adaptations, e.g. external wall insulation with new external blinds and two new windows sills one on top of each other as well as a wooden frame for future installation of a Passive House window in the insulation layer, see Window Details in Appendix 2.
- Interventions that must be carried out in the future, once the building element is in need of renovation, e.g. connection of the airtightness layer of external wall and roof, window replacement.

Thus, the challenge of this particular project was the application of a step-by-step EnerPHit approach in a project were past interventions did not address any of the recommendations mentioned in the EnerPHit or step-by-step EnerPHit info boxes, see Figure 2 and Figure 9, which represents a very typical scenario for a retrofit project in Germany today.

<u>Step-by-step</u>

While a comprehensive retrofit is always the best way to increase energy efficiency in existing buildings, it is unfortunately not always possible. Often, financial or other challenges get in the way - the reality can be more complex...

Each part of a building has its own life span. While the facade may be crumbling, the roof tiles may still be in great shape. Perhaps the heating system is shot, yet it will be another 20 years before the windows need to be replaced. Renovation measures can be time and resource intensive, which is why they are typically only carried out when absolutely necessary. Once the facade has been newly insulated and painted, it will typically stay that way, for better or worse, for the next generation or two. At the same time, energy efficiency measures for any one part of the building are always most affordable when that part is already in need of renovation. Step-by-step renovation is the natural result. One of the additional benefits of such an approach is that it gets the most out of each building component so that the initial investment is taken advantage of to its fullest. Also, renovation work is spread over a variety smaller measures is easier to finance.

If you do it, do it right from the start!
It is important to avoid missed opportunities by carrying out every retrofitting measure with an eye to quality and energy efficiency. It is also essential to remember that when we retrofit, we are not just improving aesthetics and reducing energy losses – we are also directly affecting a building's moisture balance, air-flow, surface temperatures and much more besides.

Figure 9: Stepwise EnerPHit info box. Source: www.europhit.eu

The design principles to achieve an airtight building envelope also have to be considered. According to Passipedia [2] "there are two central planning fundamentals for implementing an airtight building envelope (based on [Feist 1995]):

1. The "pencil rule":
It must be possible to trace the airtight layer of the envelope in the plan (for each building section) using a pencil without lifting the pencil – except for any planned ventilation openings.

2. There must be only one single uninterrupted airtight layer.
Leaks CANNOT be remedied by another airtight layer before or after the first one (e.g. double lip seals at windows, vestibule door behind the front door). A comparison to illustrate this point: water won't stop leaking from a bucket with a leak if the bucket is placed inside another bucket with a leak."

This pencil rule, see Figure 10, was not followed rigorously enough during the implementation of step 1, as the airtightness tests revealed.

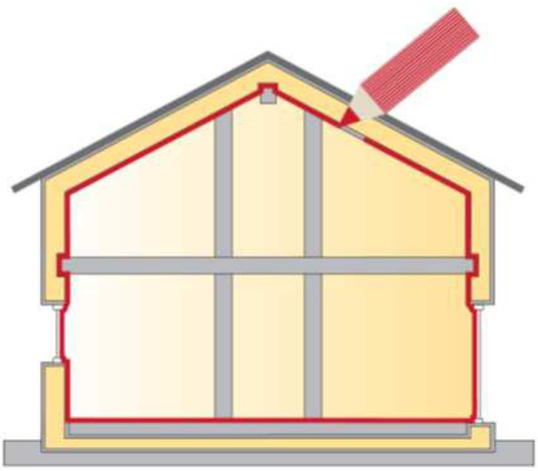

Figure 10: Design principle "Pencil rule". Source: PHI

As a result, the airtightness tests produced poor results. Both quality of planning as well as quality of implementation, led to those results. The most important issue was the airtight connection of the roof and wall airtightness layers, which was not properly addressed, see Figure 11.

Figure 11: Eaves connection is not airtight. Provision should have been made to close the leakages. Instead, the timber (not airtight) joints were sealed. Source: Karl Theumer

One of the challenges was the project's short time frame (two winter months December 2013 and January 2014) due to new tenants moving in at the end of January. The goal was to finish as quickly as possible. It has to be mentioned that the project's success depended largely on the huge personal contribution of the investor, the building owner.

6 Energy balance calculations

To set up an energy balance of the thermal envelope, all the energy flows from the inside to the outside of the building and vice versa have to be identified. The energy balance tool “Passive House Planning Package“ (PHPP) was used to verify space heating and primary energy demands before the intervention, after retrofit step 1 (winter 2013/2014), future scenario 2050 (when windows have to be replaced) and future scenario 2070 (final stage, when all elements have been upgraded to or replaced by Passive House components and EnerPHit-Standard has been achieved). With this information at hand, an overall retrofit plan can be set up to guide the client to a sustainable long-term solution. An excerpt from PHPP “step 1_2014”, see Figure 12, shows the main results on the verification page.

Specific building demands with reference to the treated floor area					
	Treated floor area	127,0	m²	**Requirements**	**Fulfilled?***
Space heating	Heating demand	**116,11**	**kWh/(m²a)**	-	**-**
	Heating load	**53**	**W/m²**	-	**-**
Space cooling	Overall specif. space cooling demand		**kWh/(m²a)**	-	**-**
	Cooling load		**W/m²**	-	**-**
	Frequency of overheating (> 25 °C)	0,5	%	-	**-**
Primary energy	Heating, cooling, dehumidification, DHW, auxiliary electricity, lighting, electrical appliances	**217**	**kWh/(m²a)**	241 kWh/(m²a)	**yes**
	DHW, space heating and auxiliary electricity	163	kWh/(m²a)	-	**-**
	Specific primary energy reduction through solar electricity		kWh/(m²a)	-	**-**
Airtightness	Pressurization test result n_{50}	**2,9**	**1/h**	1 1/h	**no**
EnerPHit (retrofit): building characteristic values					
Building envelope	Exterior insulation to ambient air	**0,18**	**W/(m²K)**	0,15 W/(m²K)	**no**
Average U-Values	Exterior insulation underground	**0,41**	**W/(m²K)**	0,21 W/(m²K)	**no**
	Interior insulation to ambient air		**W/(m²K)**	-	**-**
	Interior insulation underground		**W/(m²K)**	-	**-**
	Thermal bridges ΔU	0,11	W/(m²K)	-	**-**
	Windows	**2,45**	**W/(m²K)**	0,85 W/(m²K)	**no**
	External doors	**0,99**	**W/(m²K)**	0,80 W/(m²K)	**no**
Ventilation system	Effective heat recovery efficiency	**82**	**%**	75 %	**yes**
				* empty field: data missing; '-': no requirement	
EnerPHit building retrofit (according to component quality)?					**no**

Figure 12: Excerpt from PHPP. Source: Susanne Theumer

The building information needed for the energy balance calculation was derived from the building site, research, the architect and component manufacturers specifications, interviewing the building owner and the detailed thermal bridge calculations contained in PHPP, see PHPP files in the Appendix 3.

7 Thermal bridge calculations

Unlike new buildings built to the Passive House Standard, existing buildings as well as modernized buildings are typically not “thermal bridge free“. However,there is a significant difference between those cases. While thermal bridges hold only a negligible share of the total energy losses in an old building, using highly efficient components, also known as Passive House components, to modernize an existing building reduces the total energy losses to such an extent that addressing thermal bridge heat losses makes sense.

This is illustrated in the Sonnenstrasse 39 energy balance before renovation (PHPP Step 0, 2013) where the shares caused by thermal bridges are shown, see Figure 13.

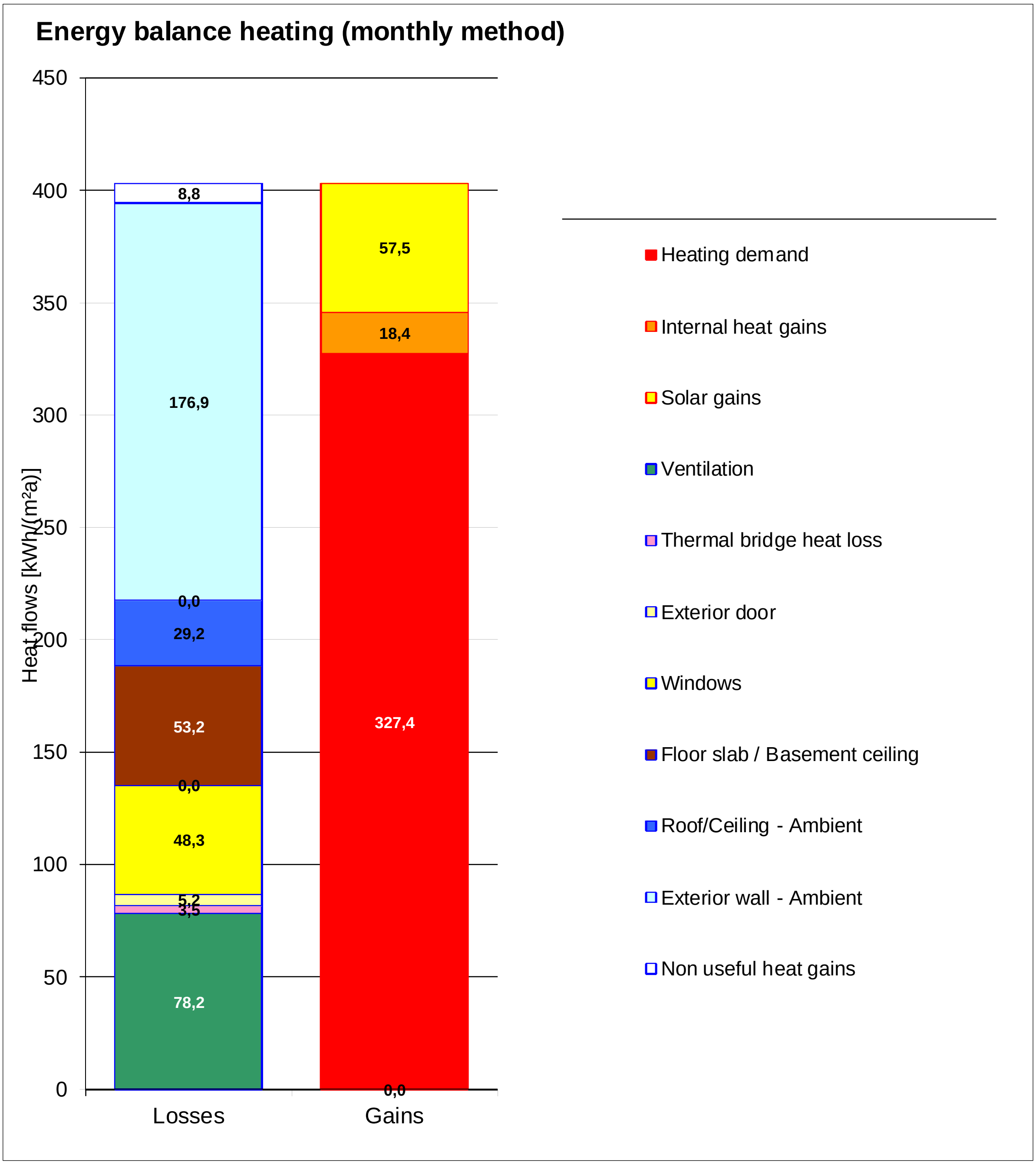

Figure 13: Existing building’s energy balance and share of thermal bridges

Goals of a successful deep retrofit are to ensure that those weak points (or thermal bridges, see Figure 14) in the envelope are alleviated to an extent that they become harmless and to reduce the impact of thermal bridge effects on the energy balance as much as possible, whilst keeping the effort reasonable. To double-check surface temperatures, which might be critical, thermal bridge calculations can be made. In PHPP, where all thermal bridge effects have to be entered. This can be done using estimations or through calculating the value in a separate tool.

Thermal bridges

Heat makes its way from the heated space towards the outside. In doing so, it follows the path of least resistance.
A thermal bridge is a localised 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.

Figure 14: Info box Thermal bridges. Source: Passipedia

The difficulty to assess thermal bridges in modernized buildings is that detailed drawings often do not exist; the material properties are unknown and the effort, to do a site measuring and draw all required details is very high. Thorough planning of the details is however, essential for a successful deep retrofit. It is of great help, if general guidelines exist for standard details of building typologies and case studies are available where buildings were examined in detail in research projects in order to get reference values. Among architects and building owners it is known that modernization of an existing building comes with surprises because before intervention it is often not possible to know what is hidden in the construction. To cope with those is already a challenge. In addition, time costs money and a building owner does not want to spend a large amount of money into the modernization of a building. The Sonnenstrasse experience is that there is simply not enough time or resources available to clients and architects to assess every possible mistake properly in advance and the design team and the building owner are often forced to make quick decisions. Integrated design comes into play here because nearly every decisions has an impact on the building's energy performance, too.

To prove the effect thermal bridges have on the energy balance in a Franconian detached house, the thermal bridges of the step-by-step retrofit project Sonnenstrasse 39, Zellingen, are examined in detail. The Flixo reports in Appendix 2 show the main thermal bridges which occur in the building before and after the intervention in detail. In PHPP, the thermal bridges are listed at the bottom of the Areas worksheet.

To determine the exact thermal bridge effect values, the thermal bridge calculation tool Flixo was used [Flixo_2014]. First, the details have to be drawn to scale with closed lines in a CAD programme and exported to Flixo in .dxf format. After successfully importing the respective detail, all areas receive a colour-code which represents the material‘s thermal conductivity based on rated values. Furthermore, the boundary conditions have to be assigned. Flixo then calculates the thermal bridge effect and also produces isothermal pictures as an output. A typical thermal bridge report page for PHI-building system certification also shows the detail's dimensions, boundary conditions and minimum surface temperatures, see Figure 15. The thermal bridge effect and the surface temperature are checked. According to the rules of simplification defined in [PHI-RG16] a psi-value of ≤0.01 W/(mK) is considered thermal bridge free. This criterion is also shown on the top right of the report page and an evaluation of the psi-value can be derived. In this example, a green check indicates that the thermal bridge value calculated below, -0.049 W/(mK), is smaller than 0.01 W/(mK), i.e. the detail is thermal-bridge-free. Entering this value in PHPP will have a positive effect on the energy balance.

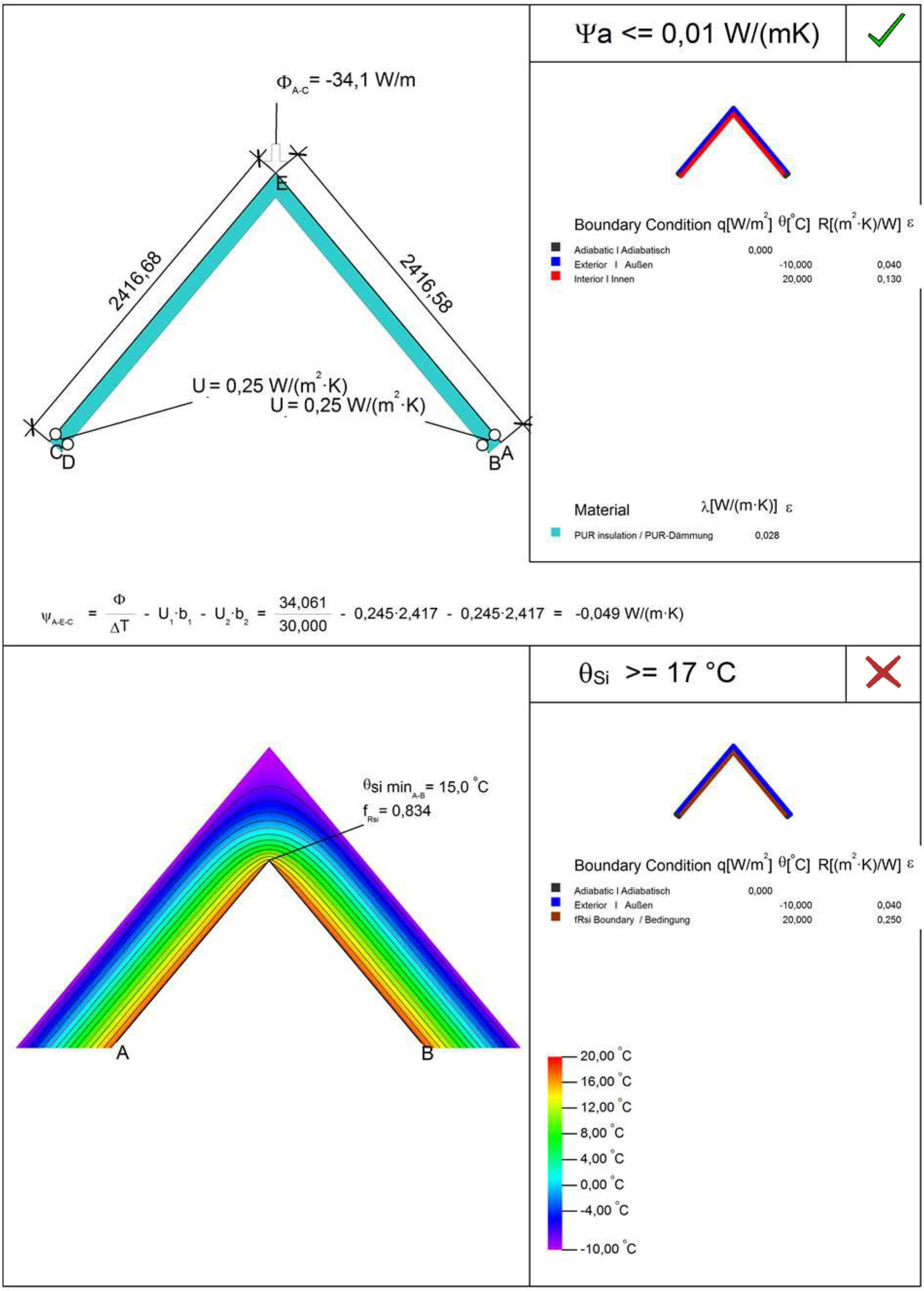

Figure 15: Thermal bridge report page, here: thermal-bridge-free ridge detail. Surface temperature above 12.6° C but below 17°C. Comfort is impaired. Source: PHI-template, thermal bridge calculation by Susanne Theumer

In this example, the surface temperatures is below the 17° C comfort threshold value which is a quality criterion for surface areas. It is used for PHI-building system certification, for example, as a strict criterion to ensure comfort. If it is met then the temperature differences within a room are smaller than 4.2 K, no temperature asymmetry issues occur such as drafts and comfort is guaranteed.

According to [DIN 4108-2], hygiene is reached if the minimum surface temperature at the given boundary conditions -5°C outside and 20°C inside does not fall below 12.6° C.

All in all, the comfort criterion is not met which is indicated by a red cross in the center right of the report page. But as the lowest temperatures still do meet the hygiene criterion and comfort is not an issue at the ridge, this detail is fine.

In [PHPP_8], the exterior emissivity of the building material surfaces in contact with the sky such as walls and the roof has to be entered to consider radiation balance. For the thermal bridge calculation of the window frames, the emissivity of the surfaces of the air chambers of the PVC window frame in the case of Sonnenstrasse also has to be considered. Thus, the boundary condition "emissivity" of 0.9, "epsilon", is stated on the transparent components' report page. For the opaque components such as ridge, eave and wall, the emissivity is already included in the boundary condition "Exterior / Außen".

Window thermal bridge calculations

To determine the window thermal bridges, the installation situation at the bottom, side and top of the window has to be assessed.

First, the u-value of both window frame and wall needs to be known. The unknown installation situation can then be determined.

Each situation is compared to the undisturbed situation: the thermal bridge is the simulated heat flow for the window connection minus the regular heat flow of wall and window. For each situation, two cases are calculated with Flixo: The window installation using a 30 K temperature difference for determining the psi-value and the same detail with adapted boundary conditions to determine the minimum surface temperature using a worst-case scenario.

Before the simulation can start the window frame has to be modelled in Flixo for each type and installation situation. To reflect the existing double-glazed PVC window, a suitable frame type with three chambers and a double glazing was chosen in accordance with the information provided on old window invoices from 1999 and 2004.

PHPP contains the window values for before/after and future scenarios. Of course, window development is constantly occurring and better thermal quality windows are to be expected for the 2050 scenario. However, extremely high-performing windows already exist today and the following example is used for the calculation of the future scenario: phA+ very advanced component: smartwin arctic, with U_f bottom = 0.72, U_f side/top = 0.64 W/(m²K) and U_g = 0.44 W/(m²K), see PHI-certificate in Appendix 4.

As the windows in Sonnenstrasse 39 had been replaced in 1999 and 2004, see Chapter 4, and are thus still relatively new, they were not replaced in 2013/2014 but will be replaced in some decades, when their life expectancy is reached (2050 scenario). Appendix 1 shows a photo series of the window detail before, during and after intervention.

However, the installation situation has improved a little bit during the retrofit in 2013/2014 due to the application of external insulation. The external blinds were exchanged and installed already in the correct position inside the insulation layer. This has effects on the window installation thermal bridge.

The 30mm reveal insulation at the top is, unfortunately, mechanically fixed using aluminium (!) 40/40/4 mm brackets. They are hard to spot on the photos but they are shown on a supplementary claim and appear in the invoice (10 pieces, mean length 1.268 m, total costs 445 euros incl. VAT). As they are made of a material with a high thermal conductivity, they have, of course, a negative effect on the energy balance.

Door thermal bridges

The entrance door of Sonnenstrasse 39 was replaced by a door with an u_d-value of approx. 0.99 W/(m²K). Although the door features a very well-insulated door pane, the frame detail is a stainless steel profile with a much lower thermal quality, resulting in a significant reduction of the expected performance of 0.8 W/(m²K) or better. The connection between floor slab of the porch and external entrance stairs was cut and insulation as a thermal break between wall and concrete stairs was introduced. The door was installed in the insulation layer and the thermal bridges for top, bottom and side were estimated with 0.1 W/(mK) and incorporated into the u-value u_d using a workaround in PHPP via the windows worksheet.

The basement door in the unheated basement was left untouched. A typical issue occurred here because the low ceiling height in the basement of only approx. 2m and the flush installation of the door made it impossible to insulate the ceiling area where the door opens, see Appendix 2 drawing “basement details”.

As a result, there is additional heat loss from the ground floor towards this area and the surface temperature at this part of the basement ceiling will be higher.

Chimneys

The two existing chimneys are made of stone. They penetrate the thermal envelope twice. As they start in the cold basement, they enter the thermal envelope first through the insulated basement ceiling and exit it through the roof insulation. Thus, they have to be considered as four point thermal bridges.

The first chimney is currently in use for extracting fumes from the modern gas heating and DHW system. In winter, it can be assumed that this chimney is operating on a regular basis. As the building required less energy following the retrofit, a new duct with a smaller diameter had to be inserted. Since the house was originally heated with oil and switched to gas in the 1980's, a stainless steel duct already existed inside the stone chimney. During the retrofit step 1 (2013/2014) a plastic duct with a diameter of 80 mm was installed inside of the stainless steel duct.

An estimated thermal bridge coefficient χ of 1.1 W/K is used for the PHPP to account for the roof penetration by the first chimney.

One chimney is currently not in use. To avoid cold air constantly entering the house through the chimney it had been closed off with a copper plate at the top of the flue system in the 1990's. For this chimney, a slightly smaller thermal bridge coefficient χ of 0.8 W/K is assumed.

For the two penetrations in the insulated basement ceiling, a thermal bridge coefficient χ of 0.5 W/K each has been estimated.

Furthermore, existing flue systems are typically not airtight and infiltration losses occur. This means that it would be best to reduce the amount of chimneys to the bare minimum rather than having a second chimney "just in case" as it was usually done in former times.

Airtight chimney solutions for existing buildings is a task for component developers because the infiltration losses of those old chimneys have a significant impact on the level of airtightness. The PHI certification criteria for flue systems can act as a guide [PHI_FlueSystems].

To address airtightness leakages in the roof, the penetration was sealed using spray foam. During the airtightness tests, the penetration was tight.

The consideration of these two chimney thermal bridges results in approx. 2 kWh/(m²a) increase of the space heating demand.

Balcony slab

The balcony was added to the building in 1974. Probably, at that time a thermal break was installed, but standard steel was used for connecting the concrete balcony with the external wall. The main load is carried by two columns, see Figure 6.

Although this is still a quite a significant thermal bridge after the 2014 intervention, the Passive House insulation softens its negative effects and ensures sufficiently high temperatures at the critical points, see balcony thermal bridge calculation, Appendix 2.

The thermal bridge effect for the “step 0, 2013” PHPP was calculated as 0.505 W/(mK). Typically, the value calculated for an insulated envelope is higher, in the case of the balcony the value is 0.653 W/(mK). By applying insulation, the thermal bridge effect gets larger, but the overall energy demand decreases. As a result, the share of energy losses via thermal bridges is increasing compared to the building’s total energy demand.

To receive the value for the thermal bridge coefficient χ of the balcony penetration according to [DIN EN ISO 10211], the heat flow of the undisturbed wall detail is calculated, see Appendix B30_W2. This is the reference scenario.

Then, the same detail is calculated with the balcony slab protruding the thermal envelope. It is unknown whether the first floor slab and the balcony slab are only connected via steel bars or if the two slabs are in direct contact with each other. Therefore, the worst-case scenario is assumed: a continuous concrete slab, see Appendix B34_Bal2.

The reference heat flow is then deducted from the heat flow of the penetration and the result is divided by the temperature difference. In this case, the temperature difference used is 20° C inside temperature and -10 ° C outside temperature, thus 30 Kelvin.

In PHPP, the linear thermal bridge effect and the length, in this case 8.5m, have to be entered.

Unheated basement

The basement was unheated before the intervention and has an even lower mean temperature after the installation of the insulation at the basement ceiling. It must be said, though, that the building services room is still very warm due to heat loss from the new ducts. This was left on purpose for a later stage detect water leaks easily. In fact, one leak already occurred within the first year after the intervention. Once the duct insulation will be completed the room temperature will drop.

To reflect the unheated basement in a realistic manner (thermal bridge in contact with ground) the two standards [DIN EN ISO 10211] and [DIN EN ISO 13370] need to be considered which are defining terminologies as well as thermal bridge calculations in contact with ground. The Ground worksheet in PHPP is based on those standards.

Regarding the basement ceiling and based on the recommended detail from page 79 in [Kaufmann 2009], the solution to use a high-performance insulation material to compensate for the reduced thickness, see Appendix 2, basement details, was realized. However, huge thermal bridges, the internal basement walls and the perimeter walls remain and there is a potential to reduce heat loss by insulating the flanks.

Mechanical fixings for external wall insulation

When external insulation is applied, most tradespeople follow the manufacturers recommendation to put many additional mechanical fixings and a warranty is not provided if this is not done according to manufacturer's specifications. In Sonnenstrasse 5 fixings per m² were installed. Countersunk screw dowels were used and penetrate the airtightness layer (existing render on the existing external wall). The hoes were covered with foam insulation.

Mechanical fixings of stairs

The decision in 1999 to have a direct access from the kitchen to the garden resulted in the detail shown in Figure 16, with two thermal bridges just at the bottom of the door.

Figure 16: Kitchen access. Source: Karl Theumer

According to the table on page 79 and corresponding photograph on page 87 in [PHI-RG35], the linear thermal bridge effect was estimated to be 0.05 W/(K) for each penetration and considered in the PHPP energy balance. A 3D calculation would have been necessary to determine the exact thermal bridge effect of the detail both without and with external wall insulation. This is outside of the scope of this master thesis.

8 Results

The role which thermal bridges play in deep retrofits can be illustrated using the graph from the PHPP heating worksheet, see Figure 17.

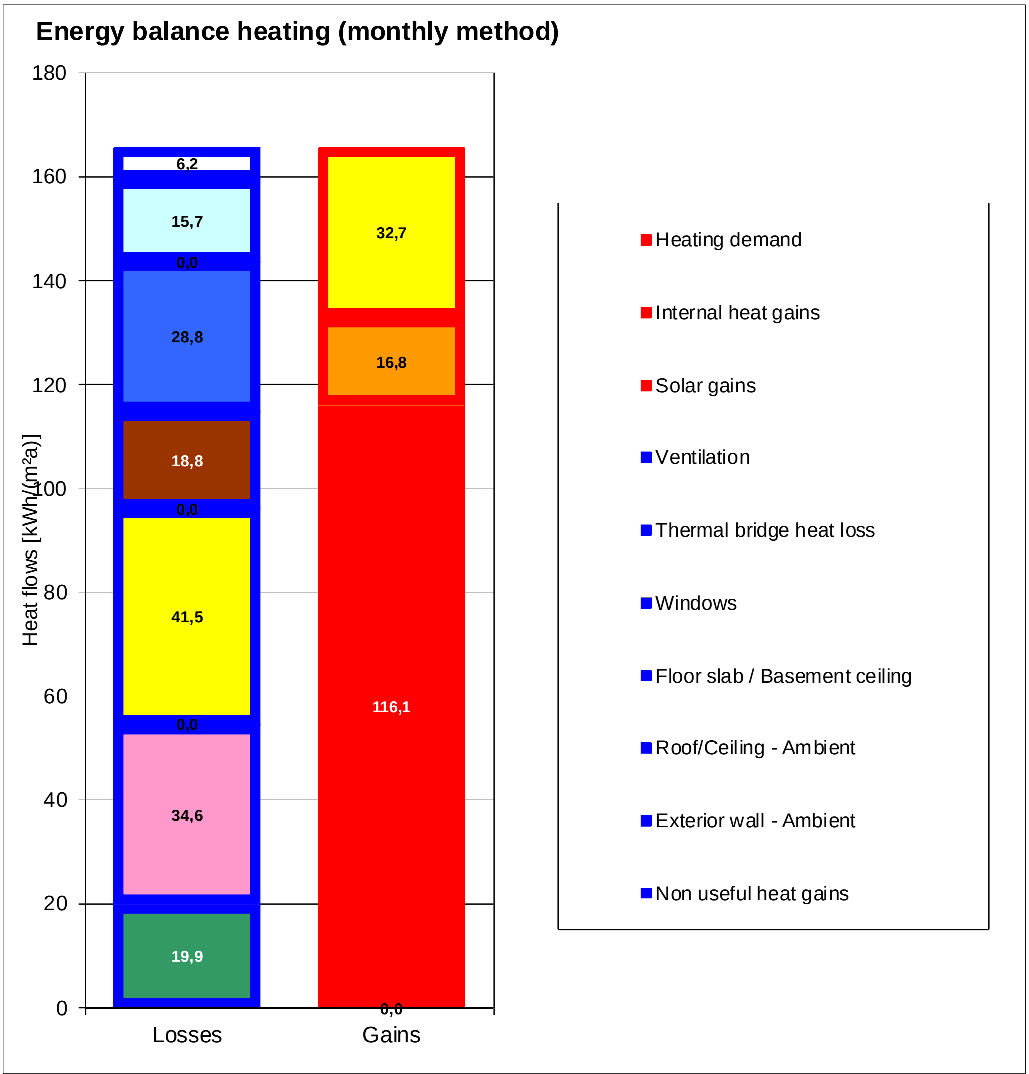

Figure 17: Heating energy balance for the retrofit step 1. The contribution from thermal bridges to the losses are approx. 35 kWh/(m²a)).

As a result, it is important to address thermal bridges in a proper way. The thermal bridge calculations or just the similar details can be compared with thermal bridge values and details in literature such as [PHI-RG24].

Also, the cost side has to be briefly mentioned. The total investment costs of the retrofit were 110 000 euros. The home owner received approx. 20 000 euros in funding from the municipality and KfW bank. The rent was increased by 200 euros/month and the increased comfort will probably have the effect of being able to retain the same tenants for a long time.

The first gas bill proved that the building is already on its way towards "Nearly Zero Energy" with total annual costs for heating and DHW of 467 euros incl. 19% VAT in 2014/2015 instead of 2159 euros incl. 19% VAT in 2012/2013 which is approx. 5 times less than before the intervention, a real cost saving of >70%. The current annual electricity costs are 653 euros incl. 19% VAT and translate into a low electricity consumption compared to similar German households.

Furthermore, the building's airtightness was tested when the works was completed, to prove the performance for the KfW documentation. To receive KfW grants, the signature from the architect and all building companies involved is required, including key documents such as the airtightness certificate.

The pressure test was carried out at various pressure differences for over and under pressure, the latter being sufficient to fulfill [EN 13829] requirements. Over pressure was also measured because the information from the airtightness measurement can be increased with only little more effort. This is recommended for energy efficient buildings and a requirement for PHI-certification. In addition, two more tests were carried out during the retrofit process: a very early test was carried out in order to evaluate the "as-is"-state of the building. When negative pressure was established, a leakage search started as described in [CEPHEUS]. A second test was completed to show the improvements and to localize remaining leakages while they were still accessible.

The infiltration air change $n_{V,Rest}$ caused by leakages in buildings with a balanced ventilation system with heat recovery is determined in PHPP.

The final airtightness result is listed in "PHPP step 1" with 2.9 1/h. Compared to approx. 9 1/h at the first test, it was a significant improvement. However, there is more to be done to meet the final target of 0.6-1 1/h according to the EnerPHit-Standard.

The findings leading to the airtightness testing results as documented in [Peper_2014] can be summarized as follows:

1. In order to avoid infiltration of (humid) air, closing the found leakages was attempted. This was, however, in many cases not possible because of the step-by-step approach. Many leakage origins were not detected as the airtightness layer could not be accessed at the most critical points such as eaves (inside and outside).
2. A concept of the airtightness needs to be translated into the detailed drawings at planning stage. It has to be clear to all involved where the airtightness layer is planned (here, the concrete floor slab, the existing plaster of the walls and the existing aluminium layer of the roof insulation were used) and appropriate airtightness materials need to be on site (seals for cables are not available in small numbers and need to be ordered in advance).
3. The combination of improving the airtightness and ventilation system reduces the risk of building damage.

During project implementation, several possibilities for developing retrofit components for simplifying the step-by-step approach were identified which will be further explored within the EU project EuroPHit. Among them are, for example, an airtightness kit for small houses and ventilation units integrated into the external wall insulation or the window interim solution with two window sills as shown in Appendix 1.

9 Conclusions

The Sonnenstrasse project was, all in all, a success for the home owner as well as for the tenants.

However, due to many obstacles such as recently carried out retrofit steps without an overall refurbishment plan, a decision to follow a step-by-step approach, lack of rigorous airtightness planning, the building's performance can be understood as an intermediate result which will improve over time. Although it has not achieved the EnerPHit targets yet, it will eventually do so in the future. It is a pioneer project and acts as a case study project for the step-by-step refurbishment of single-family houses.

Of course, many lessons can be learnt from this step-by-step retrofit and will be done better, faster and more cost-effectively next time.

The optimization potential was shown in this master thesis and client and designers of a similar project have to calculate more time for the planning process to use this potential to the maximum. They can avail themselves of a number of off-the-shelf solutions and reliable component certificates, see [PHI_EnerPHitSystems], which are welcomed by clients. These are a huge relief as well as support for investors and architects alike. The EU project EuroPHit will be a great means to communicate this to a wider audience.

Moreover, the PHPP 9 (2015) should be used to set up a sound overall retrofit plan. This is vital as it can be used to display and compare various scenarios with each other to derive the best solutions for the individual situation.

Having said this, the most surprising and rewarding lesson learnt for the home owner and tenants comes from the first energy bills received. They prove a significant cost reduction of more than 70%. Coupled with higher comfort (warm surfaces, fresh air, neat appearance) this house is on the right path towards climate protection.

Last but not least, several possibilities for developing retrofit components were identified which will be further explored within the EU project EuroPHit.

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11 Subject index

12 List of figures

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13 Appendix 1: Photo series

14 Appendix 2: Drawings and Flixo reports

14.1 Ground floor plan EXISTING DRAWING

14.2 Basement floor plan EXISTING DRAWING
14.3 First floor plan EXISTING DRAWING
14.4 East elevation EXISTING DRAWING
14.5 South elevation EXISTING DRAWING
14.6 West elevation
14.7 North elevation
14.8 Section A-A
14.9 Window details
14.10 Basement details
14.11 Roof details
14.12 Wall details
14.13 Flixo report pages

15 Appendix 3: PHPP worksheets

15.1 PHPP “before, 2013”
15.2 PHPP “step 1, 2014”
Two more PHPPs (future scenarios) on enclosed CD.

16 Appendix 4: Additional information

16.1 EnerPHit certification criteria
16.2 Window Frame Certificate “Certified Passive House Component”
16.3 Heating and electricity energy use documentation
16.4 Specification sheet (Pflichtenheft)