The Energetic Retrofit of Historic Masonry Buildings

Focus on Central & Northern Europe

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1. Introduction

40% of the total energy consumed in Europe is consumed by building operation and usage (Itard, et al., 2008). In the temperate climate of central and northern Europe, a significant proportion of this consumption is attributed to building heating during the winter months. Although recent trends in European legislation favor an increase in thermal efficiency of building enclosures for new constructions, the majority of the building stock consists of buildings built to a lower standard of energy efficiency.

Over 56 % of the building stock in the central and northern European countries was built before 1970, when the first building energy efficiency regulations were adopted across Europe (Itard, et al., 2008). Even if current regulations require significant energy efficiency measures (EnEV 2009 in Germany requires a maximum heating energy consumption of 50 kWh/m²a) and the trend is to increase the standards even more, a vast portion of the building stock will have been built to much lower standards. Retrofitting existing buildings represents thus a priority, if a significant reduction in energy usage for buildings is to be achieved. There is a great opportunity in tackling this problem, especially when keeping in mind the fact that most of these inefficient building require significant renovation measures, as the lifespan of their systems comes to an end

The case of historic masonry buildings across Europe is especially relevant, as they pose special challenges related to the historic preservation of facades and even interiors. It is thus the aim of the present research to compile a set of principles and technologies that can be used for the thermal retrofit of historic buildings.

2. Hypothesis

As the need for retrofitting existing buildings increases, there is an increased demand in a performance based approach to the process. The pilot projects carried out on non-historic buildings, such as the Tevesstrasse Project in Frankfurt, Germany or the Mundenheim Project in Ludwigshafen, have shown that retrofit measures can lead to a more than 90 % reduction in heating energy consumption compared to the same buildings before retrofit . These projects have been successful in showing that the Passive House Standard of 15 kWh/m²a is achievable for retrofitted buildings. Nevertheless, such buildings were mostly built in the period between 1920 – 1970 and represent only 40.3% of the building stock.

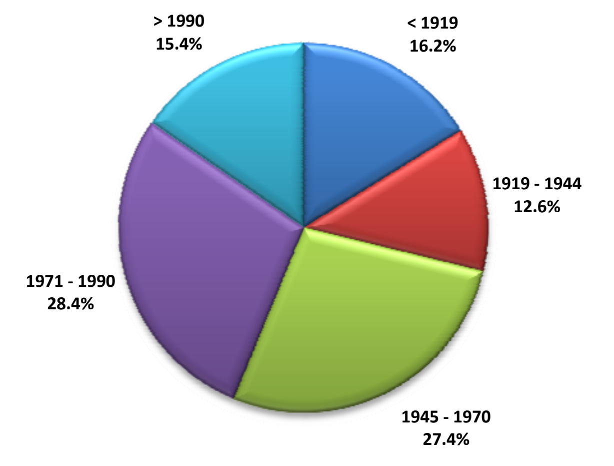


Figure 1 Building typology by year of construction for 8 Central and Northern European Countries

Historic buildings, primarily built prior to that period represent between 16.2% of the total number of buildings and pose significant renovation challenges due to their historical value. Historic preservation constraints on the façades and interiors prevent the same measures to be applied across the board.

According to the Competence Center for Energy and Mobility in Zurich, Switzerland (CCEM), historical buildings count for about 20% of the existing building stock in Europe. A vast majority of these buildings were built in the period prior to 1920 and are part of the cultural heritage of most European cities, contributing to the character of these urban areas. Even though the number of protected historical monuments is small compared to the overall number of historical buildings, most of the buildings built before 1920 have historic significance and generally have valuable facades which need to be preserved.

In tackling the energy efficiency of a building, an air tight construction and the use of highly insulating materials for the envelope are the primary concern. In the case of historic buildings, the thermal insulation of the facades proves to be more challenging, as the facades need to be preserved, thus making interior insulation the only viable option. When applying insulation to the interior of walls, the moisture balance within the original masonry construction needs to be carefully assessed in order to prevent moisture build up, mould growth and the eventual deterioration of the façade (CCEM, 2008).

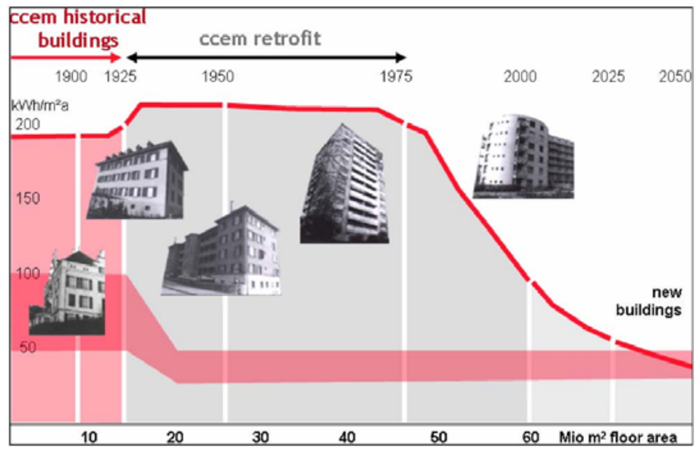


Figure 2 Heating Energy Demand/ sqm. in the Canton of Zurich (CCEM, 2008)

The same report mentions that, if all but the historic buildings were retrofitted, the older structures would amount to 60% of the heating energy consumption in the European building stock.

My hypothesis is, that historic buildings can be retrofitted to achieve a performance higher than the current European building codes and regulations and that such performance improvements can go as far as achieving the Passive House Standard. This reduction can be achieved by providing additional insulation to the building envelope, reducing air infiltration rates and improving mechanical systems.

3. The Central & Northern European Building Stock – Reasons for Retrofitting Buildings

In their report "Towards a sustainable Northern European housing stock" from 2008, Itard and Meijer analyze the characteristics of the building stock in 8 Central and Northern European Countries. The countries included in the report were Austria, Finland, France, Germany, the Netherlands, Sweden, Switzerland and the United Kingdom. Although not identical, these countries exhibit similar climates and similar methods of construction for their respective building stocks. Values regarding number and age o constructions as well as fuel usage could be deducted and calculated with reasonable accuracy from the charts and figures presented in the report mentioned above.

3.1. Energy Consumption of the Central and Northern European Building Stock

The total final energy consumption for the countries included in the report amounted to 29,554 TJ/a, equivalent to approximately 2.5 billion MWh. This consumption could be split according to the main categories of the economy. The building sector consists of residential and non-residential buildings, with residential buildings split into single and multi family constructions. The other sectors are shared by industry, agriculture, forestry and fishing. The construction industry is made up by the building materials industry. Thus, the Buildings account for 41% of the total final energy use in Northern Europe. Residential buildings are responsible for about three quarters of that consumption.

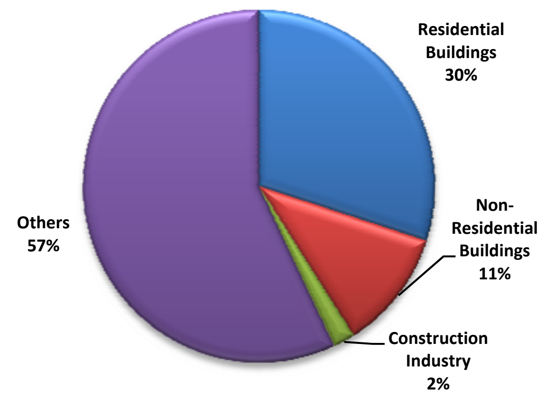


Figure 3 Energy Consumption, by Category, for 8 Central and Northern European Countries

The Residential building Stock on average is evenly split between single family and multifamily units, with the individual countries exhibiting considerable differences. Across Northern Europe, 44 % of residential units are in single family buildings, while 56 % are in multi family buildings. On average the usable area for residential units is 39 m^2 across the countries included in the study. As in the case of all the categories, there are variations from country to country.

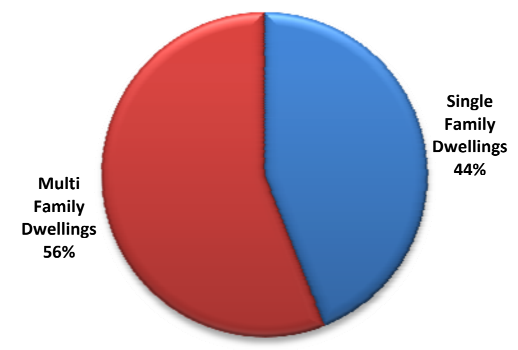


Figure 5 Average Percentages of Single and Multi Family Units for 8 Central and Northern European

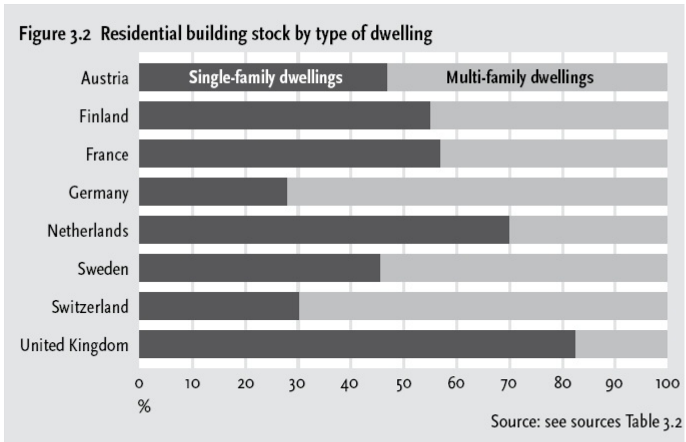


Figure 4 Percentage of Single and Multi Family Units by Country (Itard, et al., 2008)

3.2. Age of the Central and Northern European Building Stock

According to the information published in Itard and Meijer's study, 40 % of the total Nothern European Building Stock consists of buildings built in the period between 1919 -1970 and 16.2 % before 1919. These two periods are relevant for the current paper, as most of the buildings built before 1919 are listed as having historical significance and most of the buildings built between 1945 and 1970 have no historical significance, but still perform poorly in terms of their energy usage. Furthermore, there is also a difference in the architectural layout of buildings from the two periods. While older buildings tend to have big rooms with high ceilings, post-war constructions have smaller rooms and ceiling heights.

Insufficient data was available for the period between 1919 and 1945. Many buildings built in this period are historically significant, but the percentage is not known to me at this time, making it difficult to draw a

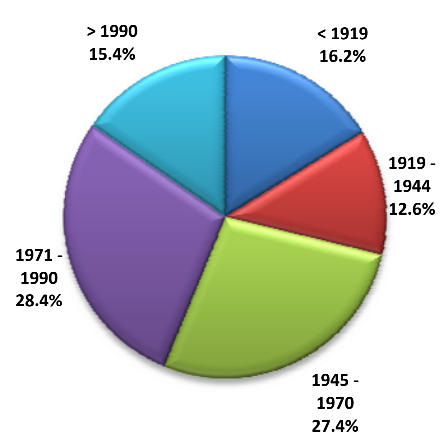


Figure 6 Type of Dwellings by Construction Period for 8 Central and Northern European Countries

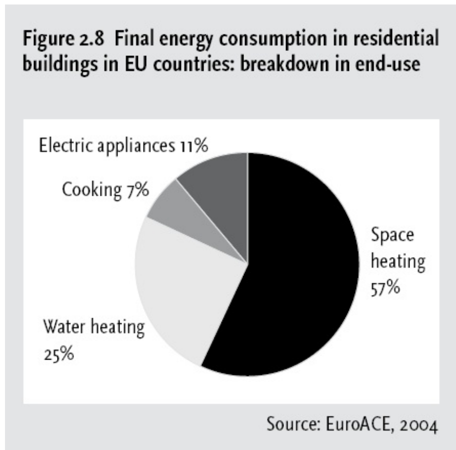


Figure 7 Consumption Breakdown for Residential Buildings in Europe (Itard, et al., 2008)

conclusion on the effectiveness of retrofit measures.

On average, residential buildings consume 57 % of the total final energy for space heating, 25 % for water heating and 18 % for cooking and electrical appliances. Although retrofit measures often achieve a reduction for energy use for water heating as well, for the purpose of this case study I will focus on the final heating energy consumption, as it is the only measure which allows a direct comparison between various construction standards and retrofit results.

3.3. Importance of Historic Buildings for the European Building Stock

Historic buildings have a very high significance for the European Building Stock, as they make up most of the inner city urban landscape of European Cities. These types of buildings were mainly built before 1919 and represent about 16 % of the total residential building stock in Central and Northern Europe. Even though this number might seem low, the historic value of the building facades and of the historic ensembles contributes significantly to the success of the European tourism industry, which in itself amounts to about 5 % of the EU GDP (EU Business, 2010).
Significant efforts are being made across Europe in order to retrofit existing buildings to a higher energy efficiency standard. In Germany alone the renovation efforts amounted to 1.6% of the building stock in 1994, a number which grew to 2.2 % in 2006 (Erhorn, et al., 2009). This effort was sustained by various national policies aimed at retrofitting existing buildings. Even so, by 2006, 70% of buildings in need of energetic retrofit still needed to be renovated.
The retrofit of historic buildings poses several challenges, mainly due to the necessity of conserving the historic substance, mainly the historic facades. While non historic buildings can be easily upgraded using a combination of exterior insulation material and a redesign of the facades, historic building facades need to be treated using interior insulation and very careful construction techniques in order to avoid moisture buildup and mould growth.

3.4. The Climate of Central and Northern Europe

The aim of the present paper is to analyze the energy retrofit measures which can be recommended for historical buildings in the climate of Central and Northern Europe. The climate in this area is dominated by the heating season, with more than 5000 HDD (at 65 F). The average number of **HDD** for the 22 locations of the case studied within this paper is **5,943** and for the **CDD is 443**. These values correspond to the **Climate Zone 5** classification applied by the ASHRAE 189.1-2009 standard.

The cases studied within the context of the present report are clustered in the area of Germany, Switzerland and Austria. Nevertheless, the climate of this area is significant for the whole Central and Northern European context. The weather is characterized by cold winters and warm to moderate summers.

Due to the similarities in the weather patterns between the studied area of Europe and the U.S. climate zone 5, retrofit recommendations made within this report are also valid for similar constructions in the United States.

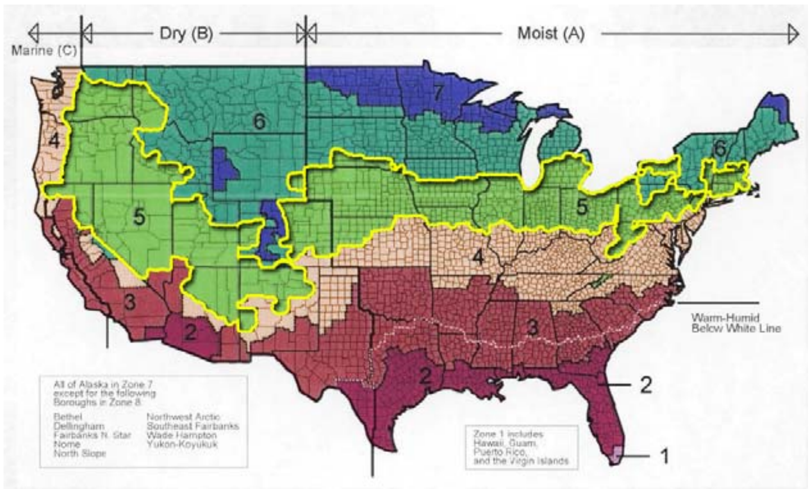


Figure 8 Climate Zones of the United States - ASHRAE 189.1-2009

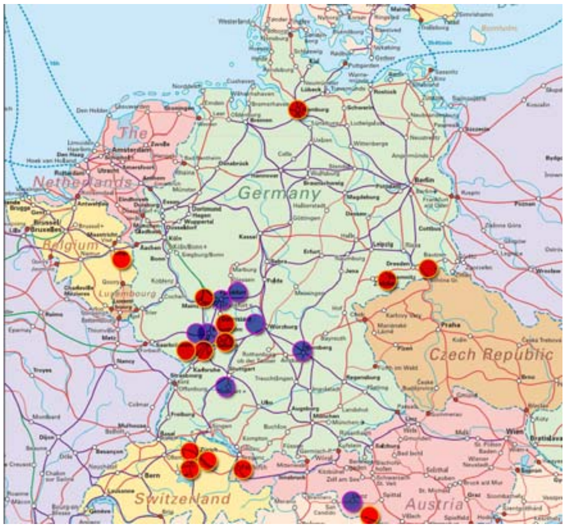


Figure 10 Location of Cases - Historic (red) Nons Historic (blue)

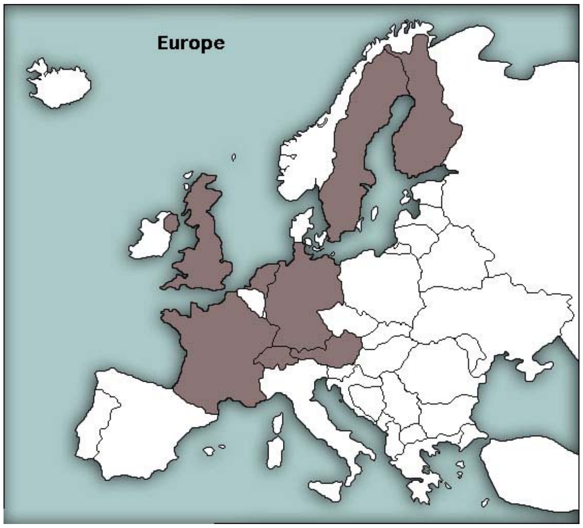


Figure 9 8 Central and Northern European Countries included in the context of the present report

4. The Passive House

The concept of a Passive House was developed during the early stage of the 1990's in Germany by Professors Bo Adamson (Sweden) and Wolfgang Feist (Germany). The concept combined ideas of passive solar design and superinsulation in order to create a building which would be able to maintain a comfortable interior climate without conventional heating or cooling systems. Dr. Wolfgang Feist founded the Passiv Haus Institut in Darmstadt, Germany. The main activity of the institute is to conduct research in the field of Passive House design and construction, conducting numerous experiments in order to validate the concept.

4.1. The Passive House Standard

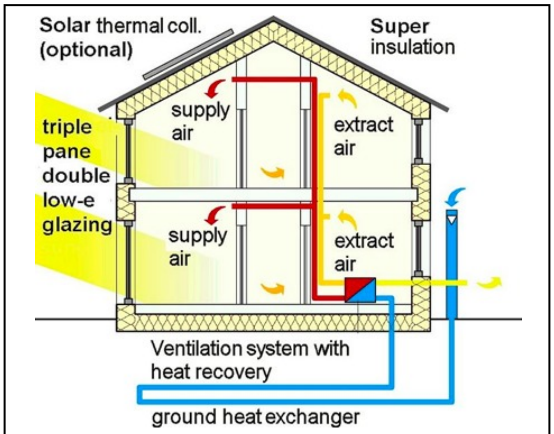


Figure 11 Passive House Schematic Section (www.treehugger.com)

The Passive House standard refers to a type of building which, through an exceptionally high level of insulation, "ensures a comfortable indoor climate in summer and in winter, without needing a conventional heat distribution system" (Schnieders, et al., 2006). In order to achieve this level of performance, it is essential that the building does not exceed a heating load of 10 W/m^2, equivalent to annual space heating requirement of 15 kWh/m^{2}a (4.8 kBtu/ft^{2}a). This space heating requirement is 80% lower than the 1999 code requirements for new construction throughout Europe.

The Passive House achieves its performance through a combination of high insulation values for both walls and windows, low air leakage rates through the envelope, passive solar gain and efficient building systems. The U values for the exterior building elements are typically between 0.1 and 0.15 W/m^{2}K and thermal bridges are avoided as far as possible. Highly efficient glazing and window insulated frames are used, with overall U-values less than 0.8 W/m^{2}K (recommended for the Middle European climate – (Schnieders, et al., 2006)) and average solar heat gain coefficients of 0.5 – 0.6. Triple low-emissivity glazing with a filling of heavy noble gases is typically used. Net gains can thus be achieved even in the winter months. Solar heat gain can be used to cover as much as a third of the total heat demand of the house. Nevertheless, passive houses are not dependent on orientation.

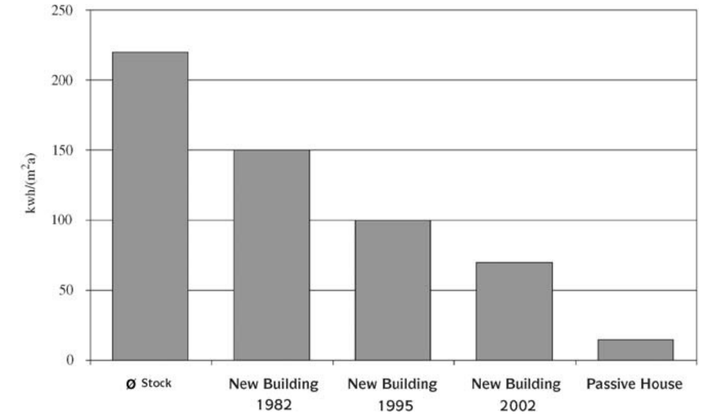


Figure 12 Comparison of Heating Energy Consumption between the building stock, the German Standards from various periods and the Passive House Standard (Schnieders, et al., 2006)

The infiltration rate for the envelope is set for the passive house at a maximum of 0.6 ACH for a difference in pressure of 50 Pa between the inside and the outside. Due to the low natural infiltration rates, a mechanical ventilation system with heat recovery at an efficiency of minimum 75 % is required in order to maintain indoor air quality and recover heat from the exhaust air (Schnieders, et al., 2006). The heating of passive houses is typically done by terminal reheating the incoming fresh air by the means of a water based heating element, normally connected to a central boiler. The ventilation rates for the system are between 0.25 and 0.4 h^{-1}, enough to provide occupant comfort, and the post heating is done at temperatures of up to 55 C in order to avoid dust carbonization.

4.2. Experimental Results from the Cepheus Project

The experience from the pan European CEPHEUS project, lasting between 1998 and 2001, during which 221 housing units were built to Passive House standards in five European countries, shows that the ventilation systems can be turned off in summer, when opening the windows for ventilation is possible. Solar thermal collectors and other renewable energy technologies can easily be used to provide the necessary heating energy required by passive houses. Results from the Cepheus project have shown large differences in heating energy consumption between housing units in the same project. This variation has been attributed to human behavior or mistakes during the construction process,

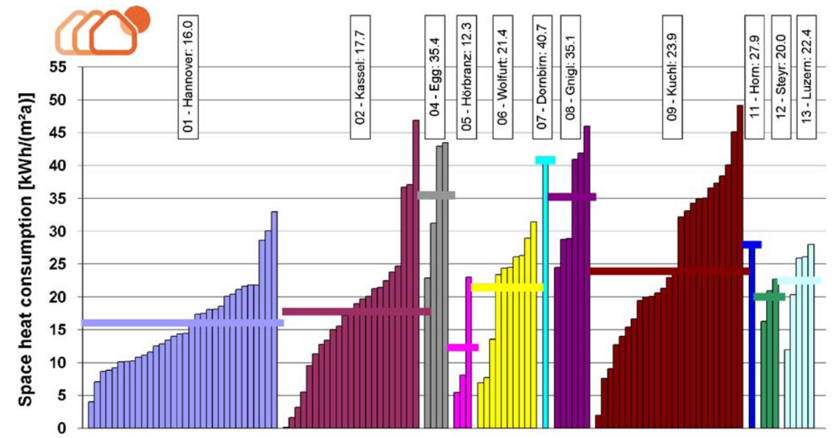


Figure 13 Comparison of Measured Heating Energy Consumption for the Cepheus Projects (Schnieders, et al., 2006)

which allowed for higher infiltration rates than calculated. Although these variations affected the overall performance o the buildings, simulation results were well within the 15 kWh/m2 proposed limit, thus validating the theoretic concepts put forward.

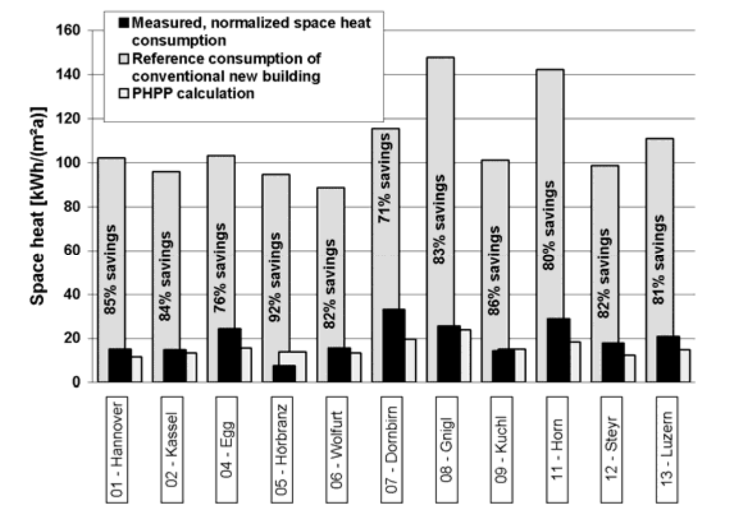


Figure 14 Projects within the CEPHEUS study: Space heat consumption levels determined by measurements, extrapolated for a whole year and normalized to 20°C indoor temperature ('normalized space heat consumption') compared to the consumption of conventional new buildings and to the values calculated in advance using the PHPP Passive House Planning Package (Feist, et al., 2001)

One of the most important findings of the project, which would subsequently be confirmed by various other monitoring experiments, is that the user behavior plays a huge role in the performance of the building. It has been shown, that users have different preferences towards the comfort temperature set point, setting the temperature higher than calculated. Furthermore, many of them were not accustomed to the potential of the mechanical systems and the passive house design. Opening windows for natural ventilation in winter is just one of the practices still employed by users (Schnieders, et al., 2006).

"Figure 11 compares the normalized space heat consumption levels to reference consumption levels of conventional new buildings that have the same geometry and are built in accordance with locally applicable construction law (cf. Section 2.4.1), and with the space heat requirement values calculated in advance (using the PHPP Passive House Planning Package). Compared to the reference consumption of conventional new buildings, analysis of the normalized space heat consumption shows that the buildings saved 84% space heat over the area-weighted mean. Savings were lowest in those projects that were only occupied during or shortly before the measurement period and were not yet fully completed. In all houses that were already occupied for a longer period, savings figure more than 80%". (Feist, et al., 2001)

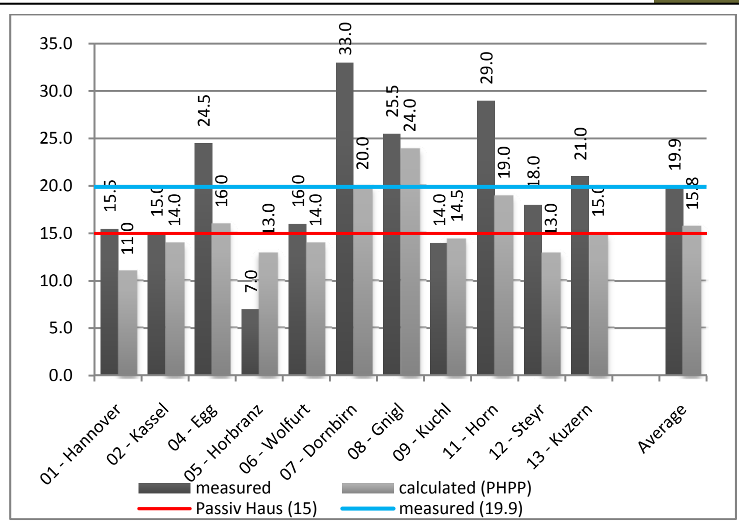


Figure 15 Heating Energy Consumption for the CEPHEUS Project - Comparison of calculated and measured values

The difference between calculated values has been attributed to the user behavior (Schnieders, 2003) and to the fact that measurements were conducted primarily in the first year of operation, when the mass of the building had to be heated starting from a very low temperature. Feist indicates that 3-4 kWh/m2a can be lost due to the need to heat up the building mass following the construction period. In the case of user behavior the main issues are related to higher set point temperatures in the winter, traditional behavior of ventilation by opening the windows and failure to understand how the mechanical systems should be set up.

The overall user satisfaction with the Passive House design of the homes involved in the study was positive. “Moreover, the higher surface temperatures and the even temperature distribution throughout the space (no temperature stratification) compared to ‘normal’ houses are experienced as highly pleasant. For summer, too, the occupants confirm the measurement results – 88% of those surveyed state that they are satisfied or very satisfied with the indoor climate in summer. Air quality is rated by 95% of occupants as good to very good. Not a single occupant gave a negative rating. When asked about their satisfaction with their ventilation system, there was not a single negative assessment of the ventilation system with heat recovery.” (Schnieders, 2003)

5. Special Issues with Retrofitting Existing Masonry Buildings

As the existing European building stock ages, the need for renovation measures arises for more and more buildings. Coincidently, old buildings in need of retrofit do not fulfill present energy efficiency standards, so the opportunity presents itself to improve the thermal envelopes of these constructions. Since the majority of buildings in the Central and European climate were built using masonry construction techniques, improving the thermal behavior of external walls by means of additional insulation layers needs to take into account several challenges. The most important of these challenges relate to the issue of moisture flow and buildup within the wall structure.

Solid masonry walls exhibit a dynamic moisture balance between infiltrating moisture and evaporation to the exterior and interior of the building. Even though the moisture in a traditional masonry wall has the capacity to migrate and evaporate on either surface depending on the season, its presence within the wall material affects the overall thermal insulation capacity of the assembly. If the exterior wall surface allows for driving rain to penetrate the mass of the assembly, the drying process to the interior often leads to hygienic problems. Thermal insulation measures which need to be taken in order to improve the energy efficiency of the building can also address moisture related problems.

While exterior insulation is generally regarded as the best option for retrofitting existing buildings, because it allows for the drying of the wall to the interior space and thus a balancing of the moisture content, it is often not feasible, especially in the case of historic buildings. Interior insulation poses significant challenges to a solid masonry envelope, since it stops the moisture balancing towards the interior space and potentially leads to a higher moisture content within the wall structure due to the increase in temperature within its mass. By means of field tests and hydrothermal simulation studies, it has been possible to achieve technical solutions to the most important issues.

The protection against moisture related problems aims at tackling three main causes: condensation due to diffusion or convection from increased interior humidity levels; driving rain from the exterior environment; ascending moisture from the ground or from within construction elements. These three factors are responsible for a variety of problems amongst which the most important are:

- Mould growth (especially on thermal bridges or behind insulation panels)
- Saline damage
- Frost damage (e.g. spalling of the exterior finish)
- Corrosion (e.g. steel mountings or structural elements within the wall)
- Rottenness (e.g. wooden beams)

5.1. Condensation

When applying exterior insulation, the masonry wall remains exposed to the interior humidity and temperature conditions. Although interior humidity levels during winter reach 50% under normal residential occupancy (Kunzel, 2004), the wall is allowed to dry out towards the interior space every time interior humidity levels drop (e.g. in the summer). Furthermore, in the case of exterior insulation, the wall retains a similar temperature as the interior space.

In the case of interior insulation, the masonry wall has a similar temperature to the outside, which, in the winter, makes condensation possible at the boundary between the solid wall and the interior insulation. Condensation occurs at this point, if moisture from the interior

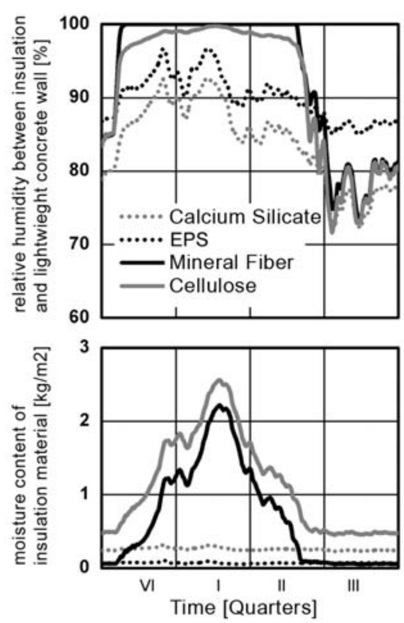


Figure 16 Moisture decrease over the course of a year and the moisture content of different insulation materials over the same period when applied internally to a lightweight concrete block (Kunzel, 2004)

ambient can make its way to the cold wall, past the insulation layer. The cold wall may reach temperatures below the dew point temperature of the interior air.

Moisture from the room ambient may reach the wall surface through vapor diffusion through the insulation material itself or through convection at joining points between insulation panels or between the insulation layer and construction elements such as partition walls or slabs. In order to prevent convection, the insulation layer needs to be carefully constructed so that any possible gaps are removed. Often, interior walls have an uneven finish which can allow for hollow spaces between the wall and the panels, especially if rigid insulation materials are being used. Fiber insulation materials or leveling plasters are recommended in this case (Kunzel, 2004).

As a solution against moisture buildup within the wall, vapor resistant insulation materials or vapor barriers can be used. Vapor barriers are deployed especially when the insulation material allows for vapor diffusion or capillary moisture migration. The most common interior insulation materials are:

- EPS (it is widely available and cheap)
- Mineral Wool (mostly used because of fire protection issues)
- Cellulose Fibers (a renewable material)
- Calcium Silicate (it has a lower insulation capacity than the other materials, but it allows for capillary moisture migration, favoring the drying of the external wall)

Tests using the WUFI simulation software have shown that permeable materials such as Cellulose and Mineral Fiber need to be protected by a vapor barrier in order to prevent moisture buildup at the wall surface. The impermeable characteristics of EPS prevent moisture migration from the interior ambient, but it also prevents the drying of the wall during the summer months. In this case humidity levels remain above 80% generating a risk of mould growth. Calcium Silicate insulation was shown to both prevent dangerous moisture buildup and allow for the drying of the wall during summer months (quarter 3) (Kunzel, 2004).

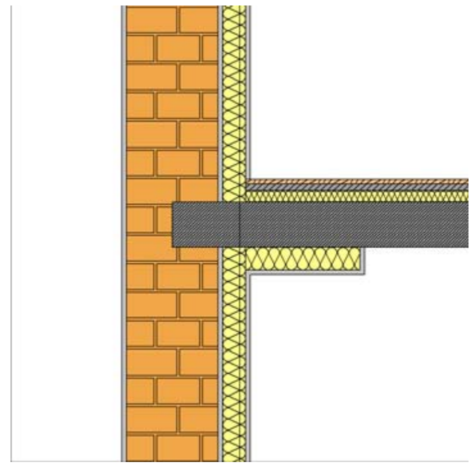


Figure 17 Minimizing thermal bridges through interior insulation along partition elements (in this case – a concrete slab)

Besides the danger of condensation on the wall surface, there is a similar risk at the location of thermal bridges. Most of the times interior construction elements such as partition walls, slabs or wooden beams are connected to the exterior masonry wall, thus conducting heat to the outside. These elements become colder than the insulated wall and can reach due point. The most common solution in these cases is to extend the insulation along the interior elements in order to minimize the thermal bridging effect.

Regardless of the technical solution chosen to remove the risk of condensation on the masonry wall structure, the success of the retrofit depends on the careful execution of the insulation layer. Gaps in the insulation or vapor barrier need to be removed and the insulation needs to be connected continuously to the original wall surface.

5.2. Driving Rain

Driving rain is a phenomenon that contributes to the increase of the moisture levels within solid masonry walls due to exposure to the outside climate. Modern masonry buildings do not have this problem due to the development of impermeable exterior plasters which protect the façade from penetrating rain. In the case of historic buildings, the brick is either exposed or covered with a permeable plaster. Rain hits the façade and thus causes the moisture levels within the material to rise. Rising moisture levels reduce the insulation capacity of the assembly.

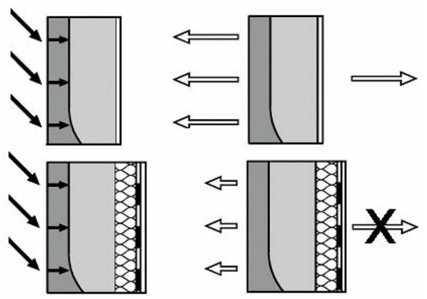


Figure 18 Drying of a solid masonry wall after driving rain without insulation and with interior insulation (Kunzel, 2004)

An uninsulated exterior wall has the capability of releasing moisture both towards the exterior and towards the warm interior space, thus drying up. This process is especially facilitated during the summer months, when exterior temperatures are also sufficiently high. The moisture is released mainly through the exterior surface, as temperature rise in the summer season.

An exterior insulation layer made up from a non hygroscopic insulation material such as EPS forms a very effective barrier against driving rain. Even in the case of mineral fiber, experimental results have shown the wall has the capacity of drying out over the course of two years (Kunzel, 1998). The EPS protected wall dried up in twice the time it took the mineral wool protected one, the reason for that being the increased vapor permeability of mineral wool. Special care needs to be given to the selection of the external plaster because of the risk of moisture build up between the plaster layer and the insulation if there is a large difference between the vapor permeability of the plaster and the insulation material. A lower vapor permeability of the plaster can act as a barrier for moisture released through the insulation material, especially in the case of mineral wool. The main feature of the exterior insulation is, that it forms both a protective barrier against driving rain and it allows the wall to balance its moisture content towards the interior space.

By contrast, when applying insulation to the interior of a masonry wall, the temperature of the wall is reduced during the winter months, thus lowering the drying capacity of the wall towards the exterior. Although the drying capacity to the interior is lowered by the presence of the insulation material, the most effective way of preventing dangerous humidity levels within the wall is by controlling the surface rain water flow and preventing the wetting of the masonry. In this case, the application of an external hydrophobic treatment on the façade becomes necessary. This treatment should be applied some time before installing the interior insulation in order to allow sufficient time for the original wall to dry up (Kunzel, 1998).

In addition to the surface of the exterior wall, special care should be given to the design of locations which have the highest intensity of wetting, such as window sills (at the lowest corners of window openings) and at grade. Water should be directed away from the wall (Straube, et al., 2007)

5.3. Ascending Moisture

The drying process of the wall is of critical importance for the prevention of mould growth and the reduction in its insulating capacity. Given a careful planning and execution process the wall can be protected from moisture penetration from the outside and the inside. Nevertheless residual moisture can still be present in the structure at significant levels due to insufficient time allowed for drying of the original or the use of additional solid masonry construction elements connected to the original wall. Furthermore, the reduced drying capacity of the wall can provoke a rise of the ascending moisture level caused by capillary moisture migration (mostly from the ground). Moisture ascends at higher levels within the wall and can induce damages within the new assembly.

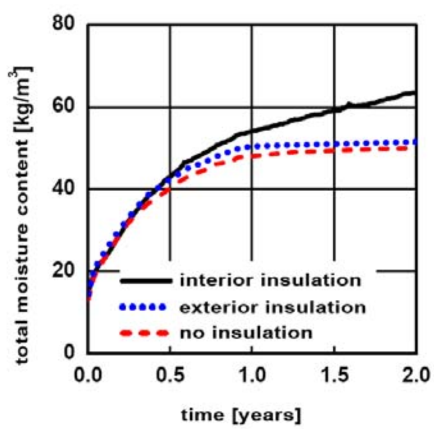


Figure 19 Moisture content of a masonry wall due to ascending moisture (Kunzel, 2004)

A possible measure consists of using a vapor permeable interior insulation material in conjunction with a vapor retarder in order to reduce the impermeability of the interior insulation layer, or the use of capillary active insulation materials such as calcium silicate which favor the moisture transfer into the interior space. In the case of the first option, problems can arise from moisture transfer into the wall from the interior environment as discussed previously. In both cases the dangers of moisture levels to increase to dangerous values or of an insufficient drying capacity of the wall are too high. The removal of the source of ascending moisture proves to be the safest option in order to insure a "healthy wall" (Feist, 2005)

6. Retrofitting Non Historic Buildings

6.1. Characteristics of Non Historic Buildings

Non historic buildings are buildings which do not have any historic preservation restrictions imposed on them. These types of buildings have been typically built after the First World War and haven't been recognized, in their vast majority as having historical significance. These constructions are part of various architectural movements, the most notable characteristic being the absence of decorations on the façade or on the interiors. The split between historic and non historic buildings can be made around the year 1920, with the majority of the buildings built before having historical significance and the ones built after that date typically being non historic.

The change in architectural styles can be attributed to the modernist movement and its concept of removing any decoration from the architectural object and the focus on pure form as a result of the function. This development coincided with large public housing projects which were carried out in Europe starting with that period. New design principles and construction methods as well as a change in public policy prompted these new projects to be constructed.

The period spanning from 1919 and 1970 is the most relevant terms of the non-historic building stock in Central and Northern Europe due to the abundance of residential buildings being built using similar construction techniques. Furthermore, the 1970's were characterized by the introduction of European wide standards for building energy efficiency following the oil crisis. Residential buildings built between 1919 and 1970 account for 40% of the European residential building stock (Itard, et al., 2008) and were erected using solid brick masonry construction methods. Projects from the early part of the period tend to have solid brick slabs and later structures have concrete slabs. Although the cases I have analyzed have load bearing walls, the later part of the period was characterized by the construction of taller buildings with reinforced concrete and hollow core or lightweight masonry walls. In all cases the lack on a thermal insulation layer led to high heating energy requirements.

For the purpose of the present paper I have analyzed 8 buildings built between 1919 and 1970 which have been retrofitted to high efficiency standard. The proclaimed aim in all cases was to achieve Passive House new construction performance characteristics. They are representative for the Central and Northern European Building stock of that period.

6.2. Energy Consumption of Non Historic Buildings

Due to the nature of the Central and Northern European climate, dominated by heating degree days (more than 5000 for a reference temperature of 65F) the most reliable indication of a building's energetic performance is its heating energy consumption.

The data from the analyzed buildings shows an average heating energy consumption before retrofit measures of 215 kWh/m2a. This high energy consumption is four times higher than the current German building codes (ENEV 2009) indicate as a maximum value for new residential construction. The poor performance of the buildings can be attributed mainly to the lack of insulation of the walls and slabs, insufficient or lacking insulation at roof level, poorly performing windows and window frames, and a high air leakage rate. The use of outdated and inefficient mechanical systems is also a reason for the high consumption values.

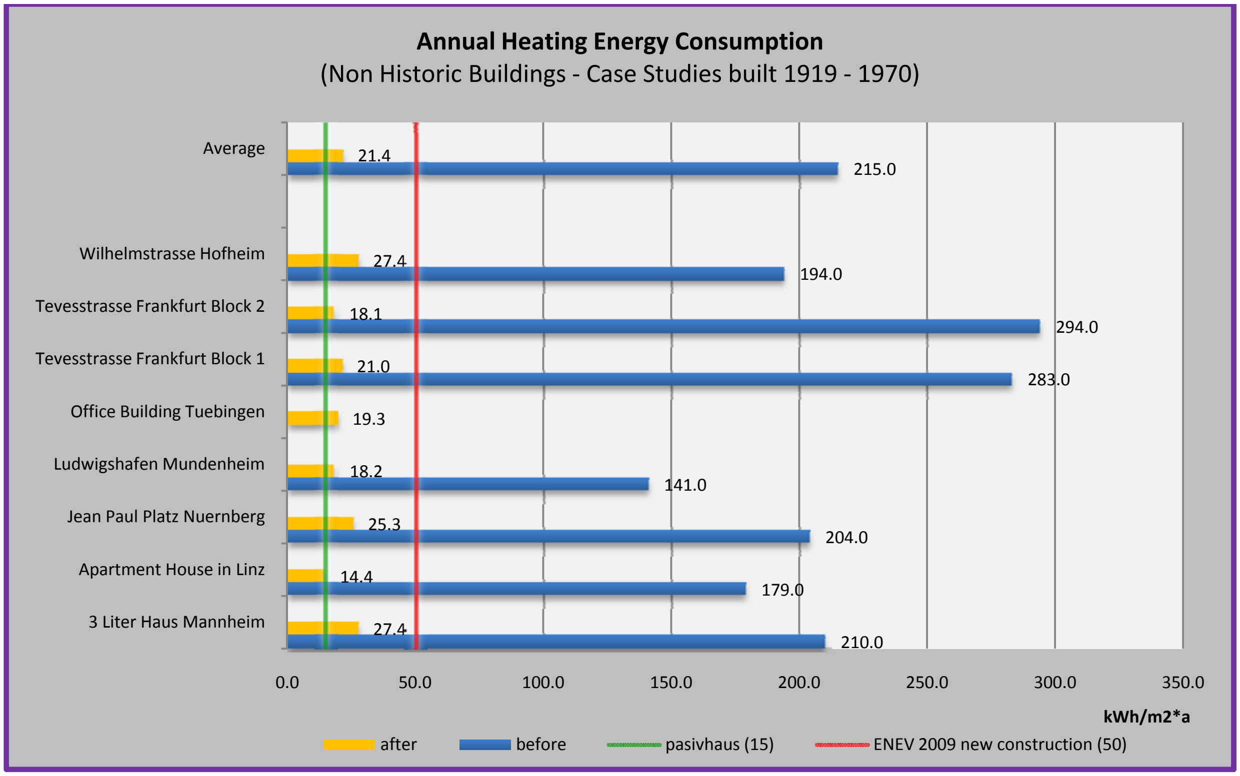


Figure 20 Annual Heating Energy Consumption – Non Historic Buildings - Case Studies built 1919 – 1970

The average heating energy consumption for the retrofitted case buildings is 21.4 kWh/m2a, which represents a 90.5% reduction compared to the "before" value. Interventions included the upgrade of the envelope insulation capacity through additional insulation and the replacement of windows, the removal of the majority of leakage areas in order to obtain an air tight construction, the replacement of mechanical systems and the use of renewable energy, most notably solar thermal collectors (for hot water). This result is consistent with the findings of the CEPHEUS Study, which evaluated 200 newly constructed passive house units. The final report of that study indicated an 84% saving compared to the calculated potential consumption of the same building if it was built using conventional techniques (similar to those characteristic to the building stock) (Feist, et al., 2001).

The results of the measurements after retrofit indicate an average heating energy consumption 33% higher than the Passive House Standard. With 21.4kWh/m^{2}a, the heating energy consumption for the case buildings is considerably low, but slightly above the targeted value. When considering that similar results have also been achieved within the CEPHEUS study for Passive House new constructions (average heating energy consumption of 19.9 kWh/m^{2}a) (Feist, et al., 2001), it can be safely assumed that buildings retrofitted using passive house design methods have achieved the Passive House Standard. As indicated in a previous chapter, the differences between measured and calculated values can be attributed to the user behavior and to the fact that measurements were conducted primarily in the first year of operation, when the mass of the building had to be heated starting from a very low temperature.

6.3. Case Studies of Non Historic Building Retrofits

The analyzed cases of non historic buildings are mostly multifamily residential buildings. The retrofit measures carried out were accompanied by extensive measurements and assessment of the results. 8 cases were studied in total.

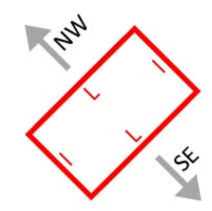
6.3.1. "3 Liter Haus" Mannheim

Location	Mannheim / Germany	
Location Type	suburb	
HDD	5,090	
CDD	666	
Year of Construction	1931	
Year of Retrofit	2004	
Historic Preservation	none	
Building Use / Type	residential / detached	
Orientation	NE-SW	
No. of Floors	before	after
	2	2
Cond. Usable Area (m²)	1,150	1,150
Construct. Cost (€/m²)		2,300

Figure 22 3 Liter Haus Mannheim - View after rennovation

Heating Energy Consumption

	before	after	reduction
kWh/m²a	**210**	**27.4**	**87.0%**



U Values (W/m²K)

	before	after
Walls – Main Facade	**1.280**	**0.150**
Walls – Gable	**1.280**	**0.120**
Roof	**0.940**	**0.110**
Floor / Slab	**1.370**	**0.110**
Windows	**2.60**	**0.80**
Infiltration Rate (ACH at n50)	**4.2**	**1.2**

Figure 21 3 Liter Haus Mannheim - bach facade after rennovation

Insulation Materials

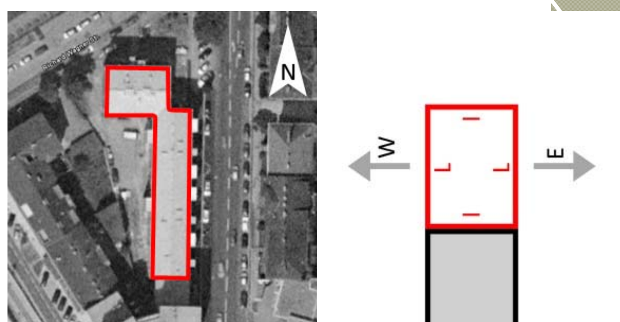
	type	location	thickness (mm)	conductivity (W/mK)
Walls – Main Facade	**EPS (Neopor)**	exterior	**200**	**0.033**
Walls – Gable	**EPS (Neopor)**	exterior	**250**	**0.033**
Roof	**EPS (Neopor)**	cavity	**360**	**0.033**
Floor / Slab	**EPS + Neopor**	interior + exterior	**45 + 250**	**0.033**
Windows	**triple**	replacement	**PVC insulated**	

Detailed Case Study Analysis of the project: ***Appendix 1***

6.3.2. Apartment House in Linz

Location	Linz / Austria	
Location Type	inner city	
HDD	6,271	
CDD	450	
Year of Construction	1957	
Year of Retrofit	after 2000	
Historic Preservation	none	
Building Use / Type	residential / attach. 1 side	
Orientation	E-W	
No. of Floors	before	after
	5	5
Cond. Usable Area (m²)	2,755	3,106
Construct. Cost (€/m²)		

Figure 24 Apartment House in Linz - view after retrofit



Heating Energy Consumption

	before	after	reduction
kWh/m²a	**179**	**14.4**	**92.0%**

U Values (W/m²K)

	before	after
Walls	**1.200**	**0.082**
Roof	**0.900**	**0.093**
Floor / Slab	**0.700**	**0.205**
Windows	**3.00**	**0.86**
Infiltration Rate (ACH at n50)		**0.60**

Figure 23 Apartment House in Linz – section after retrofit

Insulation Materials

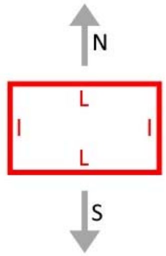
	type	location	thickness (mm)	conductivity (W/mK)
Walls	**Mineral Wool + Honey Comb**	exterior	**190 + 50**	**0.040**
Roof	**Mineral Wool**	exterior	**400**	**0.040**
Floor / Slab	**Mineral Wool + Porit**	exterior	**100 + 50**	**0.035 / 0.040**
Windows	**triple**	replacement	**PVC insulated**	

Detailed Case Study Analysis of the project: ***Appendix 2***

6.3.3. Jean Paul Platz Nürnberg

Location	Nürnberg / Germany	
Location Type	suburb	
HDD	6,325	
CDD	406	
Year of Construction	1930	
Year of Retrofit	2002	
Historic Preservation	none	
Building Use / Type	residential / detached	
Orientation	N-S	
No. of Floors	before	after
	3	3
Cond. Usable Area (m²)	894	894
Construct. Cost (€/m²)		540

Figure 26 Jean Paul Platz Nuernberg – View after Retrofit



Heating Energy Consumption

	before	after	reduction
kWh/m^2a	**204**	**25.3**	**87.6%**

U Values (W/m^2K)

	before	after
Walls	**1.447**	**0.156**
Roof	**0.870**	**0.120**
Floor / Slab	**0.880**	**0.190**
Windows		**0.80**
Infiltration Rate (ACH at n50)	**4.9**	**0.35**

Figure 25 Jean Paul Platz – wall insulation

Insulation Materials

	type	location	thickness (mm)	conductivity (W/mK)
Walls	**EPS (Neopor)**	exterior	**200**	**0.035**
Roof	**EPS (Neopor)**	exterior	**250**	**0.035**
Floor / Slab	**EPS (Neopor)**	exterior	**140**	**0.035**
Windows	**triple**	replacement	**PVC insulated**	

*Detailed Case Study Analysis of the project: **Appendix 3***

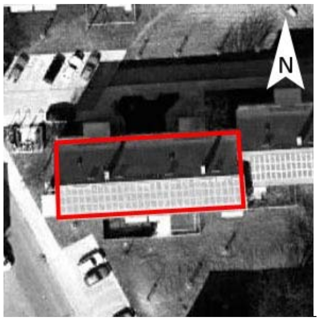
6.3.4. Ludwigshafen Mundenheim (PHiB)

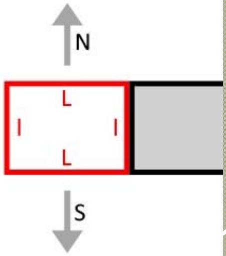
Location	Ludwigshafen / Germany	
Location Type	suburb	
HDD	5,090	
CDD	666	
Year of Construction	1965	
Year of Retrofit	2005 – 2006	
Historic Preservation	none	
Building Use / Type	residential / attach. 1 side	
Orientation	N-S	
No. of Floors	before	after
	3	3
Cond. Usable Area (m^2)	750	750
Construct. Cost (€/m^2)		1,177

Figure 28 Ludwigshafen Mundenheim - View after retrofit

Heating Energy Consumption

	before	after	reduction
kWh/m^2a	**141**	**18.2**	**87.1%**





U Values (W/m^2K)

	before	after
Walls	**1.294**	**0.100**
Roof	**0.516**	**0.114**
Floor / Slab	**0.640**	**0.170**
Windows	**2.8**	**0.83**
Infiltration Rate (ACH at n50)		**0.46**

Figure 27 Ludwigshafen Mundenheim - View before retrofit

Insulation Materials

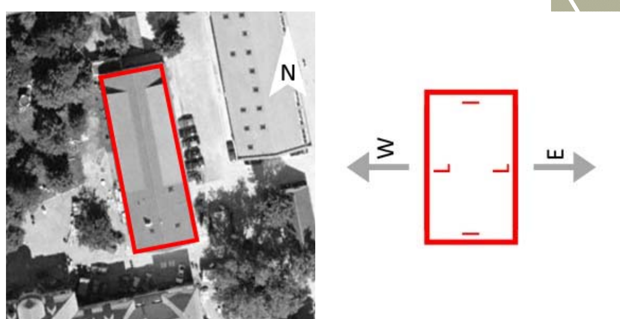
	type	location	thickness (mm)	conductivity (W/mK)
Walls	**EPS (Neopor)**	exterior	**300**	**0.035**
Roof	**EPS (Neopor)**	exterior	**300**	**0.035**
Floor / Slab	**XPS + PU foam**	interior + exterior	**40 + 120**	**0.040 / 0.025**
Windows	**triple**	replacement	**PVC insulated**	

*Detailed Case Study Analysis of the project: **Appendix 4***

6.3.5. Office Building Tübingen

Location		Tübingen / Germany
Location Type		inner city
HDD		6,089
CDD		406
Year of Construction		1954
Year of Retrofit		2003
Historic Preservation		neighborhood
Building Use / Type		office / detached
Orientation		E-W
No. of Floors	before	after
	1	1 + 1
Cond. Usable Area (m²)		833
Construct. Cost (€/m²)		972

Figure 30 Office Building Tuebingen - View after retrofit



Heating Energy Consumption

	before	after	reduction
kWh/m²a		**19.3**	**%**

U Values (W/m²K)

	before	after
Walls – Ground Floor	**1.500**	**0.136**
Roof	**1.700**	**0.138**
Floor / Slab	**2.500**	**0.350**
Windows	**2.5**	**0.8**
Infiltration Rate (ACH at n50)		**0.2**

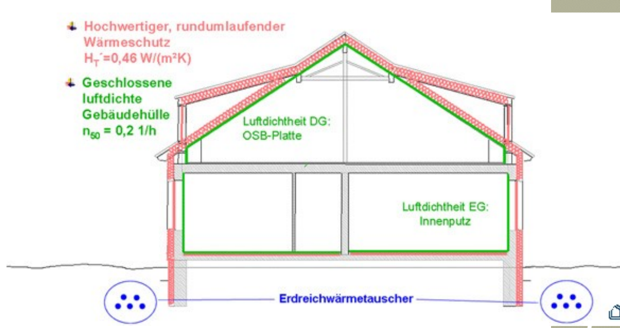


Figure 29 Office Building Tuebingen - Section after rennovation

Insulation Materials

	type	location	thickness (mm)	conductivity (W/mK)
Walls	**EPS**	exterior	**240**	**0.035**
Roof	**Mineral Wool**	cavity	**300**	**0.040**
Floor / Slab	**PU Foam+ Perlite**	interior	**45 + 30**	**0.025 / 0.050**
Windows	**triple**	replacement	**PVC insulated**	

Detailed Case Study Analysis of the project: ***Appendix 5***

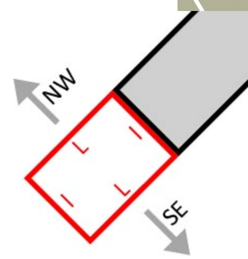
6.3.6. Tevesstrasse Frankfurt Block 1

Location	Frankfurt a.M. / Germany	
Location Type	inner city	
HDD	5,515	
CDD	513	
Year of Construction	1951	
Year of Retrofit	2005 – 2006	
Historic Preservation	none	
Building Use / Type	residential / attach. 1 side	
Orientation	NW-SE	
No. of Floors	before	after
	3	3 + 1
Cond. Usable Area (m²)	1,851	2,244
Construct. Cost (€/m²)		1,350

Figure 32 Tevesstrasse Block 1 - View after retrofit

Heating Energy Consumption

	before	after	reduction
kWh/m^{2}a	**283**	**21**	**92.6%**



U Values (W/m^{2}K)

	before	after
Walls	**1.300**	**0.122**
Roof	**1.600**	**0.106**
Floor / Slab	**1.100**	**0.177**
Windows	**1.5**	**0.87**
Infiltration Rate (ACH at n50)	**4.2**	**0.5**

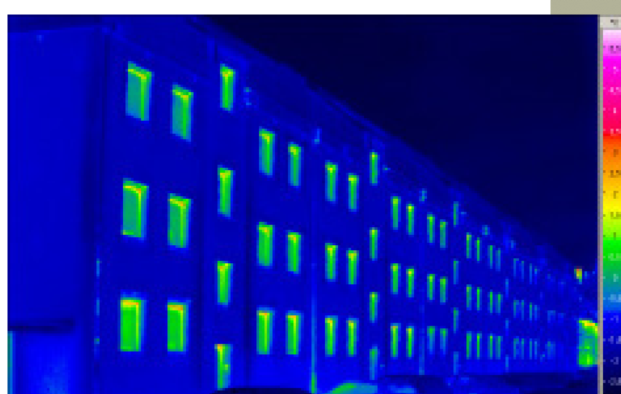


Figure 31 Tevesstrasse Block 1 - Isothermal Image after retrofit

Insulation Materials

	type	location	thickness (mm)	conductivity (W/mK)
Walls	**EPS (Neopor)**	exterior	**260**	**0.035**
Roof	**Cellulose**	cavity	**400**	**0.040**
Floor / Slab	**PU foam**	interior + exterior	**40 +80**	**0.025**
Windows	**triple**	replacement	**PVC insulated**	

Detailed Case Study Analysis of the project: ***Appendix 6***

6.3.7. Tevesstrasse Frankfurt Block 2

Location	Frankfurt a.M. / Germany	
Location Type	inner city	
HDD	5,515	
CDD	513	
Year of Construction	1951	
Year of Retrofit	2005 – 2006	
Historic Preservation	none	
Building Use / Type	residential / detached	
Orientation	NE-SW	
No. of Floors	before	after
	3	3 + 1
Cond. Usable Area (m^2)	1,123	1,350
Construct. Cost (€/m^2)		1,350

Figure 34 Tevesstrasse Block 2 - Front View after retrofit

Heating Energy Consumption

	before	after	reduction
kWh/m^2a	**294**	**18.1**	**93.8%**

U Values (W/m^2K)

	before	after
Walls	**1.300**	**0.122**
Roof	**1.600**	**0.106**
Floor / Slab	**1.100**	**0.177**
Windows	**1.5**	**0.87**
Infiltration Rate (ACH at n50)	**4.2**	**0.5**

Figure 33 Tevesstrasse Block 2 - Back View after retrofit

Insulation Materials

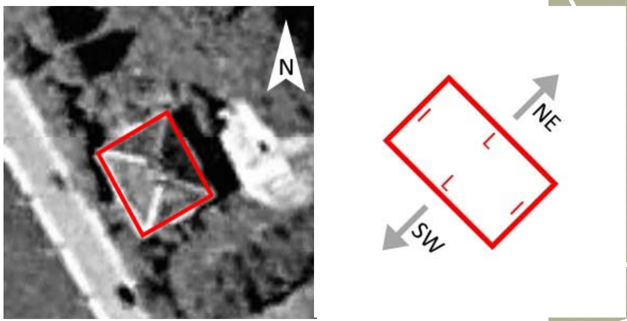
	type	location	thickness (mm)	conductivity (W/mK)
Walls	**EPS (Neopor)**	exterior	**260**	**0.035**
Roof	**Cellulose**	cavity	**400**	**0.040**
Floor / Slab	**PU foam**	interior + exterior	**40 +80**	**0.025**
Windows	**triple**	replacement	**PVC insulated**	

*Detailed Case Study Analysis of the project: **Appendix 7***

6.3.8. Wilhelmstrasse Hofheim

Location	Hofheim / Germany	
Location Type	suburb	
HDD	5,515	
CDD	513	
Year of Construction	1927	
Year of Retrofit	2006	
Historic Preservation	none	
Building Use / Type	residential / detached	
Orientation	NE-SW	
No. of Floors	before	after
	2	2 + 1
Cond. Usable Area (m²)		273
Construct. Cost (€/m²)		1,039

Figure 36 Wilhelmstrasse Hofheim - View after retrofit



Heating Energy Consumption

	before	after	reduction
kWh/m²a	**194**	**15.9**	**91.8%**

U Values (W/m²K)

	before	after
Walls – Street Façade	**0.700**	**0.190**
Walls – Back and Side	**0.700**	**0.140**
Walls – Average (rough)	**0.700**	**0.150**
Roof	**0.800**	**0.162**
Floor / Slab	**1.900**	**0.445**
Windows	**2.80**	**1.16**
Infiltration Rate (ACH at n50)		

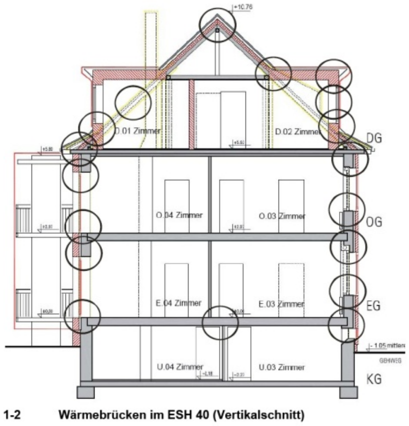


Figure 35 Wilhelmstrasse Hofheim - Section after retrofit

Insulation Materials

	type	location	thickness (mm)	conductivity (W/mK)
Walls – Street Façade	**VIP**	exterior	**40**	**0.007**
Walls – Back and Side	**EPS**	exterior	**250**	**0.032**
Roof	**Mineral Wool**	cavity	**300**	**0.045**
Floor / Slab	**EPS**		**60**	**0.032**
Windows	**triple**	replacement	**PVC insulated**	

*Detailed Case Study Analysis of the project: **Appendix 8***

6.4. Analysis of Best Practices – Non Historic Building Retrofits

6.4.1. Walls

The renovation measures carried out for the 8 studied case buildings included first and foremost the addition of an external thermal insulation layer. This concept was optimal from the point of view of the hygrothermal behavior of the walls and their overall moisture balance. Applying the insulation to the exterior of the wall also meant the thermal bridges could be eliminated completely. Typically, in the case of such interventions external balconies are either removed and replaced by independent structures, or integrated within the thermal envelope. Both examples are present within the case studies.

The average wall U-value before retrofit was 1.27 W/m²K and was reduced by 90% on average to 0.127 W/m²K. This value is considerably lower (50%) than the German ENEV standard for building retrofits and more than three times lower than the ASHRAE 189.1 guidelines for new construction in climate zone 5. This significant performance improvement was possible due to an increased insulation layer. As an insulation material for the walls, a new type of EPS, Neopor, from the BASF company, was used.

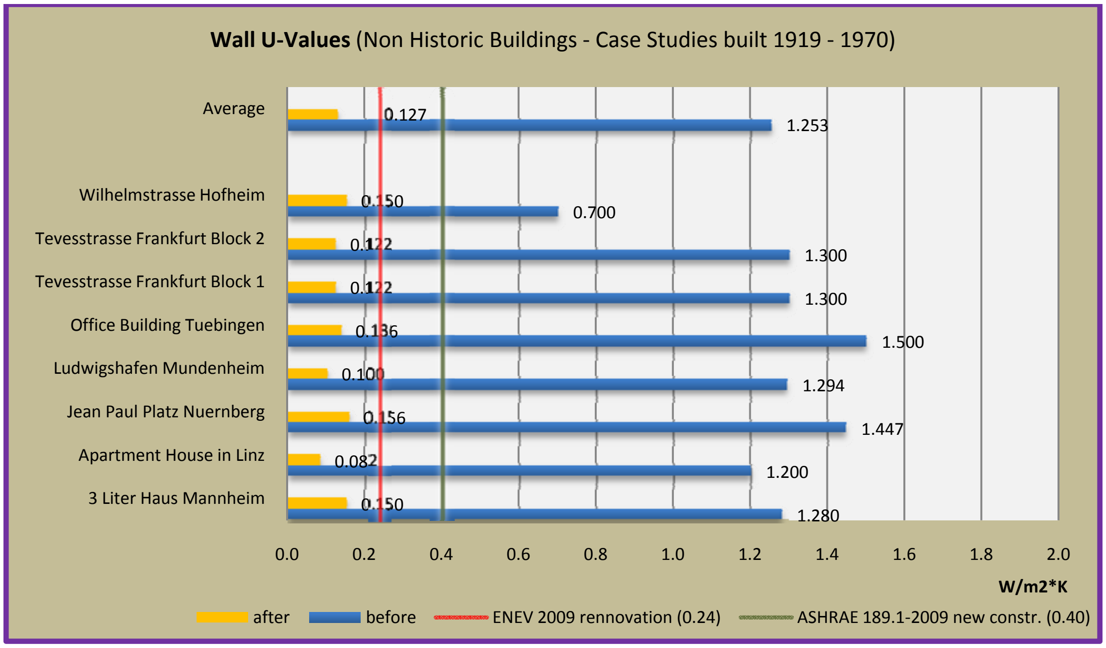


Figure 37 Wall U-Values - Non Historic Buildings - Case Studies built 1919 – 1970

There is a very strong correlation (80%) between the Wall U-Values and the corresponding building heating energy consumption, indicating the wall retrofit measures have had a significant impact on the overall performance of the projects. The higher the U-Value of the wall, the lower is the overall performance of the building. A comparison to the U-values before the renovation supports this finding.

Walls	SI Units		IP Units	
	U (W/m2K)	**R** (m2K/W)	**U** (Btu/hft2F)	**R** (hft2F/Btu)
before (avrg.)	**1.253**	0.8	0.221	**4.5**
after (avrg.)	**0.127**	7.9	0.022	**44.7**

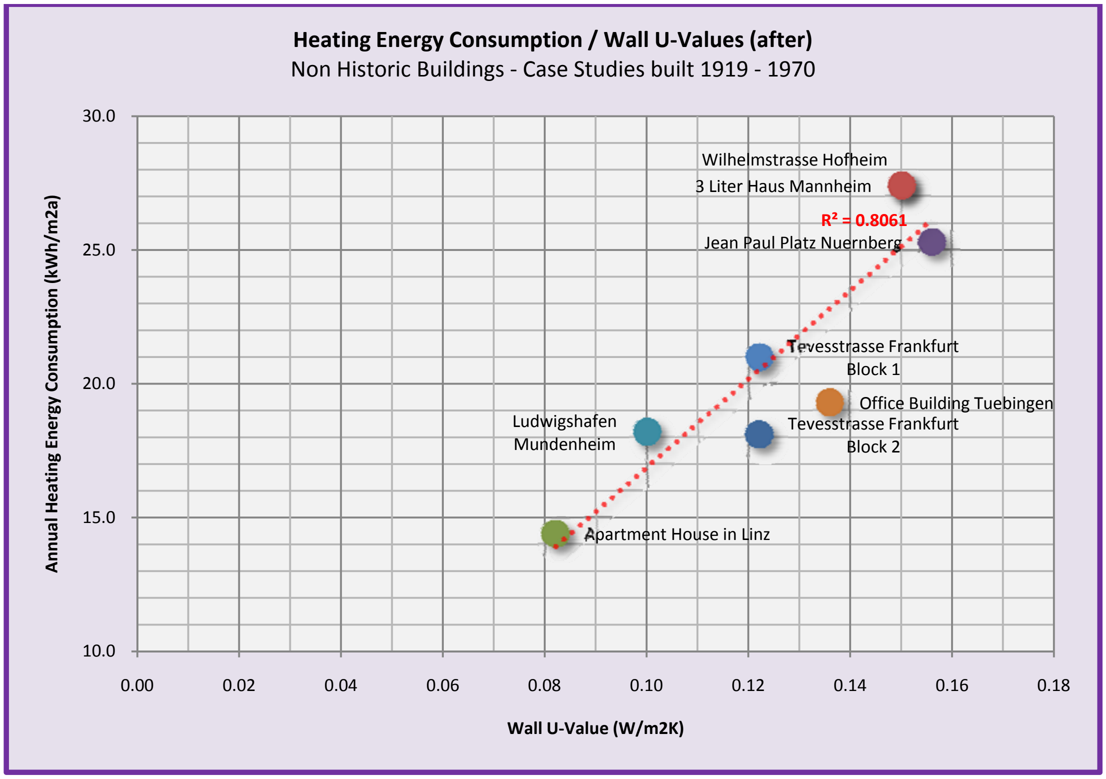


Figure 38 Heating Energy Consumption / Wall U-Values (after) - Non Historic Buildings (1919 – 1970)

The average wall insulation material thickness used in the retrofits is approximately 230 mm, ranging from 190 to 300 mm. The comparison of the different insulation thicknesses shows a strong correlation (76%) between the insulation thickness and the consumption values. The results allow for a direct comparison of the cases, since in most cases Neopor was chosen as an insulation material. The apartment house in Linz was not included in this comparison due

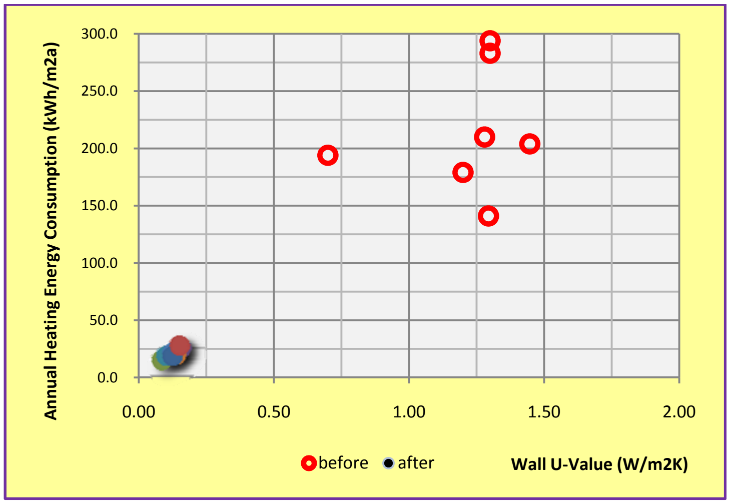


Figure 39 Heating Energy Consumption / Wall U-Values (before vs after) - Non Historic Buildings (1919 – 1970)

to the fact that the thickness of the mineral fiber insulation does not reflect the U-value of the wall assembly. For the calculation of the respective lower U-value (as compared to having just the mineral fiber) the designers have taken into account the heat trapping and capturing potential of the special honey comb construction which covers the prefabricated panels. The panels thus contribute to a total assembly U-Value of 0.082 W/m2K.

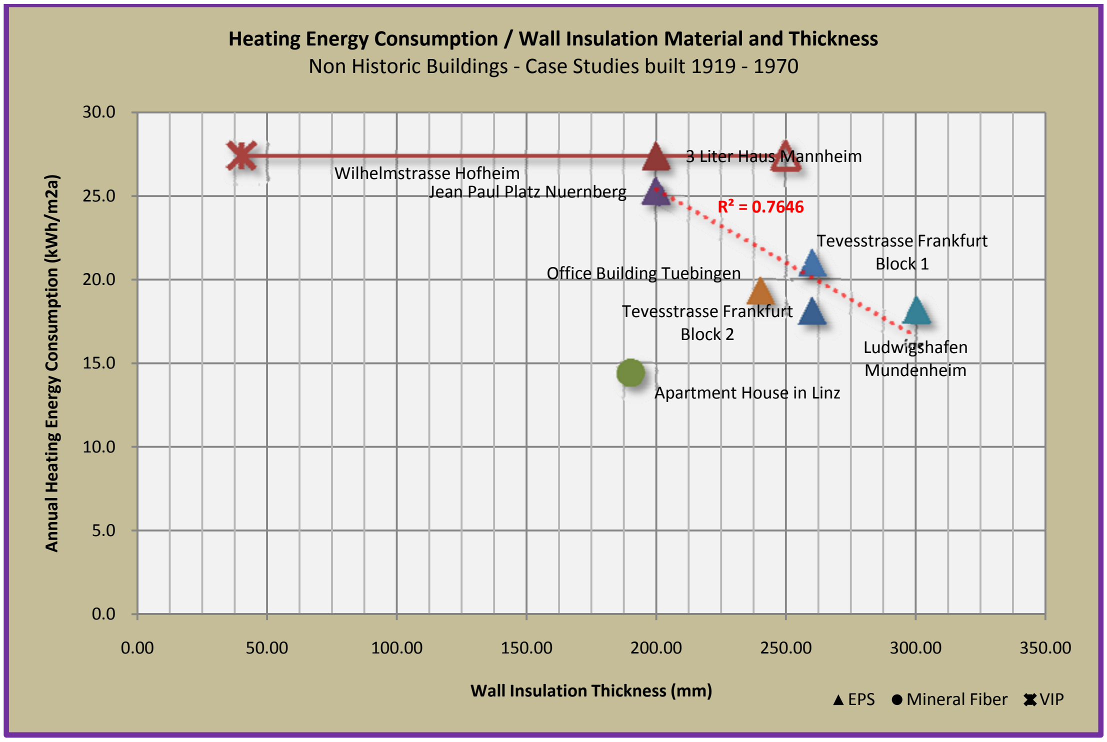


Figure 40 Heating Energy Consumption / Wall Insulation Material and Thickness (1919 – 1970)

The findings suggest the increase of the wall insulating capacity can have a very big impact on the building's overall heating energy consumption. It can be safely inferred, that increasing the insulation thickness corresponds to a decrease in the U-Value of the assembly. It must be said though, that a thicker insulation is relevant only when it is compared the same material of a smaller thickness. In the present research most cases were retrofitted using Neopor (a type of EPS). It has been used due to its reduced thermal conductivity (0.30 – 0.35 W/mK) when compared to standard EPS (0.40 – 0.45 W/mK). Furthermore, EPS is a readily available and comparably cheap insulation material, well suited for use as an external insulation material.

The case of the apartment building in Linz demonstrates that the U-Value of the insulation panels is the single most important factor in achieving a high level of performance. The conclusion is that lowering the U-value of the assembly leads to a corresponding decrease in energy consumption of the building.

6.4.2. Roofs

The U-Values for the roofs of the studied cases before retrofit were high due mainly to a lack of sufficient insulation. Typically buildings built in the period between 1919 and 1970 originally have unconditioned attics and the slab over the last floor constitutes the boundary of the thermal envelope. The average U-Value before retrofit was 1.116 W/m2K. The typical insulation used for the slab over the last floor was sand or waste material fill. This loose fill material is heavy and has poor thermal insulation properties. The advantage of using this material consists also in reducing construction material waste by recycling.

The retrofit measures were carried out in two directions. The first direction, for some projects, was the expansion of the thermal envelope to include the attic space and to create additional livable area. The second option was to keep the thermal envelope at the level of the slab and keep the attic uninsulated, in which case, the waste material fill was removed. The average U-value of the roofs is 0.119 W/m2K, about 50% less than the current German code for renovations and the ASHRAE Standard for new construction.

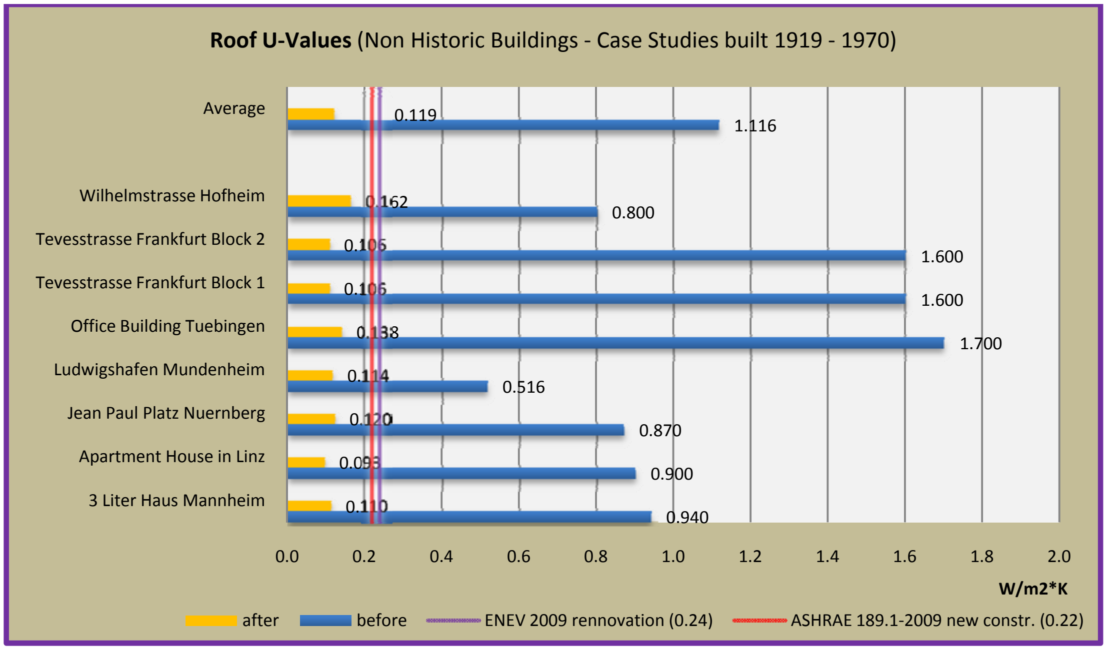


Figure 41 Roof U-Values - Non Historic Buildings - Case Studies built 1919 - 1970

This significant reduction in U-Value can be correlated with a reduction in heating energy consumption. Although the relationship is not as strong as in the case of the roofs (just 32%), the trend implies that increasing the roof insultion U-Value does imply a reduction of the energy consumption of the building. Most of the project's roof U-values are clustered in the interval between 0.1 and 0.14 W/m2K, with the heating energy consumption varying between 18 and 28 kWh/m2a. There is thus reason to believe that increasing the insulation capacity beyond this interval would not bring significant additional benefits.

Roofs	SI Units		IP Units	
	U (W/m2K)	**R** (m2K/W)	**U** (Btu/hft2F)	**R** (hft2F/Btu)
before (avrg.)	**1.116**	0.9	0.197	**5.1**
after (avrg.)	**0.119**	8.4	0.021	**47.7**

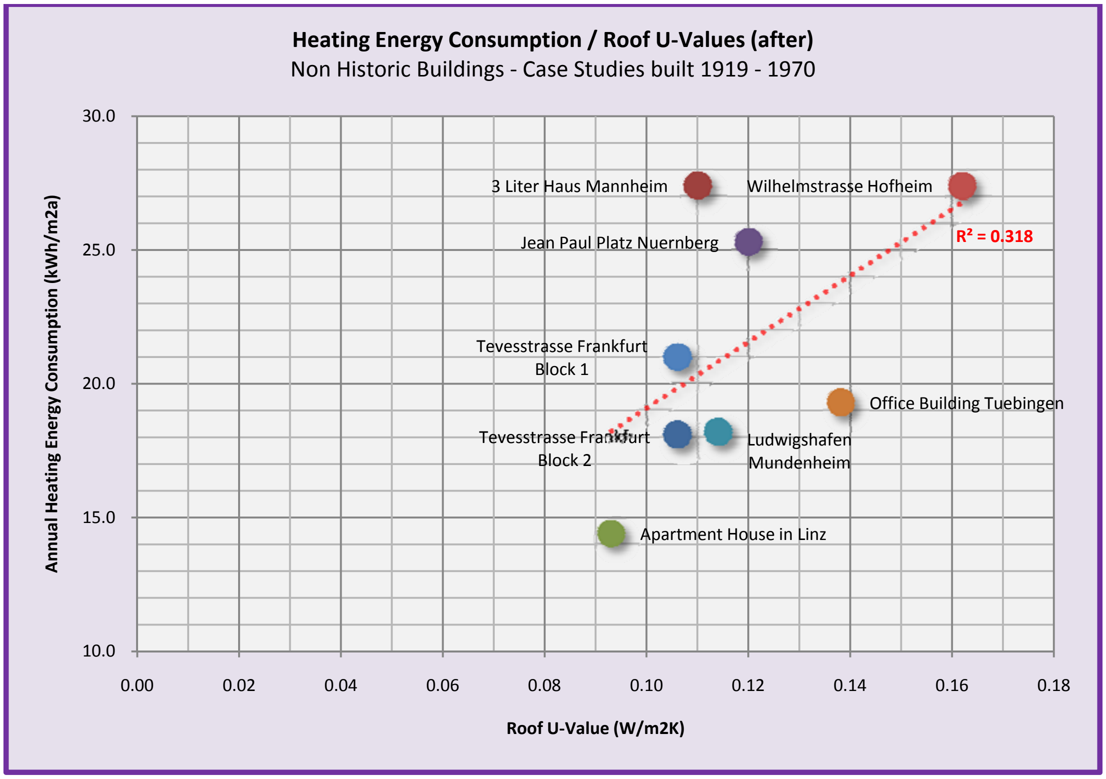


Figure 42 Heating Energy Consumption / Roof U-Values (after) - Non Historic Buildings (1919 – 1970)

When analyzing the relationship between the roof insulation thickness and heating energy consumption, the results are inconclusive. While there is a slight trend which indicates that an increase in insulation thickness leads to a decrease in energy consumption, the projects are grouped closely together with insulation thicknesses varying between 300 and 400 mm. The comparison can be made because the materials used (Nanopor, Mineral Fiber and

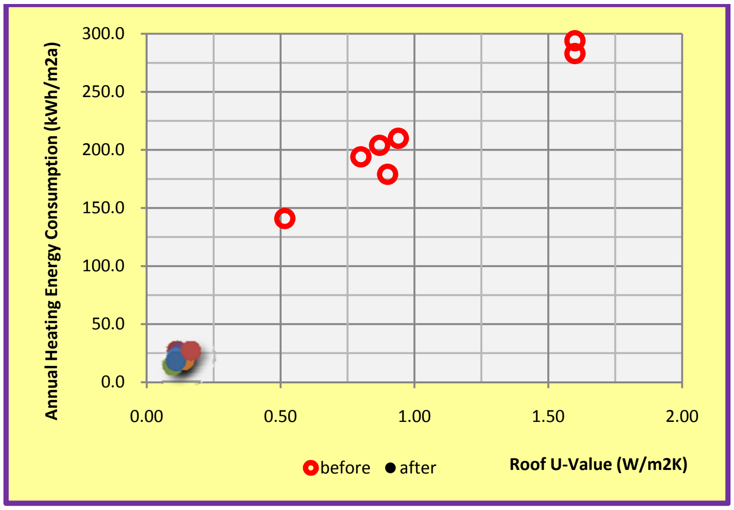


Figure 43 Heating Energy Consumption / Roof U-Values (before vs after) - Non Historic Buildings (1919 – 1970)

Cellulose) have similar thermal conductivity properties, ranging from 0.032 to 0.045 W/mK.

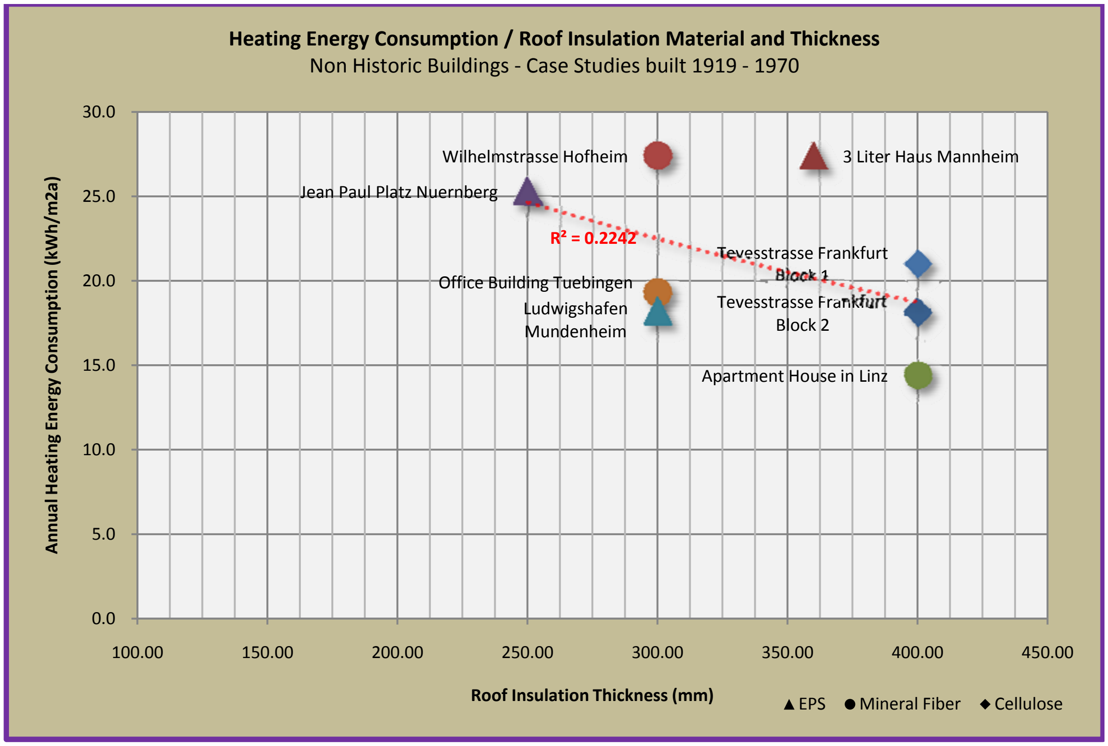


Figure 44 Heating Energy Consumption / Roof Insulation Material and Thickness (1919 – 1970)

The main insulation materials used for the roof assemblies were Mineral Fiber, EPS and Cellulose. The insulation layer was typically located in the cavity of the wooden roof or slab assembly. In some cases, the insulation was added on top of the existing slab over the last floor as an exterior insulation layer.

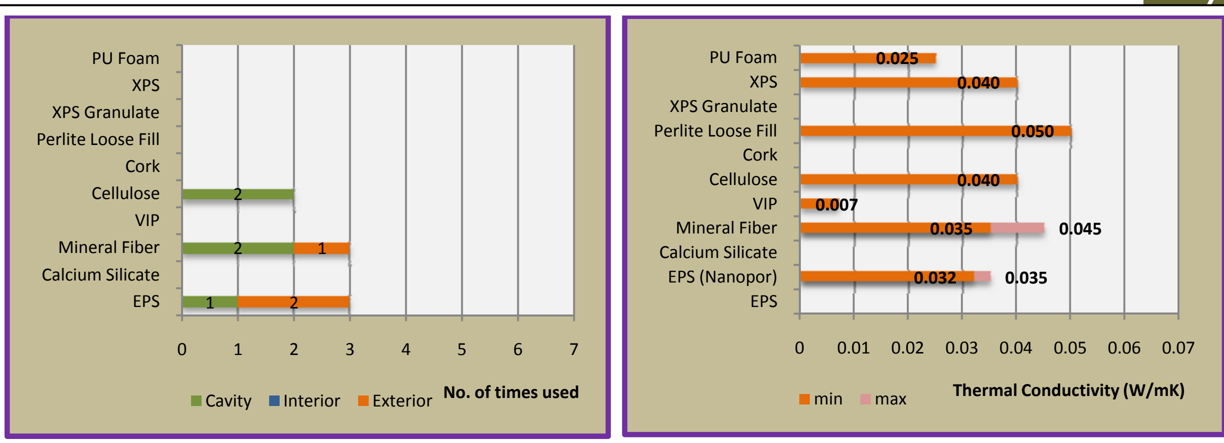


Figure 45 Frequency of Use and Thermal Conductivity of Roof Insulation Materials - Non Historic buildings (1919-1970)

6.4.3. Slabs

All the case studies had uninsulated basements prior to the renovation measures. These basements were kept in their original state, with insulation being added to the slab of the ground floor in order to improve the performance of the thermal boundary. The average U-Value achieved after retrofit is 0.228 W/m2K, close to the ENEV 2009 and the ASHRAE 189.1 standards.

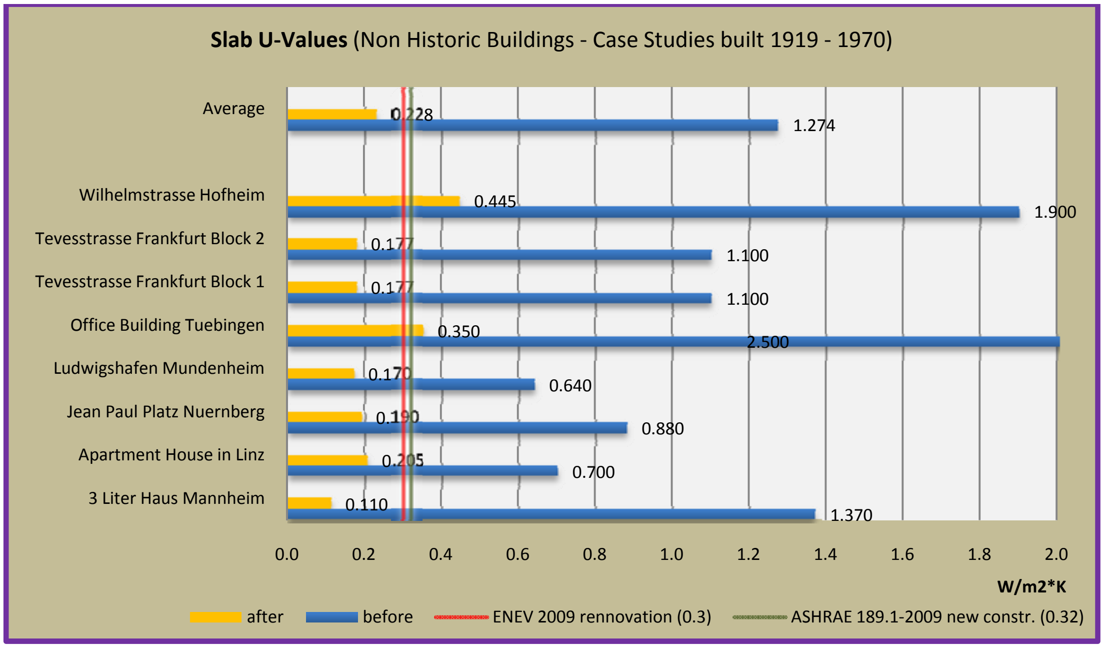


Figure 46 Slab U-Values - Non Historic Buildings - Case Studies built 1919 - 1970

The main slab construction materials for the studied cases were brick and concrete. In both cases, the thermal insulation performance of the original construction allowed for significant heat loss towards the unconditioned basement.The relationship between the slab U-values and the energy consumption is weak, leading to the conclusion that lowering the U-value of the base slab doesn't have as high of a contribution to the overall building performance as does the improvement of the walls.

Slabs	SI Units		IP Units	
	U (W/m2K)	**R** (m2K/W)	**U** (Btu/hft2F)	**R** (hft2F/Btu)
before (avrg.)	**1.274**	0.8	0.224	**4.5**
after (avrg.)	**0.228**	4.4	0.040	**24.9**

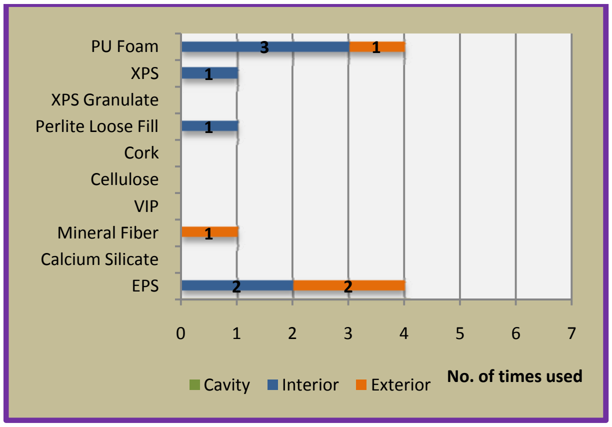


Figure 47 Frequency of Use of Slab Insulation Materials - Non Historic buildings (1919-1970)

The main insulation materials used were EPS and PU foam, with a balance between interior and exterior positioning of the insulation. Typically, the insulation was applied both to the exterior and to the interior of the slab. The exterior insulation, placed underneath the slab was meant to reduce the thermal bridging effect of the exposed structural slab material. The interior layers were added primarily as impact absorbing materials, underneath the screed.

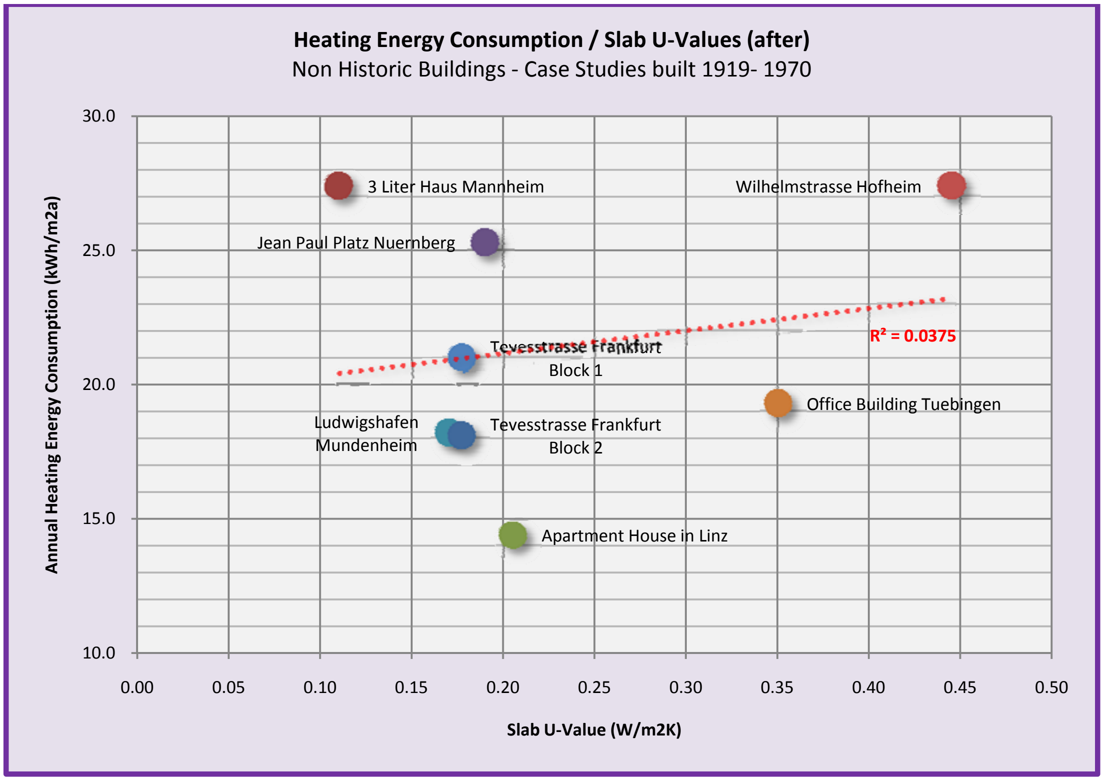


Figure 48 Heating Energy Consumption / Slab U-Values (after) - Non Historic Buildings (1919 – 1970)

The reduced height of the basement and the height limits within the livable space lead to the use of thinner layers of insulation material, thus limiting the performance of the upgraded slab assembly. Height constraints are especially visible when comparing insulation thicknesses. The value varies between 50 and 150 mm, with the Mannheim project having 300 mm of EPS insulation. The higher energy consumption of the Mannheim project supports

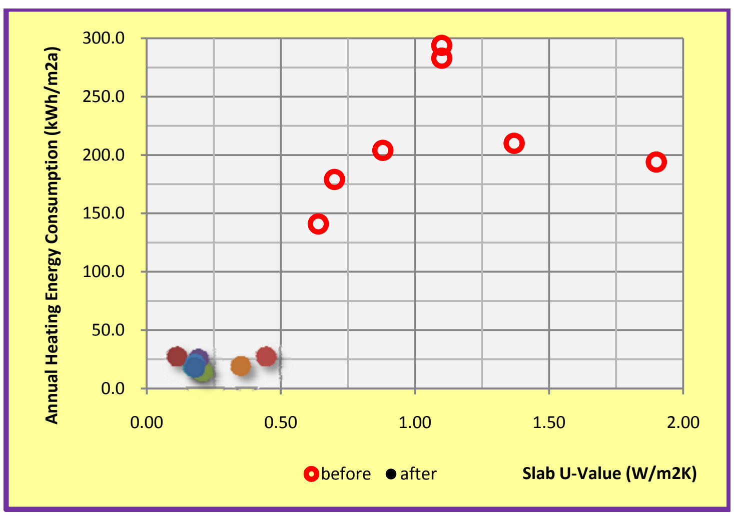


Figure 49 Heating Energy Consumption / Slab U-Values (before vs after) - Non Historic Buildings (1919 – 1970)

the assumption that slab insulation has only a limited capacity of limiting heating energy consumption. One possible reason might be the reduced area of the slab, when compared to the overall area of the thermal envelope.

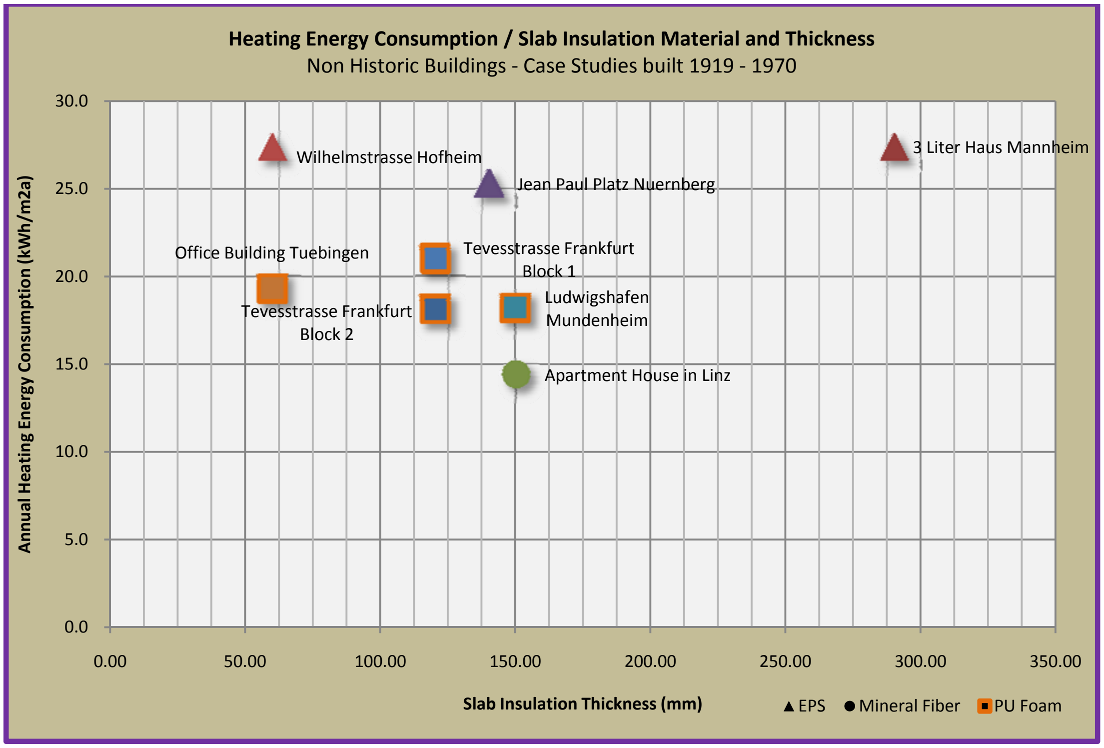


Figure 50 Heating Energy Consumption / Slab Insulation Material and Thickness (1919 – 1970)

6.4.4. Windows

The windows of the buildings built in the period between 1919 and 1970 have originally been single pane windows with wooden frames. Most of the windows in the studied cases had been replaced with double pane PVC or aluminum framed windows prior to the passive house retrofit measures. Nevertheless the actual performance of the existing windows was far lower than the various standards used for comparison. The retrofit measures included the replacement of all the windows with high efficiency triple glazed windows with insulated PVC frames. The new windows have been placed within the insulation layer, thus minimizing as much as possible the thermal bridging effect which typically occurs at the joint between the window frame and the wall.

The U-values of the new assemblies are very similar, pointing to a significant importance attributed by the designers to the heat lost through windows. The average U-Value for the windows used is 0.87 W/m2K, very close to the value recommended by the Passive House Institute for Passive Houses (0.8 W/m2K). The Solar Heat Gain Coefficient of the glazing is about 0.6 in all the cases, thus allowing for a certain level of heat gain to occur in winter.

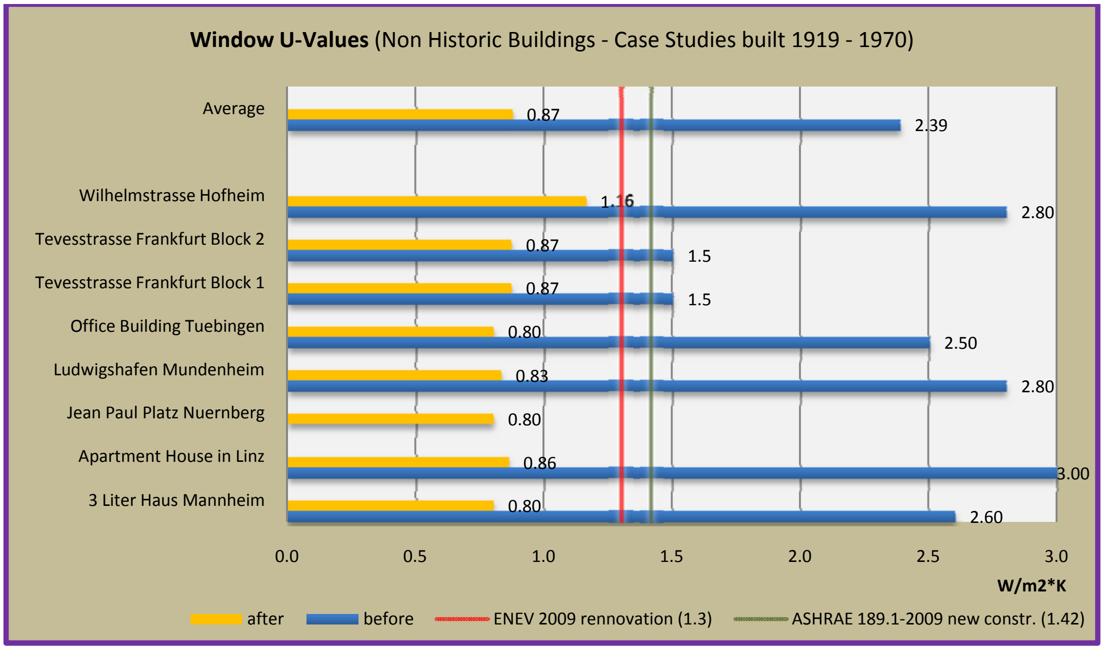


Figure 51 Window U-Values - Non Historic Buildings - Case Studies built 1919 - 1970

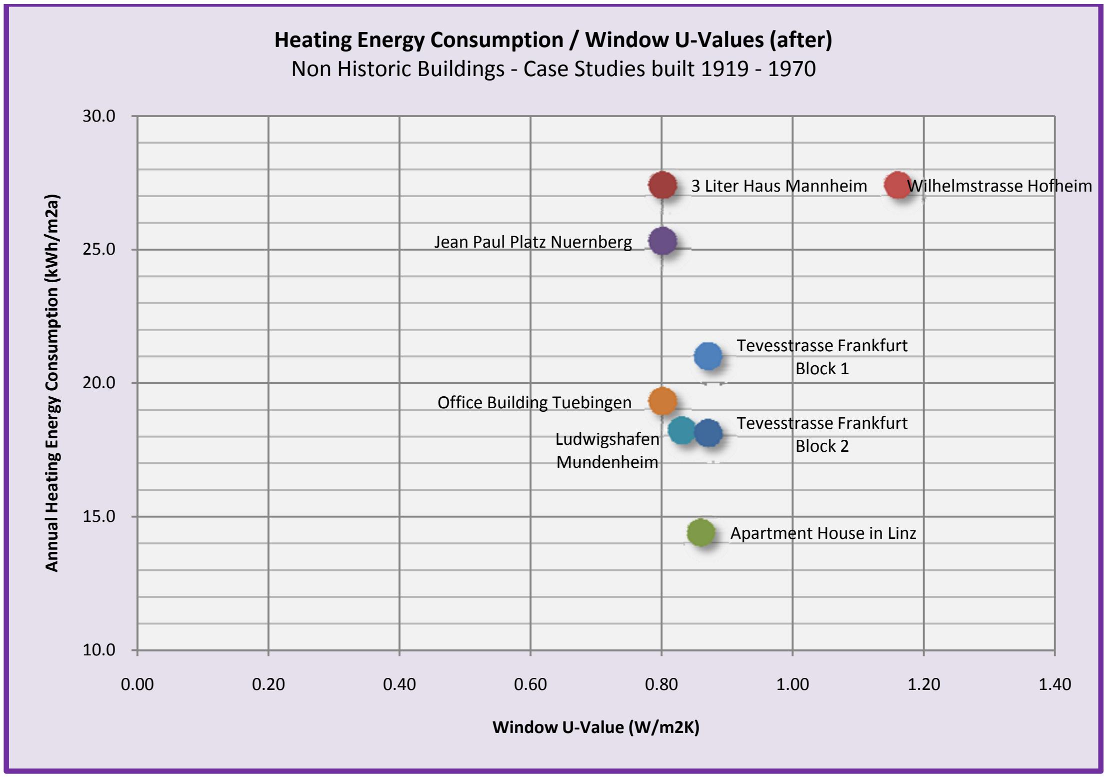


Figure 52 Heating Energy Consumption / Window U-Values (after) - Non Historic Buildings (1919 – 1970)

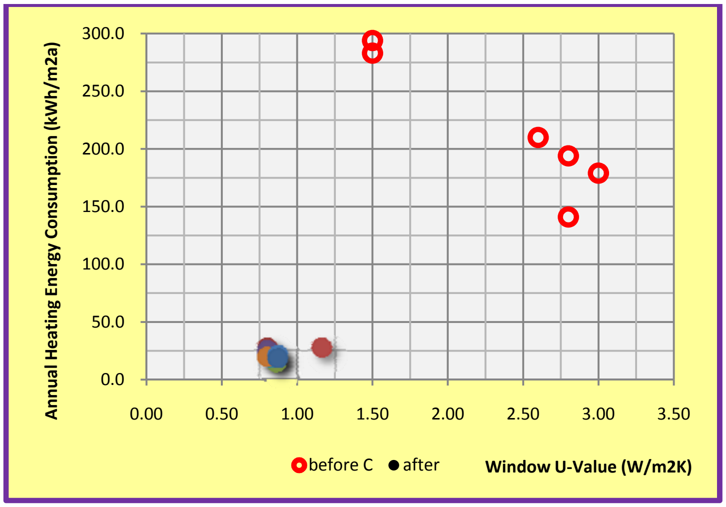


Figure 53 Heating Energy Consumption / Window U-Values (before vs after) - Non Historic Buildings (1919 – 1970)

Windows	SI Units		IP Units	
	U (W/m2K)	**R** (m2K/W)	**U** (Btu/hft2F)	**R** (hft2F/Btu)
before (avrg.)	**2.390**	0.4	0.421	**2.4**
after (avrg.)	**0.870**	1.1	0.153	**6.5**

Although the charts don't show a strong correlation between the window U-Values and the heating energy consumption, the uniformity of the applied measures leads to the conclusion that all the other components of the building envelope are responsible for the differences in performance. As windows are typically the weakest point of a building, with U-Values being 7 to 8 times higher than those of the walls or roofs, their retrofit is crucial for a high degree of insulating performance of the building. The lower efficiency of the windows in the case of the Hofheim projects represents a possible explanation for its higher energy consumption, thus strengthening the argument in favor of high performance windows.

6.4.5. Infiltration Rate

The air tightness of the building envelope is regarded as being very important by the Passive House Institute in Darmstadt. The proposed air leakage rate for passive hose certification is a maximum of 0.6 ACH (at 50 Pa pressure difference). The design and construction teams of the retrofit cases studied made significant efforts towards reducing the leakage in the thermal envelope. Primary areas of concern are duct and pipe inlets, window and door connections and even the masonry itself. The application of an exterior insulation layer together with the replacement of the windows with high efficiency ones reduced the potential for air leakage considerably. Careful detailing and execution, together with an extensive monitoring program during the construction phases led to leakage rates as low as 0.2 ACH in the case of the Tubingen building.

The average infiltration rate is 0.54 for the analyzed case studies, well within the limits for passive house certification. The Mannheim project stands out with a very high infiltration rate. When comparing the building envelope to the other projects, the high infiltration rate becomes a clear reason for the reduced performance of the project.

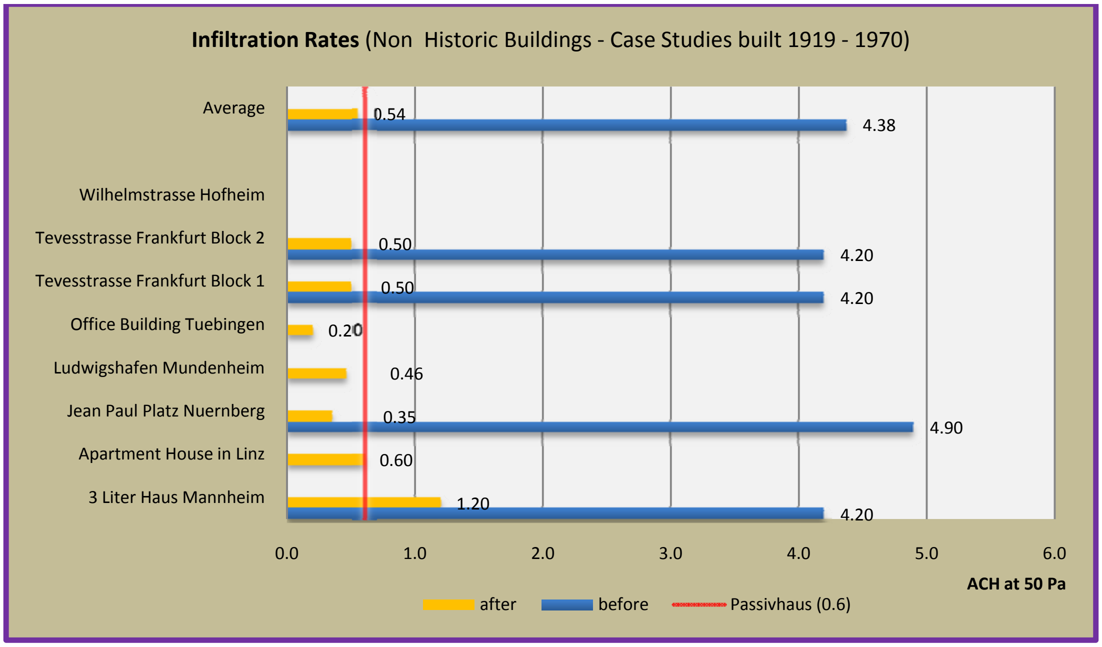


Figure 54 Infiltration Rates - Non Historic Buildings - Case Studies built 1919 - 1970

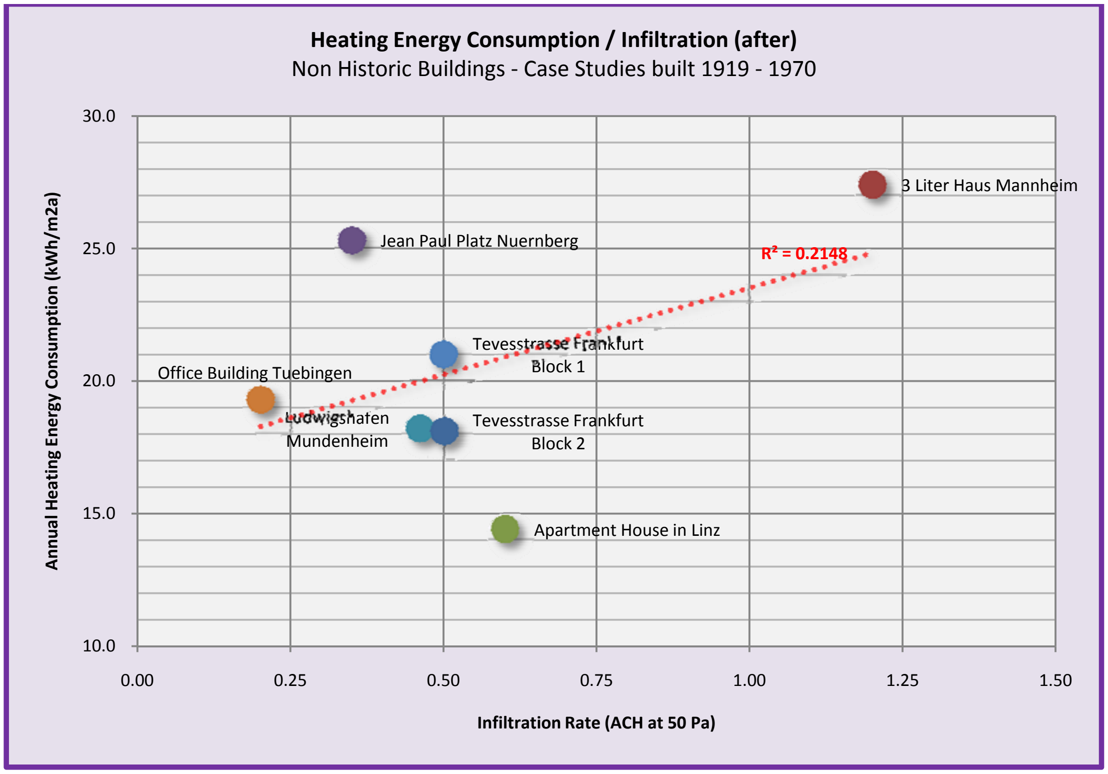


Figure 55 Heating Energy Consumption / Infiltration - Non Historic Buildings (1919 – 1970)

6.5. Conclusions – Non Historic Building Retrofits

The process of retrofitting non historic buildings benefits from the lack of historic preservation restrictions imposed on the façade This makes the application of exterior insulation and the overall retrofit process more profound in nature. There is thus the possibility of applying many of the passive house new construction technologies. The results have shown that non historic building renovation can lead to the same level of performance as achieved by newly constructed passive houses, such as the projects within the CEPHEUS study.

The analysis of the retrofit processes indicates that walls and windows, together with the infiltration rate are the most important aspect of the thermal efficiency of the building. The insulation of the roof and slabs, though important was indicated of having less an impact on the overall performance. The insulation layer used for facades was 230 mm thick on average, Neopor being the material of choice for 7 of the 8 cases. Passive House windows were used, with an average U-value of 0.87 W/m2K and the infiltration rates were bellow the passive house standard. One possible reason for the relatively low impact of roof and slab insulation is the relative small area of these assemblies when compared to the overall area of the thermal envelope.

7. Retrofitting Historic Buildings

The European building stock is characterized by a large number of buildings built before the First World War. Approximately 16% of the residential buildings in Central and Northern Europe were built before that date. These buildings are mainly concentrated in the inner city areas and many of them have already acquired historic preservation status.

In the dynamic economies of Europe, such as those studied in this paper, the building stock has always undergone dynamic transformations and one could safely state, that the buildings of that age which are still standing today are amongst the highest quality buildings from their respective age group. Furthermore they have come to shape the character of many European urban areas, which pride themselves on a rich cultural and historical heritage. Even if most such buildings are not historic monuments, they can still be regarded as historically significant and worthwhile renovating (CCEM, 2008). Indeed most of them have historic preservation constraints on their facades, which makes renovation measures especially challenging.

7.1. Characteristics of Historic Buildings

Historic buildings are buildings built before 1919. The most common building technique for historic buildings built across Europe, which have survived to the present date is the solid masonry construction using solid bricks and/or natural stone. Typically if used, natural stone was used for the basement and in some cases for the ground floor level as well, due to the fact that natural stone doesn't absorb moisture through capillarity from the ground. Solid brick was then used for the upper floors. In the case of solid masonry historic buildings, the exterior walls are approximately 400 mm thick and also have a load bearing role.

The floors of the historic buildings are constructed using wooden beams, which rest directly on the walls. The beam ends are thus encased in the masonry. The floors are typically filled with waste material or sand in order to improve the sound insulation and thermal insulation characteristics of the assembly. In some cases, the slab over the ground floor is constructed using brick vaults (towards the second half of the 19th century). In most cases, the attic is not conditioned and is not included within the thermal envelope. Just as in the case of non historic buildings the slab over the last floor serves forms the thermal boundary.

The main characteristic of Historic Buildings is the historic preservation status of the façade. This status severely limits the intervention opportunities in terms of applying insulation. Thermal insulation must therefore applied to the interior of the wall and problems related to moisture build up within the mass of the brick need to be addressed, as discussed in a previous chapter. The issue of space is also an important one, as interior insulation decreases the interior usable area.

In the case of historic monuments there might also be historic restrictions for the interior of the walls as well. The roof typically doesn't have historic preservations constraints except for the roofing material which might be used. Indeed most of the cases studied within the present thesis have had the entire roof structure replaced. Design changes were possible within the limits of the historical shape, attic windows and solar thermal collectors being in some cases added to the roof.

Another notable characteristic of inner city historic buildings is the fact that they are usually attached on two sides. This is due to higher densities within city centers and leads to historic buildings typically having a front and a back façade. While the front façade is always under a historic preservation status, the rear elevation doesn't always have the same level of detail and decoration. In most of the cases I have studied, exterior insulation could be added to the back façade, thus compensating for the lack of sufficient insulation at the front.

7.2. Energy Consumption of Historic Buildings

The energy consumption of historic buildings before retrofit is comparable to the heating energy consumption of non historic buildings. The average consumption of the analyzed cases is 237.3 kWh/m2a prior to the retrofit measures, suggesting, as expected a slightly worse performance than the non historic buildings. The studied cases varied from 122 to 361 kWh/m2a, with most of the buildings performing much worse than the average. If we take out the values which are the furthest away from the average (Pobershau, Wengistrasse, Magnusstrasse and Sulz) the average would be 250 kWh/m2a, 16% more than the non historic buildings. This difference can be attributed to the greater age of the buildings.

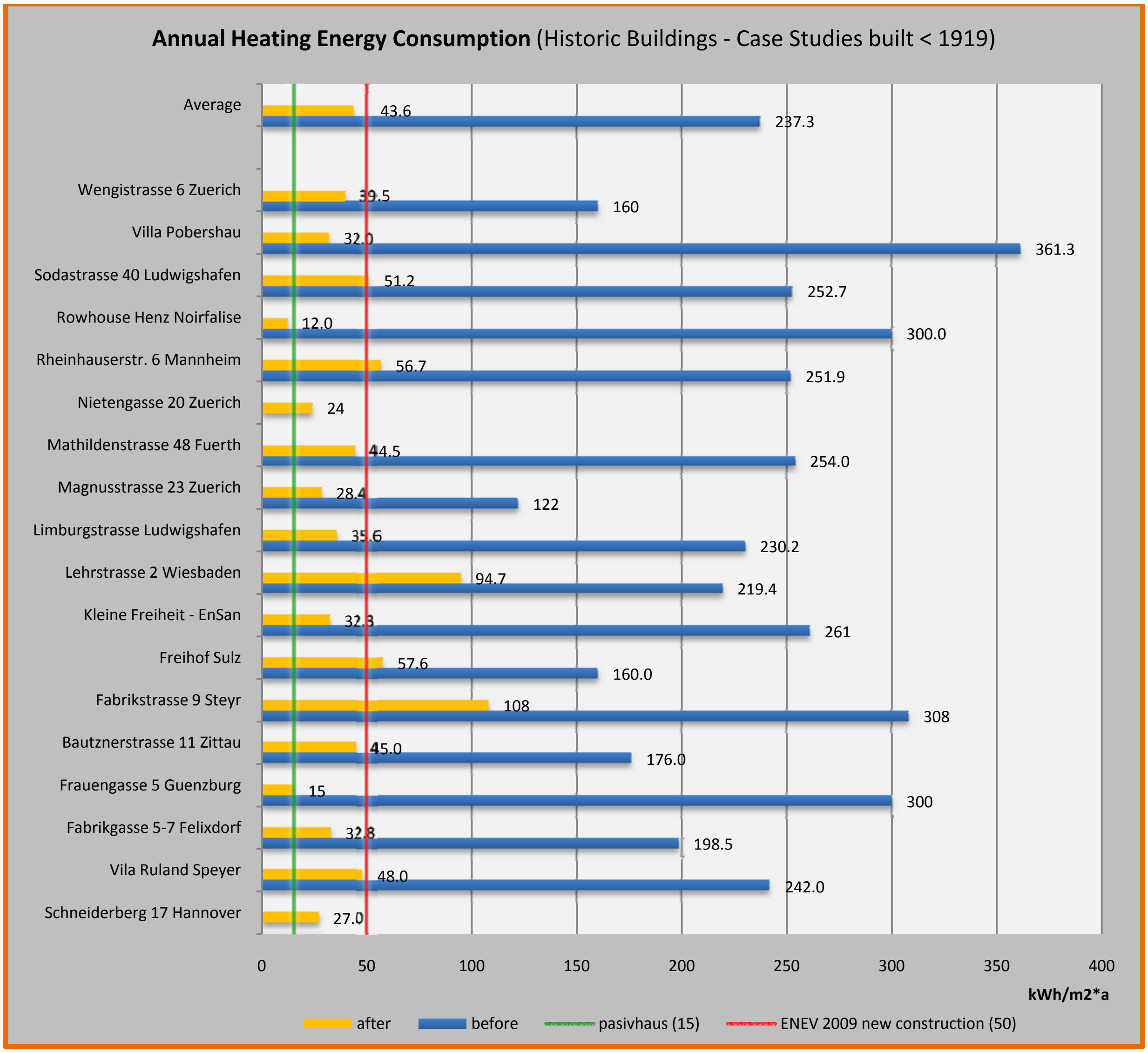


Figure 56 Annual Heating Energy Consumption – Non Historic Buildings - Case Studies built 1919 – 1970

The heating energy consumption of the historic buildings after retrofit was on average 43.5 kWh/m2a, two times higher than in the case of projects originating from the period between 1919-1970. This difference is expected, since the preservation constraints imposed on historic structures limits the efficiency of the insulation layer. By placing the insulation on the interior of the façade, the thermal storage capacity of the wall is eliminated. Furthermore, interior space restrictions limit the thickness of the insulation material. A 300 mm layer as in the case of non historic buildings is less likely under these circumstances.

Even so, the energy performance of these retrofitted buildings is better than the German standard for new constructions. Although the Passive House Standard was not achieved on average, some projects were able to get well within the range of consumption expected from a Passive House. Projects like the Rowhouse in Noirfalise and the house in Guenzburg seem to suggest, that the application of a thicker insulation layer to the interior of the wall can be enough to reduce the heating energy consumption considerably. In terms of the insulating capacity of the wall, the location of the insulation is not important, as long as thermal bridges are minimized and a sufficient insulation thickness is being used.

7.3. Case Studies of Historic Building Retrofits

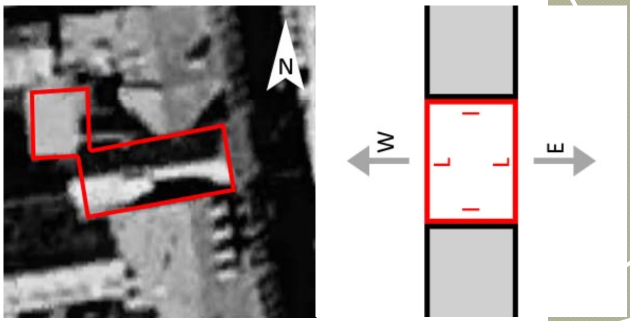
14 Projects from Germany, Austria, Switzerland and Belgium were analyzed in depth for the purpose of this thesis. With the exception of 3 projects, all of them were inner city terraced houses. Freihof Sulz, Sodastrasse 40 Ludwigshafen and Villa Pobershau are detached houses in suburban or rural locations. Their energy consumption is slightly higher than the one of the terraced houses when comparing similar insulation measures. The case of the Villa in Pobershau stands out in this category, with a lower consumption which can be largely attributed to the thicker layer of insulation used.

The analyzed projects are examples of best practices in terms of retrofitting historical buildings and applying internal insulation measures. The results of the analysis will be discussed in a future chapter.

7.3.1. Bautznerstrasse 11 Zittau

Location	Zittau / Germany	
Location Type	suburb	
HDD	6,313	
CDD	363	
Year of Construction	1880 – 1990	
Year of Retrofit	2004	
Historic Preservation	wall (street, outside)	
	roof (outside)	
Building Use / Type	residential / attach. 2 sides	
Orientation	E-W	
No. of Floors	before	after
	4 + 1	4 + 1
Cond. Usable Area (m²)	1200	1247
Construct. Cost (€/m²)		

Figure 58. Bautznerstrasse 11 Zittau - after renovation



Heating Energy Consumption

	before	after	reduction
kWh/m²a	**176**	**45**	**74.4%**

U Values (W/m²K)

	before	after
Walls – Street Façade	**1.510**	**0.500**
Walls – Back Façade	**1.500**	**0.380**
Walls – Average (rough)	**1.503**	**0.409**
Roof – Gable Roof (front)	**1.100**	**0.240**
Roof – Flat Roof (back)	**1.100**	**0.240**
Floor / Slab	**1.110**	**0.660**
Windows	**2.50**	**1.00**
Infiltration Rate (ACH at n50)		**3.4**

Figure 57. Bautznerstrasse 11 Zittau - before renovation

Insulation Materials

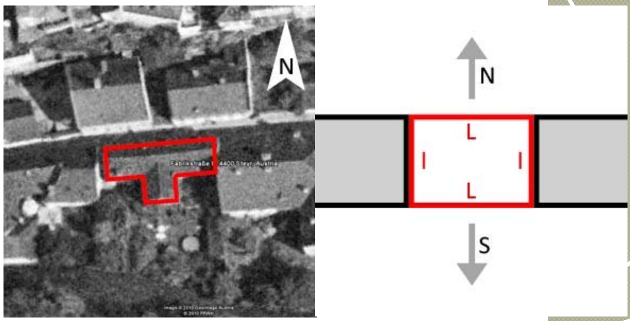
	type	location	thickness (mm)	conductivity (W/mK)
Walls – Street Façade	**Calcium Silicate**	interior	**50**	**0.065**
Walls – Back Façade	**EPS**	exterior	**100**	**0.035**
Roof – Gable Roof (frnt)	**mineral fiber**	cavity	**180**	**0.040**
Roof – Flat Roof (back)	**EPS**	cavity	**160**	**0.035**
Floor / Slab	**EPS**	interior	**100**	**0.035**
Windows	**single + double**	replacement (vent. casement windows)	**wood**	

Detailed Case Study Analysis of the project: ***Appendix 9***

7.3.2. Fabrikstrasse 9 Steyr

Location	Steyr / Austria	
Location Type	inner city	
HDD	6,141	
CDD	488	
Year of Construction	before 1918	
Year of Retrofit		
Historic Preservation	walls + roof (outside)	
Building Use / Type	residential / attach. 2 sides	
Orientation	N-S	
No. of Floors	before	after
	2	2
Cond. Usable Area (m²)	300	219
Construct. Cost (€/m²)		

Figure 59. Fabrikstrasse Steyr - Outside View - before renovation



Heating Energy Consumption

	before	after	reduction
kWh/m^2a	**308**	**108**	**64.9%**

U Values (W/m^2K)

	before	after
Walls	**1.220**	**0.486**
Roof	**0.374**	**0.112**
Floor / Slab	**0.852**	**0.340**
Windows	**2.5**	**1.4**
Infiltration Rate (ACH at n50)		

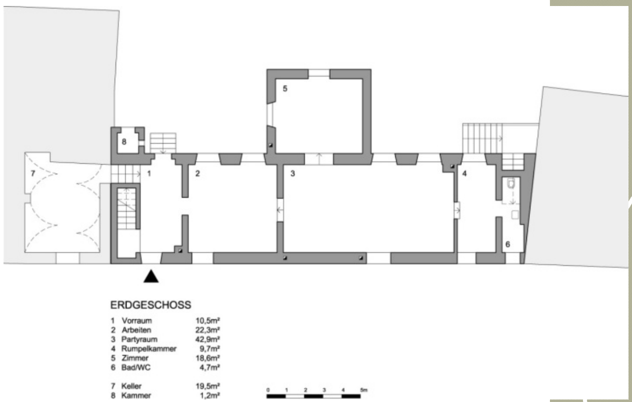


Figure 60. Fabrikstrasse Steyr - Ground Floor Plan

Insulation Materials

	type	location	thickness (mm)	conductivity (W/mK)
Walls	**mineral fiber**	interior	**50**	**0.040**
Roof	**perlite loose fill**	exterior	**200**	**0.040**
Floor / Slab	**perlite**	interior	**100**	**0.040**
Windows	**double**	replacement		

Detailed Case Study Analysis of the project: ***Appendix 10***

7.3.3. Freihof Sulz

Location	Sulz / Austria	
Location Type	suburb	
HDD (18 C)	5,149	
CDD (18 C)	697	
Year of Construction	1899	
Year of Retrofit	2004	
Historic Preservation	walls (outside + inside) + roof (outside)	
Building Use / Type	residential / detached	
Orientation	NW-SE	
No. of Floors	before	after
	3	3
Cond. Usable Area (m²)	1,018	1,018
Construct. Cost (€/m²)		

Figure 62. Freihof Sulz Exterior Image – after renovation

Heating Energy Consumption

	before	after	reduction
kWh/m²a	**160**	**57.55**	**64.0%**

U Values (W/m²K)

	before	after
Walls – AW02 (84%)	**1.259**	**0.452**
Roof – AD01 (slab)		**0.144**
Roof – FD01 (flat roof)		**0.181**
Floor / Slab KD01 (75%)	**0.407**	**0.407**
Floor / Slab KD02 (25%)		**0.172**
Walls – Average (rough)	**0.407**	**0.303**
Windows		**2.06**
Infiltration Rate (ACH at n50)		

Figure 61. Freihof Sulz Exterior Image – before renovation

Insulation Materials

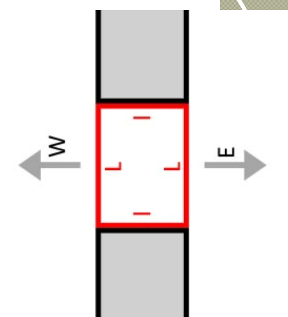
	type	location	thickness (mm)	conductivity (W/mK)
Walls – AW02 (84%)	**wood fiber board**	interior	**60**	**0.042**
Roof – AD01 (slab)	**flax fiber board**	cavity	**310**	**0.042**
Roof – FD01 (flat roof)	**flax fiber/wood fiber**	cavity / exterior	**250 / 40**	**0.042**
Floor / Slab KD01 (75%)	**wood fibers**	interior	**100**	**0.042**
Floor / Slab KD02 (25%)	**EPS**	exterior	**300**	**0.060**
Windows	**single**	existing - refurbished	**wood**	

*Detailed Case Study Analysis of the project: **Appendix 11***

7.3.4. Kleine Freiheit - EnSan

Location	Hamburg / Germany	
Location Type	inner city	
HDD	6,011	
CDD	269	
Year of Construction	1907	
Year of Retrofit	2008	
Historic Preservation	walls (street, outside) roof (outside)	
Building Use / Type	residential / detached	
Orientation	E-W	
No. of Floors	before	after
	4 + 1	4 + 1
Cond. Usable Area (m²)	647	696
Construct. Cost (€/m²)		1,611

Figure 64 Kleine Freiheit - View after retrofit



Heating Energy Consumption

	before	after	reduction
kWh/m²a	**261**	**32.3**	**87.6%**

U Values (W/m²K)

	before	after
Walls – Street Façade	**1.615**	**0.613**
Walls – Back Façade	**1.593**	**0.192**
Walls – Average	**1.554**	**0.306**
Roof – Tilted Roof	**0.761**	**0.175**
Roof – Flat Roof	**1.227**	**0.158**
Roof – Average	**1.097**	**0.200**
Slab – over basement	**1.076**	**0.231**
Slab – on grade	**0.857**	**0.176**
Floor / Slab – Average	**1.193**	**0.228**
Windows	**4.38**	**1.30**
Infiltration Rate (ACH at n50)	**10.35**	**0.53**

Figure 63 Kleine Freiheit – Facade

Insulation Materials

	type	location	thickness (mm)	conductivity (W/mK)
Walls – Street Façade	**Calcium Silicate**	interior	**50**	**0.050**
Walls – Back Façade	**Mineral Fiber**	exterior	**160**	**0.035**
Roof – Tilted Roof (32%)	**Min. Fiber & Foam**	cavity	**190**	**0.040**
Roof – Flat Roof (27%)	**Mineral Fiber**	cavity	**280**	**0.040**
Slab –on basement (41%)	**Min. Fiber / EPS**	interior / exterior	**85 / 65**	**0.035 / 0.040**
Slab – on grade (29%)	**Min. Fiber / EPS**	interior	**30 / 180**	**0.040**
Windows	**double**	replacement	**wood**	

Detailed Case Study Analysis of the project: ***Appendix 12***

7.3.5. Lehrstrasse 2 Wiesbaden

Location		Wiesbaden / Germany
Location Type		inner city
HDD		5,638
CDD		481
Year of Construction		1880 – 1890
Year of Retrofit		2002
Historic Preservation		walls (street, outside) roof (outside)
Building Use / Type		residential / attach. 1 sides
Orientation		NE-SW
No. of Floors	before	after
	3 + 1	3 + 1
Cond. Usable Area (m²)		646
Construct. Cost (€/m²)		1,424

Figure 66 Lehrstrasse 2 - View after retrofit

Heating Energy Consumption

	before	after	reduction
kWh/m^2a	**218.4**	**94.7**	**56.8%**

U Values (W/m^2K)

	before	after
Walls – Street Façade	**1.620**	**0.444**
Walls – Back Façade	**1.620**	**0.243**
Walls – Average (rough)	**1.620**	**0.334**
Roof	**1.261**	**0.272**
Floor / Slab	**0.949**	**0.444**
Windows	**5.00**	**1.70**
Infiltration Rate (ACH at n50)		

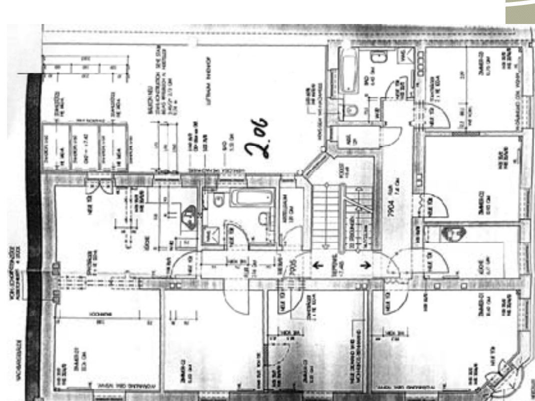


Figure 65 Lehrstrasse 2 - First Floor plan

Insulation Materials

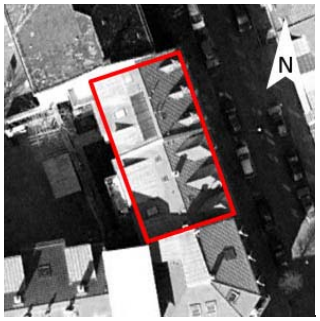
	type	location	thickness (mm)	conductivity (W/mK)
Walls – Street Façade	**EPS**	interior	**55**	**0.035**
Walls – Back Façade	**EPS**	exterior	**120**	**0.035**
Roof	**EPS / puddled clay**	interior / cavity	**110**	**0.035**
Floor / Slab	**EPS / fermacell**	interior	**40 / 20**	**0.035 / 0.050**
Windows	**triple**	replacement	**wood**	

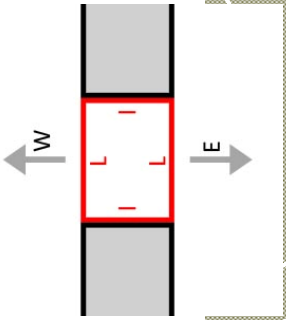
Detailed Case Study Analysis of the project: ***Appendix 13***

7.3.6. Limburgstrasse Ludwigshafen

Location	Ludwigshafen / Germany	
Location Type	inner city	
HDD	5,090	
CDD	666	
Year of Construction	1900	
Year of Retrofit	2004	
Historic Preservation	walls (street, outside) roof (outside)	
Building Use / Type	residential / attach. 2 sides	
Orientation	E-W	
No. of Floors	before	after
	4	4
Cond. Usable Area (m²)		651
Construct. Cost (€/m²)		

Figure 67 Limburgstrasse - View after retrofit





Heating Energy Consumption

	before	after	reduction
kWh/m²a	**230.2**	**35.6**	**84.5%**

U Values (W/m²K)

	before	after
Walls – Front Facade	**1.370**	**0.330**
Walls – Back Facade	**1.450**	**0.210**
Walls – Average (rough)	**1.409**	**0.257**
Roof		**0.180**
Floor / Slab		
Windows		**1.10**
Infiltration Rate (ACH at n50)		

Figure 68 Limburgstrasse - Views before retrofit

Insulation Materials

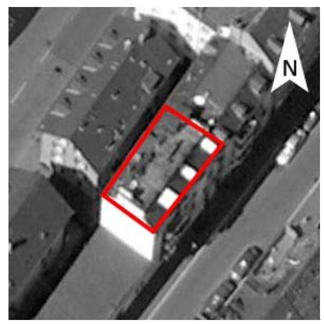
	type	location	thickness (mm)	conductivity (W/mK)
Walls – Front Facade	**Mineral Wool**	interior	**80**	**0.035**
Walls – Back Facade	**EPS**	exterior	**140**	**0.035**
Roof	**Mineral Wool**	cavity	**200**	**0.035**
Floor / Slab				
Windows	**triple**	replacement	**wood**	

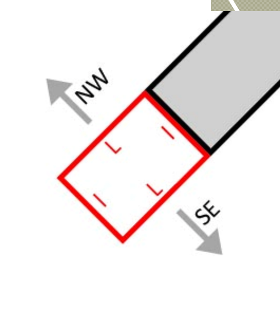
*Detailed Case Study Analysis of the project: **Appendix 14***

7.3.7. Magnusstrasse 23 Zürich

Location	Ludwigshafen / Germany	
Location Type	inner city	
HDD	6,188	
CDD	444	
Year of Construction	1894	
Year of Retrofit	2001	
Historic Preservation	walls (street, outside) roof (outside)	
Building Use / Type	residential / attached 1 side	
Orientation	NW-SE	
No. of Floors	before	after
	4 + 1	4 + 1
Cond. Usable Area (m²)	475	475
Construct. Cost (€/m²)		

Figure 69 Magnusstrasse - View after retrofit





Heating Energy Consumption

	before	after	reduction
kWh/m²a	**122**	**28.4**	**76.7%**

U Values (W/m²K)

	before	after
Walls – Front Facade	**1.600**	**0.430**
Walls – Back Facade	**1.450**	**0.196**
Walls – Side Facade	**1.600**	**0.110**
Walls – Average (rough)	**1.536**	**0.209**
Roof		**0.090**
Floor / Slab	**1.260**	**0.170**
Windows		**0.75**
Infiltration Rate (ACH at n50)		**2.0**

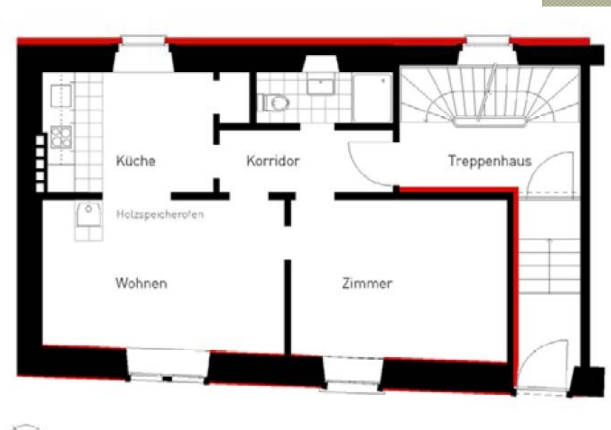


Figure 70 Magnusstrasse - Grounf floor plan after retrofit

Insulation Materials

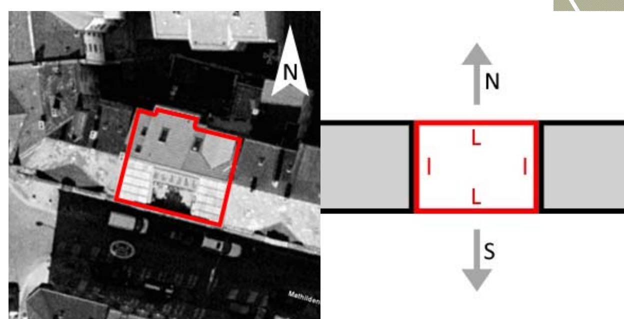
	type	location	thickness (mm)	conductivity (W/mK)
Walls – Front Facade	**Mineral Wool**	interior + exterior	**30 + 30**	0.036
Walls – Back Facade	**Mineral Wool**	exterior	**160**	0.036
Walls – Side Facade	**Mineral Wool**	exterior	**300**	0.036
Roof	**Mineral Wool**	cavity	**400**	0.036
Floor / Slab	**Mineral Wool**	exterior	**200**	0.036
Windows	**triple**	replacement	**wood + PVC**	

Detailed Case Study Analysis of the project: ***Appendix 15***

7.3.8. Mathildenstrasse 48 Fürth

Location	Fürth / Germany	
Location Type	inner city	
HDD	6,441	
CDD	382	
Year of Construction	1890	
Year of Retrofit	2002	
Historic Preservation	walls (street, outside) roof (outside)	
Building Use / Type	residential / attach. 2 sides	
Orientation	N-S	
No. of Floors	before	after
	4	4
Cond. Usable Area (m²)	404	520
Construct. Cost (€/m²)		1,078

Figure 72 Mathildenstrasse - View after retrofit



Heating Energy Consumption

	before	after	reduction
kWh/m^{2}a	**254**	**44.5**	**82.5%**

U Values (W/m^{2}K)

	before	after
Walls – Front Facade	**1.980**	**0.450**
Walls – Back Facade	**1.300**	**0.150**
Walls – Average (rough)	**1.570**	**0.225**
Roof	**1.050**	**0.100**
Floor / Slab	**0.870**	**0.250**
Windows	**2.80**	**0.80**
Infiltration Rate (ACH at n50)		

Figure 71 Mathildenstrasse - View before retrofit

Insulation Materials

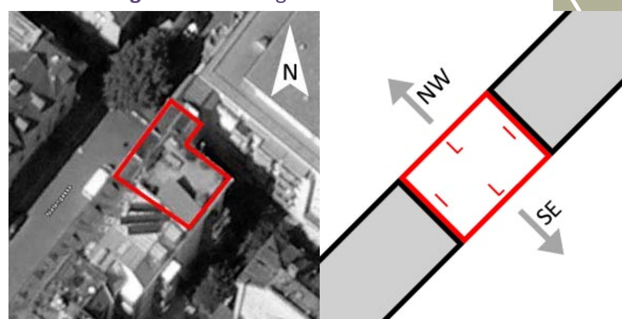
	type	location	thickness (mm)	conductivity (W/mK)
Walls – Front Facade	**Mineral Wool**	interior	**100**	**0.040**
Walls – Back Facade	**Mineral Wool**	exterior	**180**	**0.040**
Roof	**Mineral Wool**	cavity	**360**	**0.035**
Floor / Slab	**Mineral Wool**	exterior	**150**	**0.040**
Windows	**triple**	replacement	**wood / PVC ins.**	

Detailed Case Study Analysis of the project: ***Appendix 16***

7.3.9. Nietengasse 20 Zürich

Location	Zürich / Switzerland	
Location Type	inner city	
HDD	6,188	
CDD	444	
Year of Construction	1907	
Year of Retrofit	2002	
Historic Preservation	walls (street, outside) roof (outside)	
Building Use / Type	residential / attach. 2 sides	
Orientation	NW-SE	
No. of Floors	before	after
	4 + 1	4 + 1
Cond. Usable Area (m²)		574
Construct. Cost (€/m²)		

Figure 73 Nietengasse - View after retrofit



Heating Energy Consumption

	before	after	reduction
kWh/m²a		**24**	

U Values (W/m²K)

	before	after
Walls – Front Façade (ground floor)	**3.600**	**0.160**
Walls – Front Façade (upper floors)	**1.600**	**0.380**
Walls – Back Facade	**1.800**	**0.110**
Walls – Average (rough)	**1.823**	**0.146**
Roof		**0.090**
Floor / Slab		**0.160**
Windows		**0.90**
Infiltration Rate (ACH at n50)		**1.50**

Figure 74 Nietengasse - Interior insulation of ground floor using VIP panels

Insulation Materials

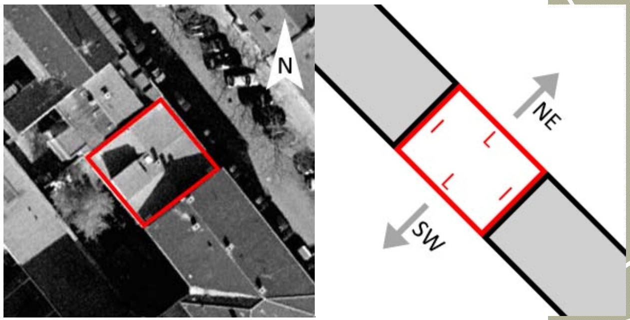
	type	location	thickness (mm)	conductivity (W/mK)
Walls – Front Façade (ground floor)	**VIP**	interior	**30**	**0.007**
Walls – Front Façade (upper floors)	**Cork**	interior	**80**	**0.040**
Walls – Back Façade	**Mineral Wool**	exterior	**280**	**0.036**
Roof	**Mineral Wool**	cavity	**360**	**0.036**
Floor / Slab	**Mineral Wool**	exterior	**200**	**0.036**
Windows	**triple**	replacement	**PVC insulated**	

Detailed Case Study Analysis of the project: ***Appendix 17***

7.3.10. Rheinhäuserstrasse 6 Mannheim

Location	Mannheim / Germany	
Location Type	inner city	
HDD	5,090	
CDD	666	
Year of Construction	1901	
Year of Retrofit	2007	
Historic Preservation	walls (street, outside) roof (outside)	
Building Use / Type	residential / attach. 2 sides	
Orientation	E-W	
No. of Floors	before	after
	4	5
Cond. Usable Area (m^2)	385	560
Construct. Cost (€/m^2)		1,210

Figure 75 Rheinhauserstrasse - View after retrofit



Heating Energy Consumption

	before	after	reduction
kWh/m^2a	**251.9**	**56.7**	**77.5%**

U Values (W/m^2K)

	before	after
Walls	**1.7**	**0.267**
Roof		**0.200**
Floor / Slab		
Windows	**2.90**	**1.30**
Infiltration Rate (ACH at n50)		**0.85**

Figure 76 Rheinhauserstrass - Back view after retrofit

Insulation Materials

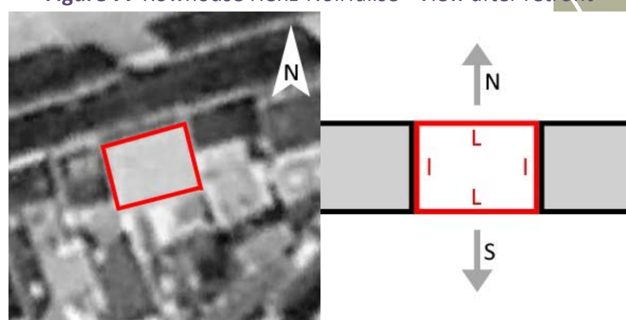
	type	location	thickness (mm)	conductivity (W/mK)
Walls	**Mineral Wool**	interior	**80**	**0.035**
Roof	**Mineral Wool**	cavity	**200**	**0.035**
Floor / Slab	**EPS**	exterior	**100**	**0.035**
Windows	**double**	replacement	**wood**	

*Detailed Case Study Analysis of the project: **Appendix 18***

7.3.11. Rowhouse Henz Noirfalise

Location	Eupen / Belgium	
Location Type	inner city	
HDD	5,720	
CDD	272	
Year of Construction	1850	
Year of Retrofit	2006	
Historic Preservation	walls (street, outside)	
Building Use / Type	residential / attach. 2 sides	
Orientation	N-S	
No. of Floors	before	after
	2 + 1	2 + 1
Cond. Usable Area (m²)	130	180
Construct. Cost (€/m²)		951

Figure 77 Rowhouse Henz-Noirfalise - View after retrofit



Heating Energy Consumption

	before	after	reduction
kWh/m²a	**300**	**12**	**96.0%**

U Values (W/m²K)

	before	after
Walls	**3.140**	**0.135**
Roof	**5.500**	**0.111**
Floor / Slab	**2.200**	**0.165**
Windows	**4.70**	**0.74**
Infiltration Rate (ACH at n50)		**0.57**

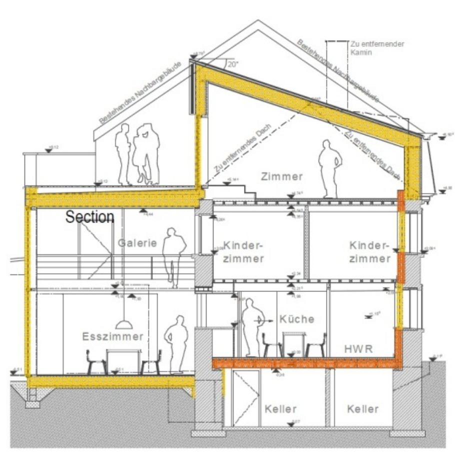


Figure 78 Rowhouse Henz-Noirfalise - Section after retrofit

Insulation Materials

	type	location	thickness (mm)	conductivity (W/mK)
Walls	**Blown in Cellulose**	interior	**280**	**0.040**
Roof	**Blown in Cellulose**	cavity	**360**	**0.040**
Floor / Slab	**Blown in Cellulose**	cavity	**240**	**0.040**
Windows	**triple**	replacement	**PVC insulated**	

Detailed Case Study Analysis of the project: ***Appendix 19***

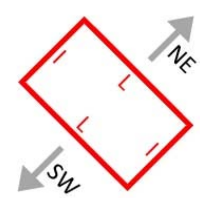
7.3.12. Sodastrasse 40 Ludwigshafen

Location	Ludwigshafen / Germany	
Location Type	suburb	
HDD	5,090	
CDD	666	
Year of Construction	1892	
Year of Retrofit	2005	
Historic Preservation	walls + roof (outside)	
Building Use / Type	residential / detached	
Orientation	NE-SW	
No. of Floors	before	after
	2 + 1	2 + 1
Cond. Usable Area (m²)		215
Construct. Cost (€/m²)		

Figure 80 Sodastrasse 40 - View after retrofit

Heating Energy Consumption

	before	after	reduction
kWh/m²a	**252.7**	**51.2**	**84.5%**



U Values (W/m²K)

	before	after
Walls	**1.548**	**0.303**
Roof	**1.314**	**0.087**
Floor / Slab	**2.276**	**0.272**
Windows		**1.17**
Infiltration Rate (ACH at n50)		**0.7**

Figure 79 Sodastrasse 40 - Schematic Section with mechanical systems after retrofit

Insulation Materials

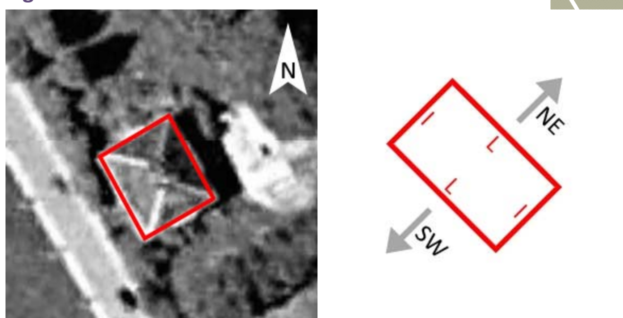
	type	location	thickness (mm)	conductivity (W/mK)
Walls	**EPS (Neopor)**	interior	**80**	**0.031**
Roof	**EPS (Neopor)**	cavity	**400**	**0.031**
Floor / Slab	**EPS (Neopor)**	interior + exterior	**200**	**0.031**
Windows	**triple**	replacement	**PVC insulated**	

Detailed Case Study Analysis of the project: ***Appendix 20***

7.3.13. Villa Pobershau

Location	Ludwigshafen / Germany	
Location Type	inner city	
HDD	6,313	
CDD	363	
Year of Construction	1882	
Year of Retrofit	2008	
Historic Preservation	walls + roof (outside)	
Building Use / Type	residential / detached	
Orientation	NE-SW	
No. of Floors	before	after
	2	2
Cond. Usable Area (m²)	277	254
Construct. Cost (€/m²)		

Figure 82 Villa Pobershau - View after retrofit



Heating Energy Consumption

	before	after	reduction
kWh/m²a	**361.3**	**32**	**91.1%**

U Values (W/m²K)

	before	after
Walls – Ground Floor	**1.200**	**0.191**
Walls – Upper Floor	**1.600**	**0.114**
Walls – Average (rough)	**1.371**	**0.143**
Roof		**0.205**
Floor / Slab		**0.095**
Windows		**0.56**
Infiltration Rate (ACH at n50)		**0.53**

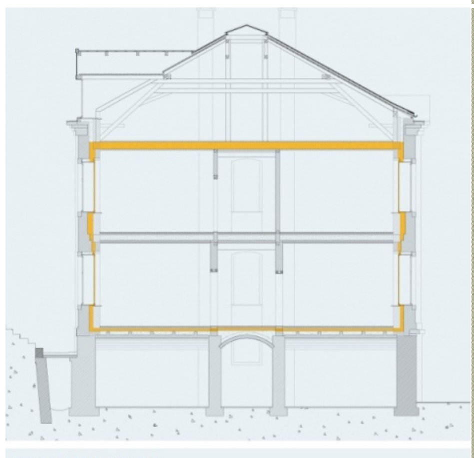


Figure 81 VIlla Pobershau - Sectoin after retrofit

Insulation Materials

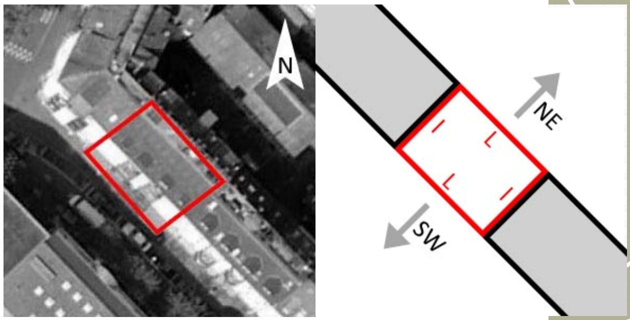
	type	location	thickness (mm)	conductivity (W/mK)
Walls – Ground Floor	**XPS Granulate**	interior (cavity)	**120**	0.035
Walls – Upper Floor	**XPS Granulate**	interior (cavity)	**250**	0.035
Roof	**Cellulose Fill**	cavity	**255**	0.040
Floor / Slab	**XPS Fill / VIP**	interior	**280 / 30**	0.080 / 0.005
Windows	**single + double**	existing + new	**wood**	

Detailed Case Study Analysis of the project: ***Appendix 21***

7.3.14. Wengistrasse 6 Zürich

Location	Zürich / Switzerland	
Location Type	inner city	
HDD	6,188	
CDD	444	
Year of Construction	1898	
Year of Retrofit	2006	
Historic Preservation	walls (street, outside) roof (outside)	
Building Use / Type	residential / attach. 2 sides	
Orientation	NE-SW	
No. of Floors	before	after
	5 + 1	5 + 2
Cond. Usable Area (m^2)	1,000	1,150
Construct. Cost (€/m^2)		1,210

Figure 83 Wengistrasse - View after retrofit



Heating Energy Consumption

	before	after	reduction
kWh/m^2a	**160**	**39.5**	**75.3%**

U Values (W/m^2K)

	before	after
Walls – Front Facade	**1.060**	**1.060**
Walls – Back Facade	**1.450**	**0.130**
Walls – Average (rough)	**1.225**	**0.232**
Roof	**1.700**	**0.150**
Floor / Slab	**2.640**	**0.160**
Windows	**2.60**	**1.20**
Infiltration Rate (ACH at n50)		

Figure 84 Wengistrasse - Installation of the prefabricated roof sections

Insulation Materials

	type	location	thickness (mm)	conductivity (W/mK)
Walls – Front Facade	**none**			
Walls – Back Facade	**EPS**	exterior	**140**	**0.036**
Roof	**Cellulose**	cavity	**240**	**0.040**
Floor / Slab	**Mineral Wool**	exterior	**200**	**0.036**
Windows	**double**	replacement	**wood**	

Detailed Case Study Analysis of the project: ***Appendix 22***

7.4. Analysis of Best Practices – Historic Building Retrofits

7.4.1. Walls

Due to preservation constraints, only part or none of the building facades could be insulated using exterior insulation panels. The interior insulation of the front façade coupled with the exterior insulation of the back façade were the most common combination, with 8 of 13 projects being retrofitted in such a manner. When applying the internal insulation layers, careful measures were taken to avoid moisture related problems.

The performance of the walls was improved on average by 83% due to the renovation measures. The average U-Value of 0.272 W/m2K after retrofit is about two times higher than the average U-Value of the non historic buildings analyzed previously. This fact can be put in relation with the heating energy consumption, which is two times higher in this case. There seems thus to be a very strong correlation between the U-Value of the Walls and the actual energy consumption.

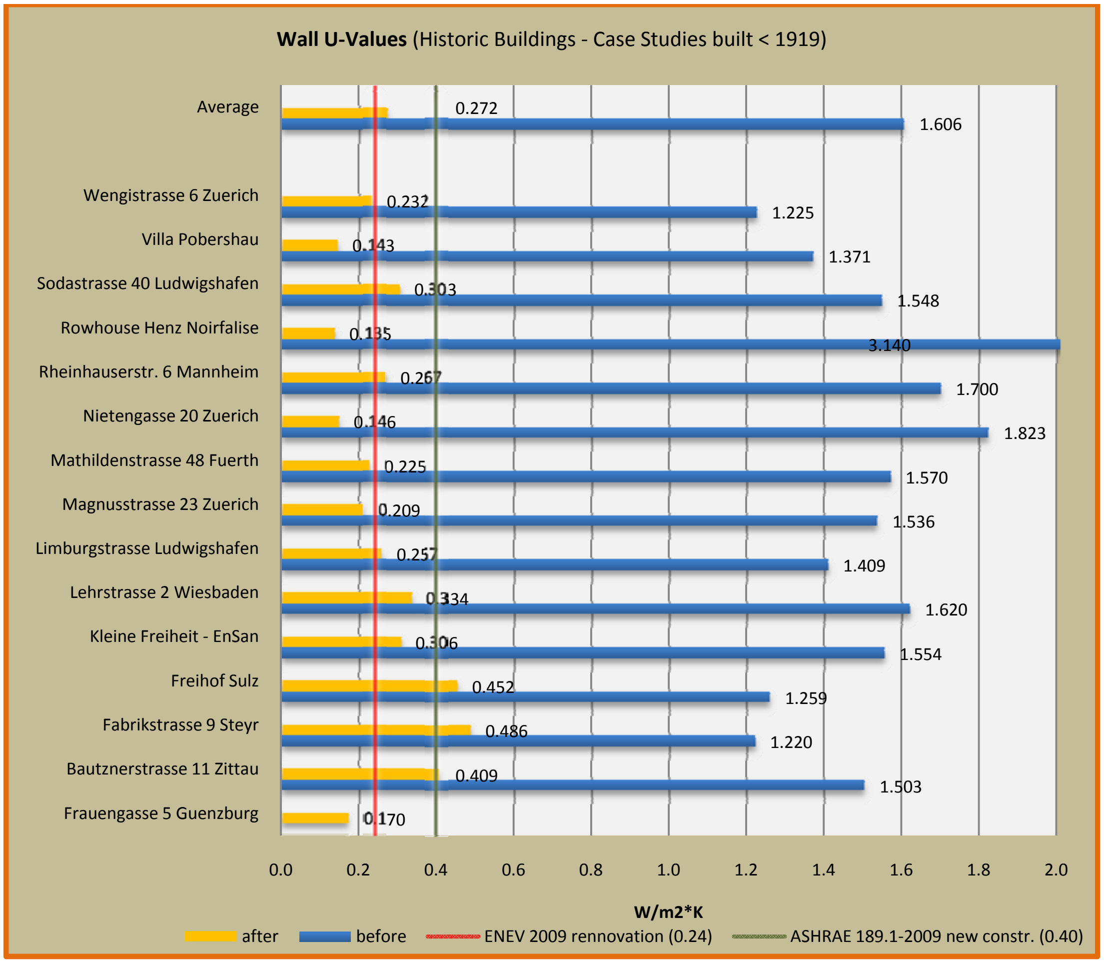


Figure 85 Wall U-Values - Historic Buildings - Case Studies built < 1919

Walls	SI Units		IP Units	
	U (W/m2K)	**R** (m2K/W)	**U** (Btu/hft2F)	**R** (hft2F/Btu)
before (avrg.)	**1.606**	0.6	0.283	**3.5**
after (avrg.)	**0.272**	3.7	0.048	**20.9**

The performance of the walls is slightly worse than the German norm for renovations from 2009. Most of the projects have been retrofitted before 2009, so this value is only a benchmark.

There is a 60% correlation between the Wall U-Value and the energy consumption suggesting, just as in the case of non historic buildings, that insulating the walls has a large impact on the performance of the building. Most cases are in the range between 0.1 and 0.2 W/m2K with those projects that have lower insulation values, exhibiting higher energy consumption, as expected.

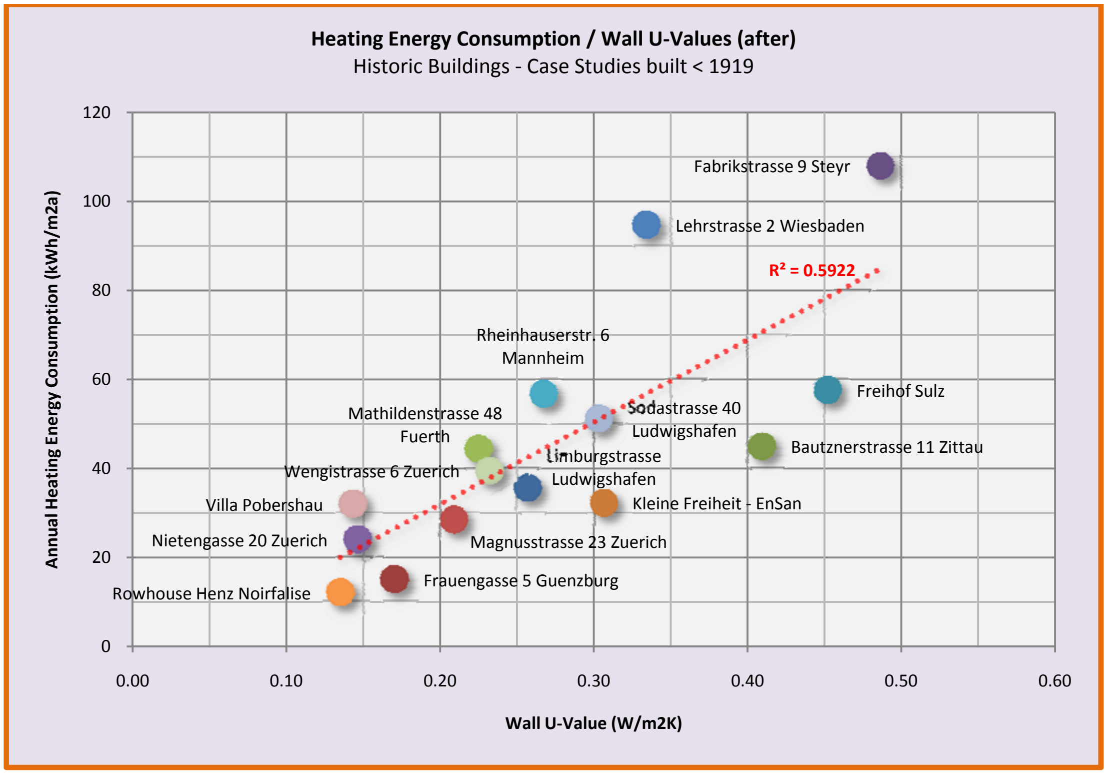


Figure 86 Heating Energy Consumption / Wall U-Values (after) - Historic Buildings (< 1919)

When analyzing the insulation thicknesses there appears to be a clear trend, with projects having thinner insulation, having a higher energy consumption than those with more insulation. The values plotted on the chart represent a combination between front insulation and back insulation, with a connecting line between them. In the case of projects which have a uniform layer of interior insulation, only one value is represented. The trend lines for the front and back insulation layers point to an interesting conclusion about the impact of the increased insulation. The R2 values for both trend lines are significant, but don't show a strong correlation. Nevertheless, the higher value for the front insulation supports the idea that the lack of sufficient insulation in the front has a higher impact on the overall building performance. The front insulation layers also vary in thickness and thermal conductivity.

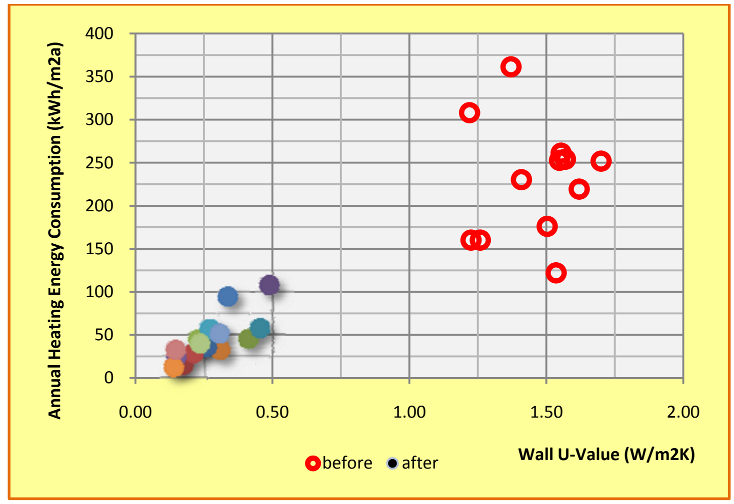


Figure 87 Heating Energy Consumption / Wall U-Values (before vs after) - Historic Buildings (< 1919)

Most of the projects had exterior insulation layers between 100 and 300 mm. and interior insulation layers between 50 and 130 mm. Even in the case of Nietengasse in Zurich, where the exterior layer is 300 mm thick, the reduced insulation capacity of the main façade prevents a significant reduction in energy consumption compared to projects with less exterior insulation. The cases of the projects in Steyr and Noirfalise are significant, as they both show how critical it is to have a large insulation layer. 50 mm are compared in this case to 280 mm of internal insulation.

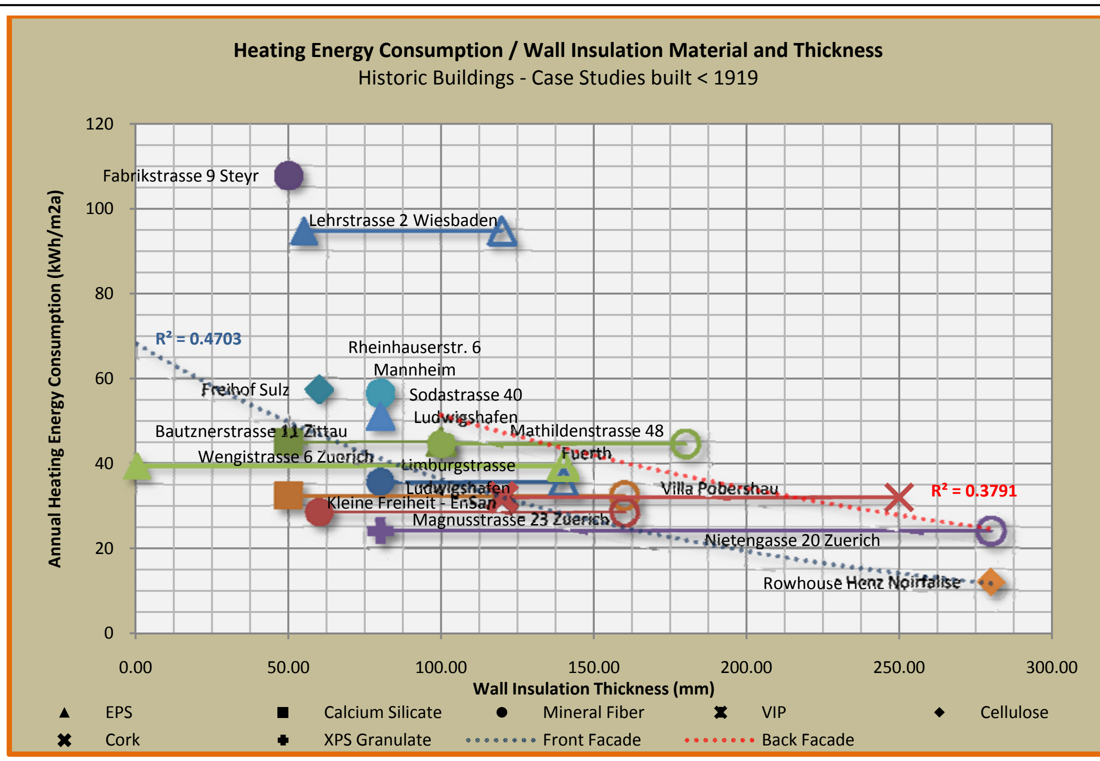


Figure 88 Heating Energy Consumption / Wall Insulation Material and Thickness (< 1919)

Most of the projects have both interior and exterior insulation, depending on the type of wall. Front facades are invariably insulated from the interior. In the case of buildings which use only interior insulation there appears to be a clear correlation between the insulation thickness and the heating energy consumption, demonstrating that the thermal insulation of the walls is directly related to the performance of the building.

7.4.2. Roofs

The roof U-values for historic and non-historic buildings are similar (0.154 compared to 0.119 W/m2K). This is due to the fact that significant interventions could be carried out in the case of the roofs of non historic buildings. The insulation materials used are similar as in the previous cases, with most of the buildings having mineral fiber or cellulose insulation. In some cases Neopor was used for the roof.

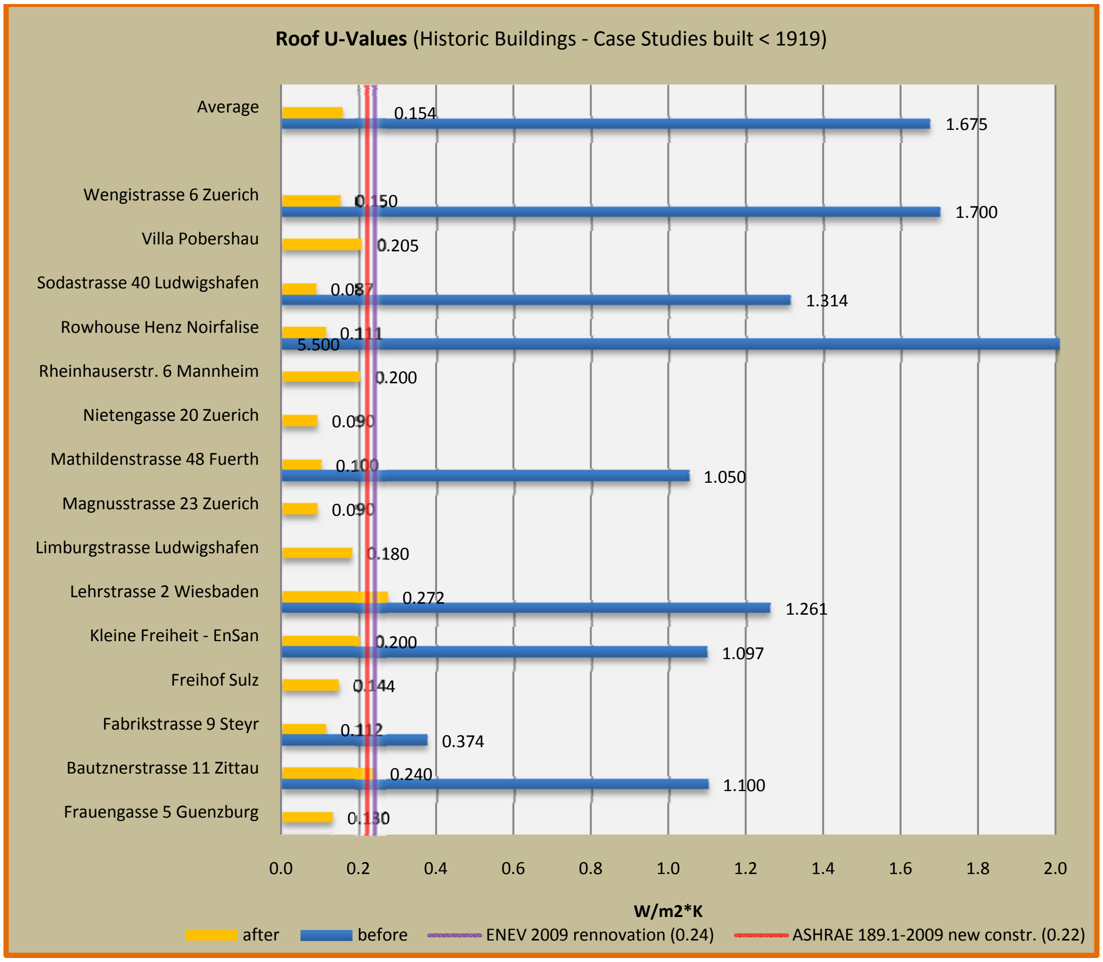


Figure 89 Roof U-Values - Historic Buildings - Case Studies built < 1919

The Roof U-Values are clustered mostly between 0.1 and 0.25 w/m2K. There is a stronger correlation between the insulation material thickness and the energy consumption than in the case of the U-values of the material, suggesting a difference in thermal conductivity properties of the material. Indeed, analysis of the insulation materials reveals slight differences in thermal conductivity within the same type of material.

Roofs	SI Units		IP Units	
	U (W/m2K)	**R** (m2K/W)	**U** (Btu/hft2F)	**R** (hft2F/Btu)
before (avrg.)	**1.675**	0.6	0.295	**3.4**
after (avrg.)	**0.154**	6.5	0.027	**36.9**

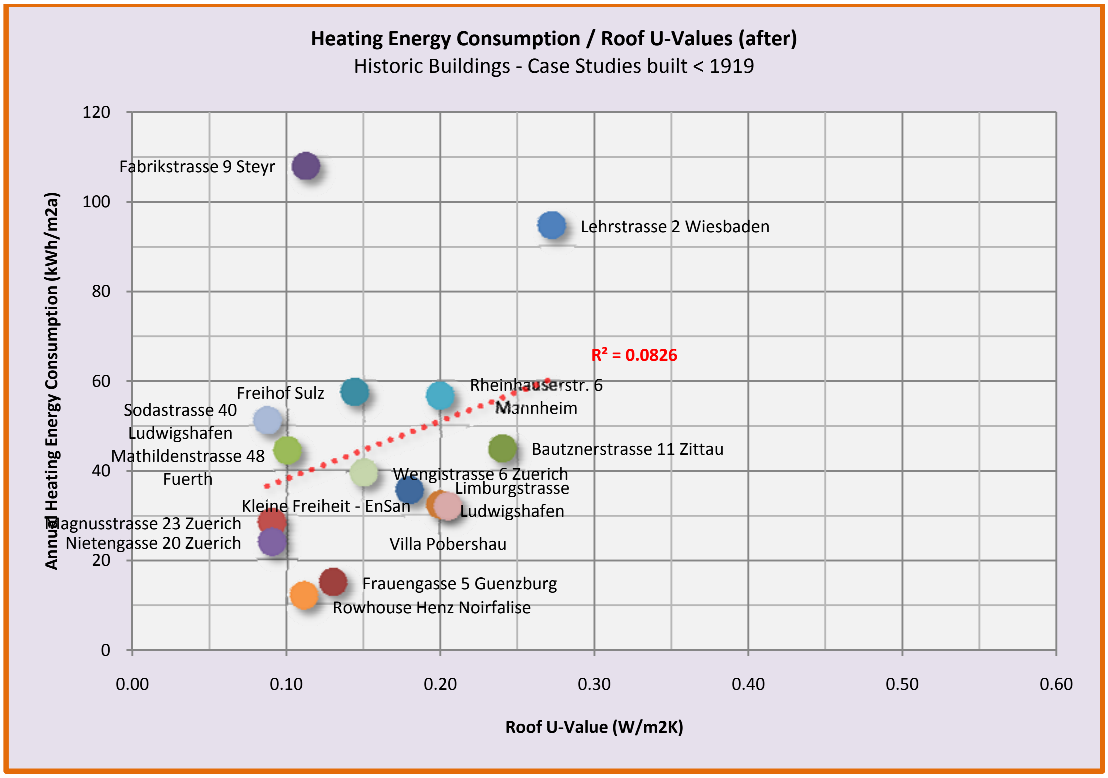


Figure 90 Heating Energy Consumption / Roof U-Values (after) - Non Historic Buildings (1919 – 1970)

The comparison with the insulation values before the retrofit supports the idea, that there is a low correlation between rood insulation and heating energy consumption. The "before" values are scattered on the chart. The same reasons as discussed in the case of non historic buildings may apply.

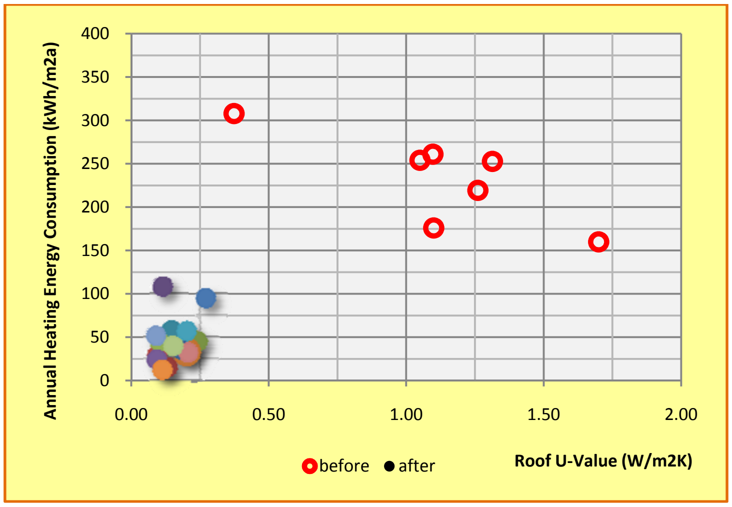


Figure 91 Heating Energy Consumption / Roof U-Values (before vs. after) - Historic Buildings (< 1919)

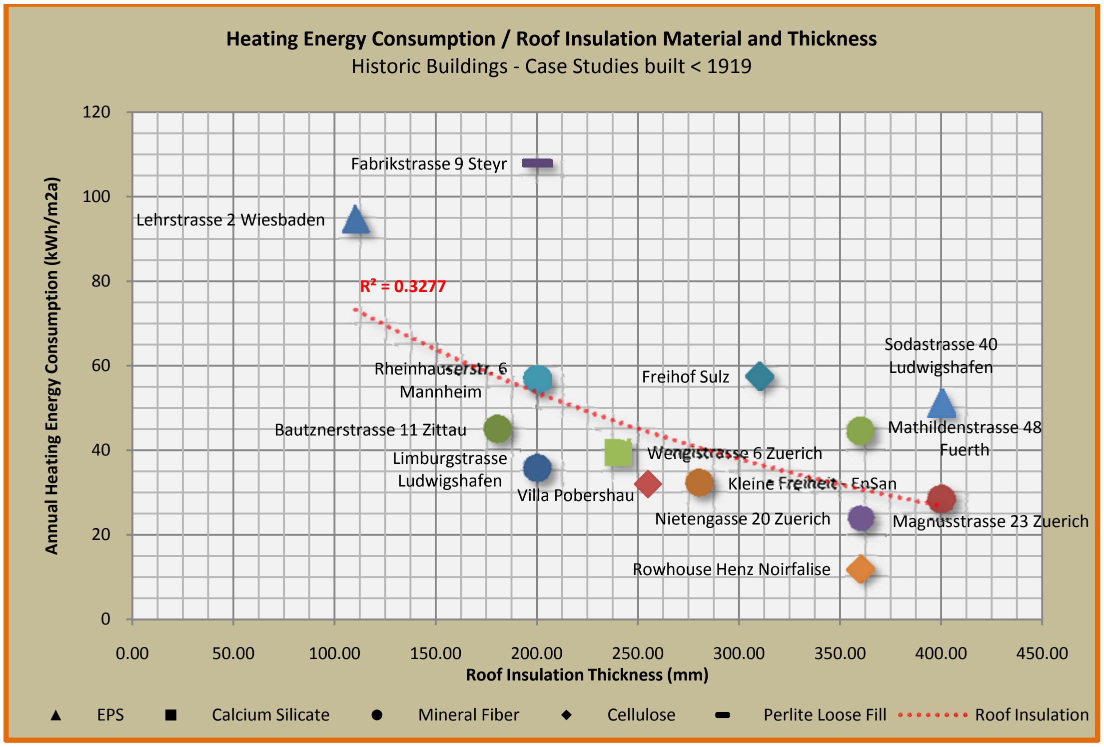


Figure 92 Heating Energy Consumption / Roof Insulation Material and Thickness (< 1919)

7.4.3. Slabs

Historic buildings typically have higher ceilings than non historic ones, thus allowing for a larger layer of insulation to be added to the slabs over the basements. Most of the cases have uninsulated basements, and even after renovation the basements were not included inside the thermal envelope. The lab construction also often included a layer of waste material or sand fill, which could be removed in order to make room for a more efficient insulation material. The materials of choice for the slabs were EPS, mineral fiber and cellulose. Even if the thickness of the slab insulation material applied in the case of the projects from before 1919 is bigger than the one for non historic projects, their thermal conductivity is higher, leading to a similar average U-Value of the assemblies. An average improvement of 81% was achieved in the case of the slabs.

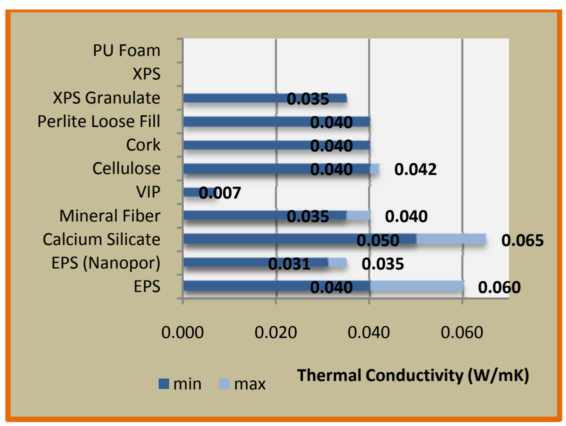


Figure 93 Thermal Conductivity of Insulation Materials used in historic buildings (< 1919)

In terms of the insulation location, there is a balance between external and internal insulation of the slabs.

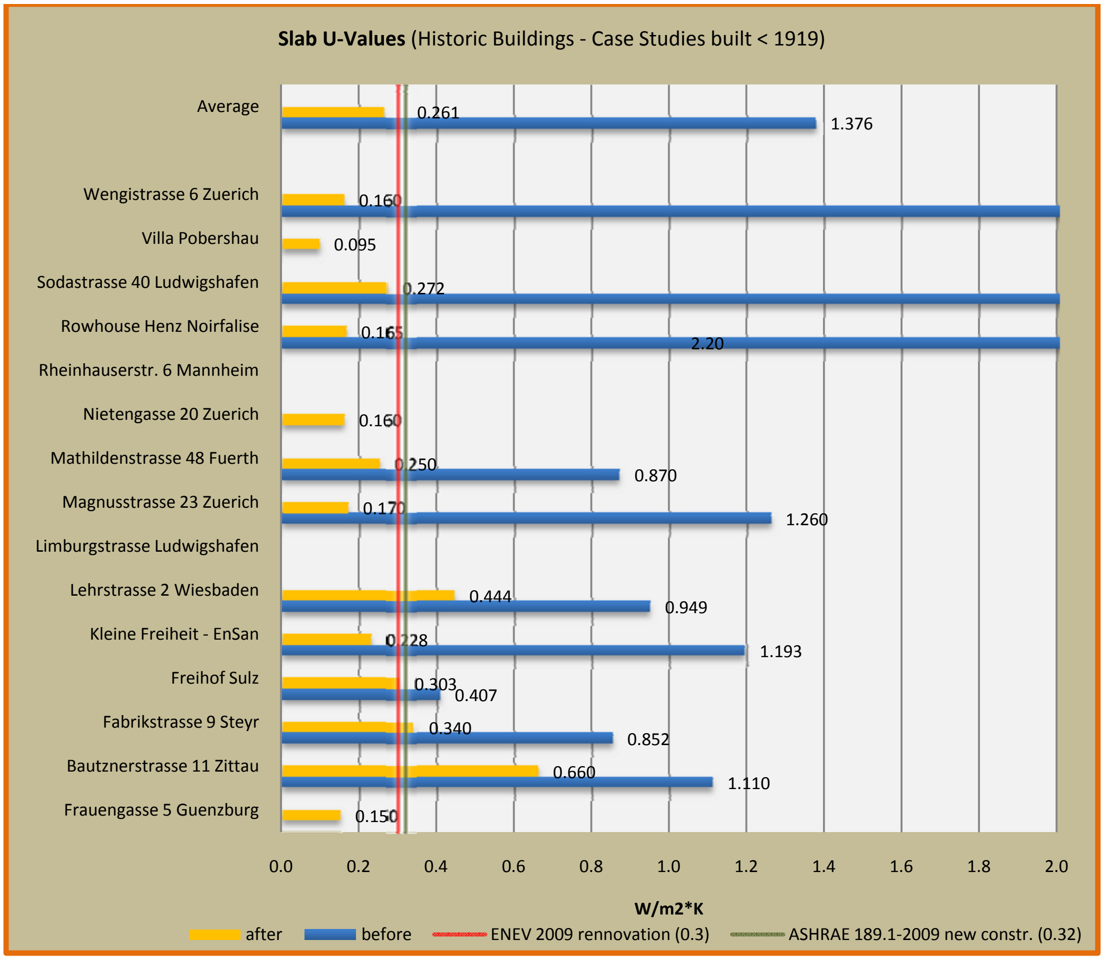


Figure 94 Slab U-Values - Historic Buildings - Case Studies built < 1919

Slabs	SI Units		IP Units	
	U (W/m2K)	**R** (m2K/W)	**U** (Btu/hft2F)	**R** (hft2F/Btu)
before (avrg.)	**1.376**	0.7	0.242	**4.1**
after (avrg.)	**0.261**	3.8	0.046	**21.8**

More than in the case of the non historic projects, the Slab U-Values offer a significant correlation to the overall energy consumption pattern (R^2=55%). The importance of the slab insulation is in my opinion increased by the lack of wall insulation. The slab thus plays a more important role in the overall consumption pattern. It would be therefore advisable to increase the U-Value of the slab as much as possible in order to compensate for the poor performance of the walls and windows.

The materials of choice for slabs have been EPS and Mineral Fiber. The low cost and ease of application makes them desirable for many projects. The case of the Rowhouse Henz-Noirfalise stands out as the only case analyzed, which has a wooden structure as the ground floor slab. In this case, a 240 mm layer of Cellulose was installed in the cavity, contributing significantly to the low consumption values of the project.

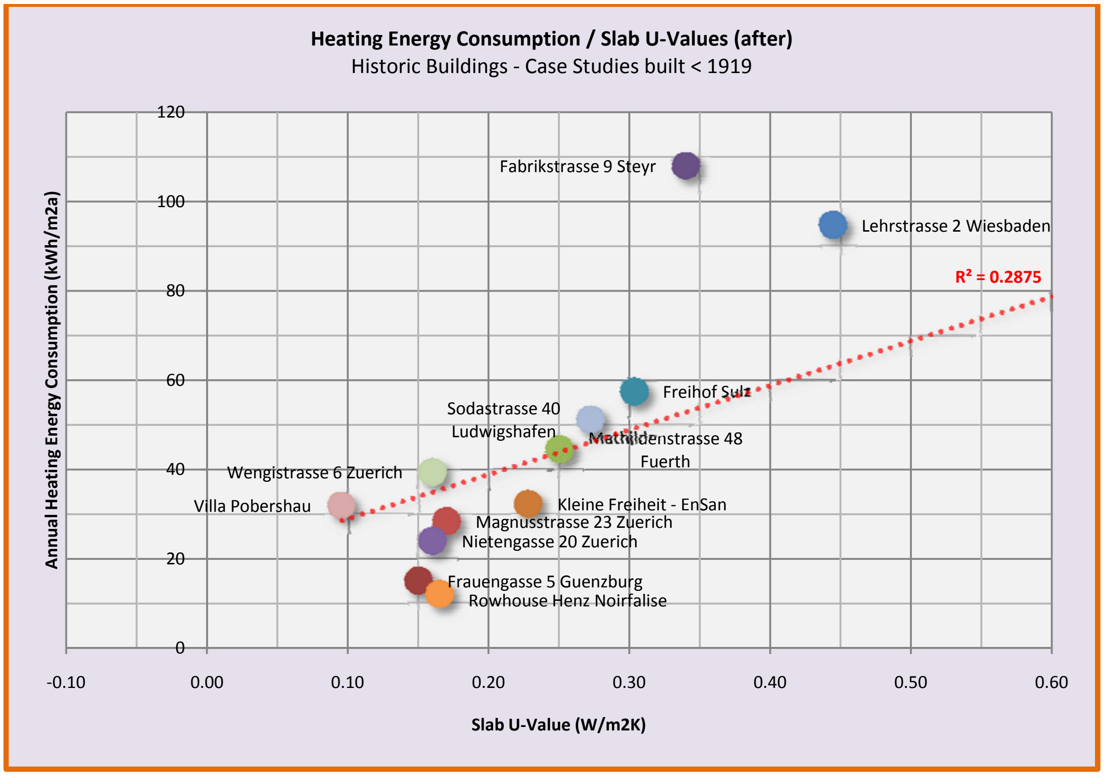


Figure 95 Heating Energy Consumption / Slab U-Values (after) - Historic Buildings (< 1919)

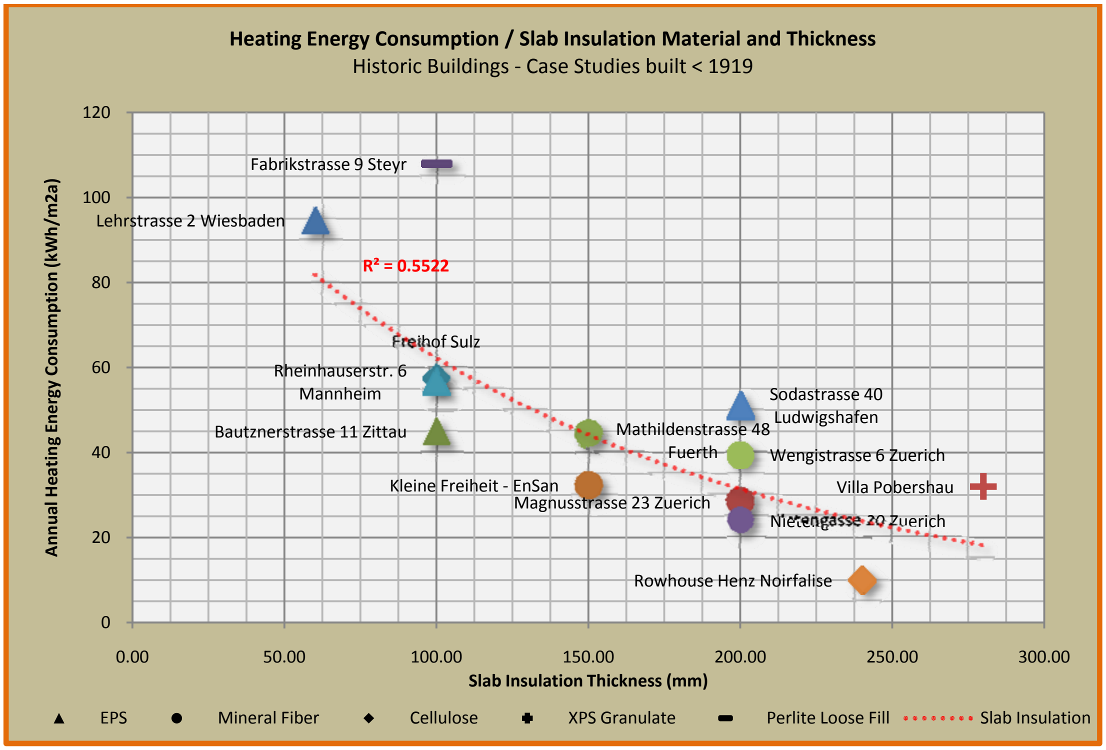


Figure 96 Heating Energy Consumption / Slab Insulation Material and Thickness (< 1919)

7.4.4. Windows

The average U-Value for the windows used for retrofitting historic buildings is 1.12 W/m2K, 30% higher than the one for none historic buildings. While the newer constructions were upgraded using the most efficient passive house recommended triple glazed windows with PVC framing, some of the projects from before 1919 had historic preservation restrictions. In some cases the original framing and glazing had to be kept in place and in other cases wooden frames had to be reconstructed and were able to hold double or triple low-E glazing.

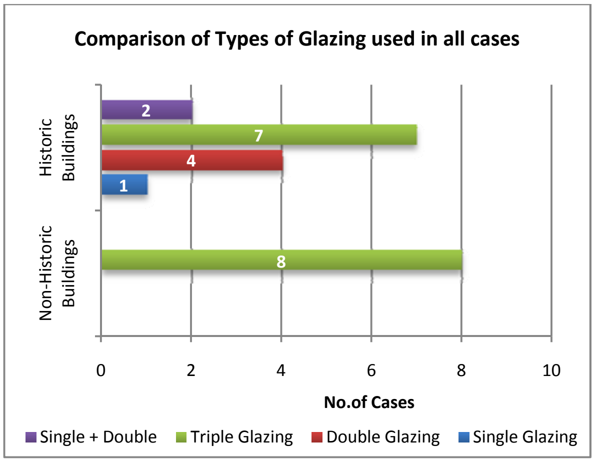


Figure 97 Comparison of Types of Glazing by Frequencey of Use for Historic Buildings

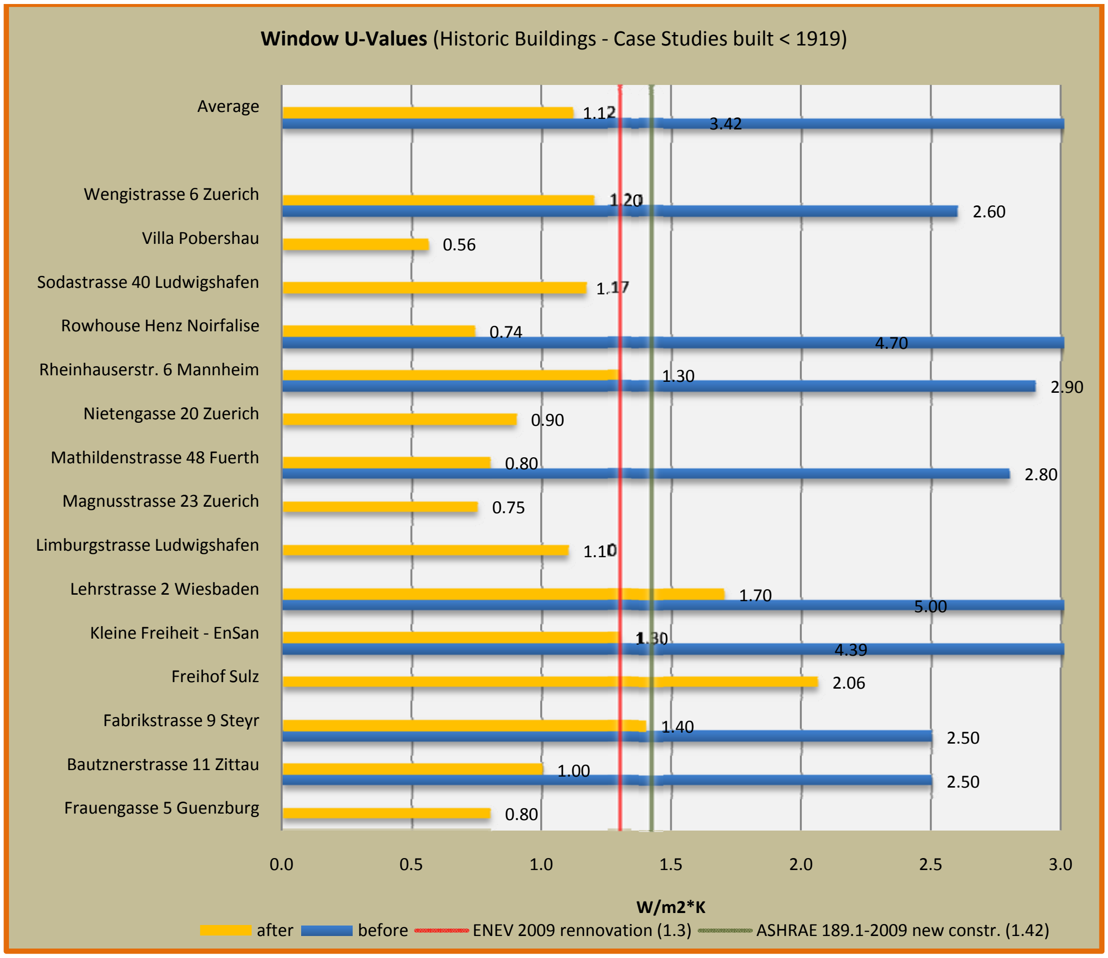


Figure 98 Window U-Values - Historic Buildings - Case Studies built < 1919

In the cases where the original windows were kept, they were either coated with a low-E coating, such as a for the renovation of the Freihof Sulz project, or they were supplemented with an additional layer of windows to the inside, like in the case of the Villa Pobershau.

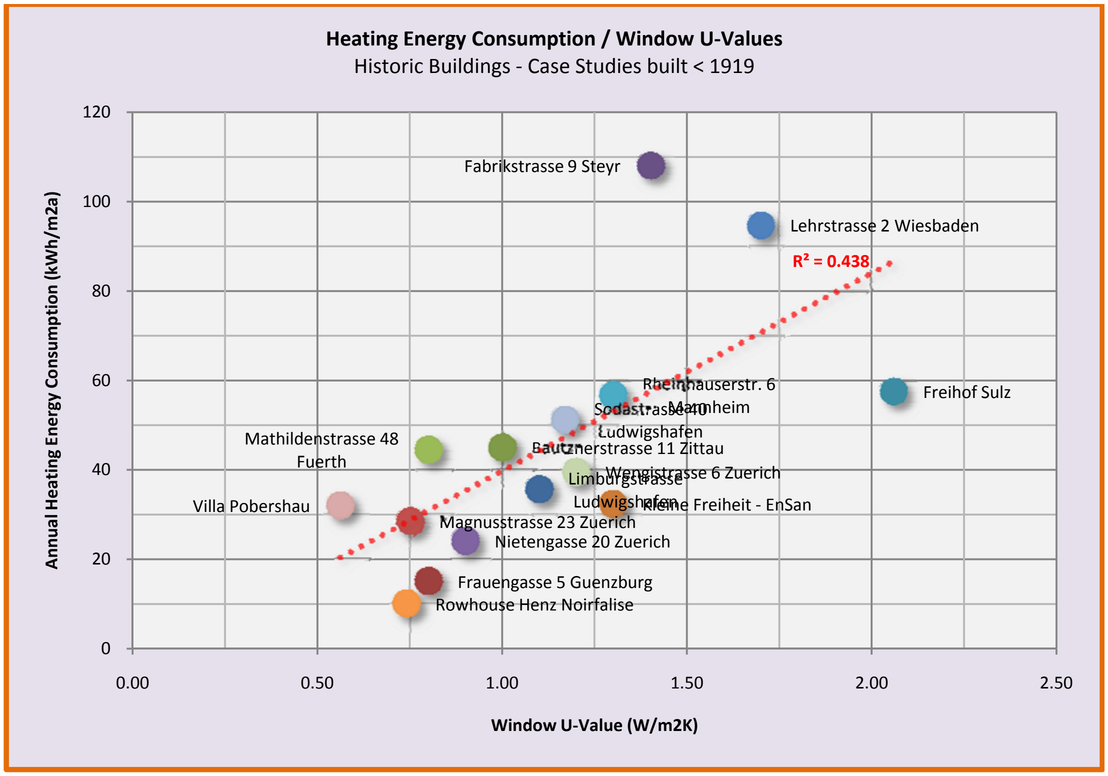


Figure 99 Heating Energy Consumption / Window U-Values (after) - Historic Buildings (<1919)

The correlation between the performance of the windows and the energy consumption of the building is sufficiently strong to indicate a high influence of the windows. Given the fact that windows are five times less efficient than the wall construction, they remain the weak spot in the thermal envelope. The most efficient windows are approximately 50% better insulating than the average wall before retrofit measures were undertaken. Due to the different constraints, the

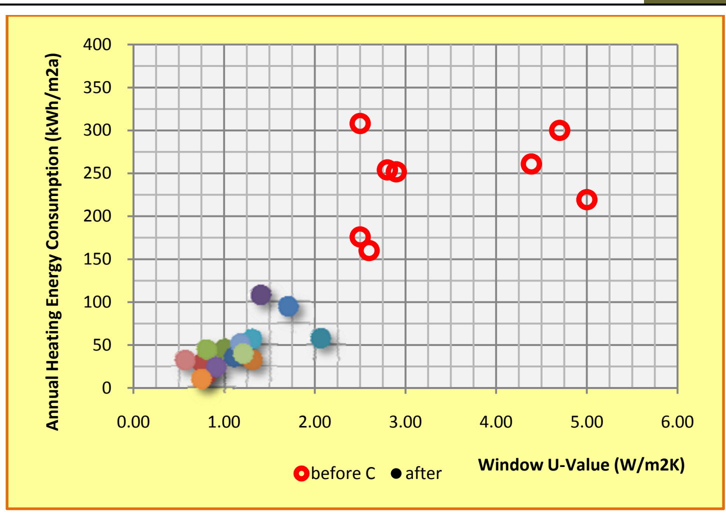


Figure 100 Heating Energy Consumption / Window U-Values (before vs after) - Historic Buildings (< 1919)

new windows for historic buildings perform below the passive house standard of 0.8 W/mK, but are well under the current German standards for retrofit and the U.S. ASHRAE Standard.

Windows	SI Units		IP Units	
	U (W/m2K)	**R** (m2K/W)	**U** (Btu/hft2F)	**R** (hft2F/Btu)
before (avrg.)	**3.420**	0.3	0.602	**1.7**
after (avrg.)	**1.120**	0.9	0.197	**5.1**

7.4.5. Infiltration Rate

The average infiltration rate for historic buildings is well above the limit set for Passive House certification (0.6 ACH) by close to 100%. It is also more than two times the average registered for. This dramatic difference can in my opinion be related to the lower performance of the window framing and to internal leakage problems towards the basement area.

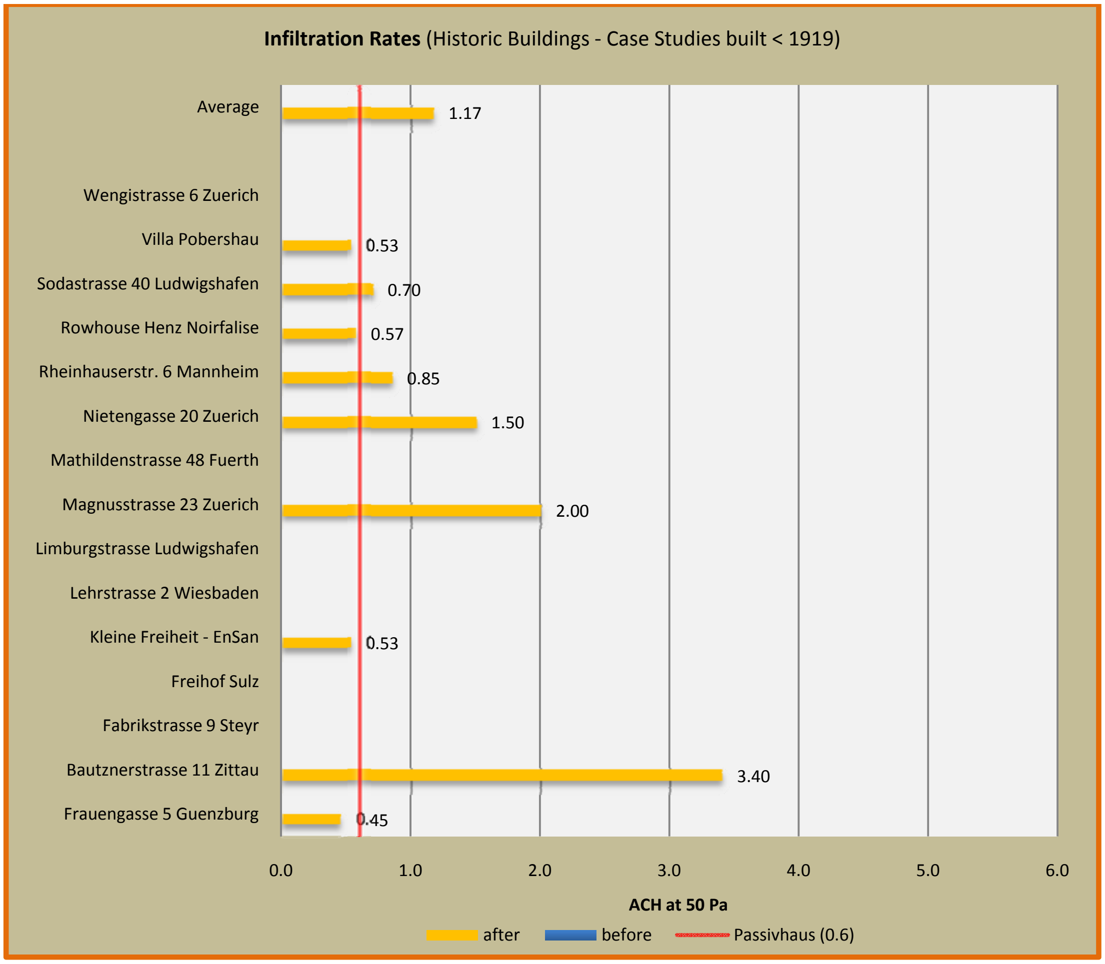


Figure 101 Infiltration Rates - Historic Buildings - Case Studies built < 1919

Interior insulation needs to be conducted under very strict air tightness guidelines in order to avoid moisture migration through convection. It is therefore unlikely that the walls or roofs are responsible for the high infiltration values. Even so, the measured average infiltration is about 4 times lower than the "before" infiltration rate for non historic buildings. The "before data for historic renovations was not available.

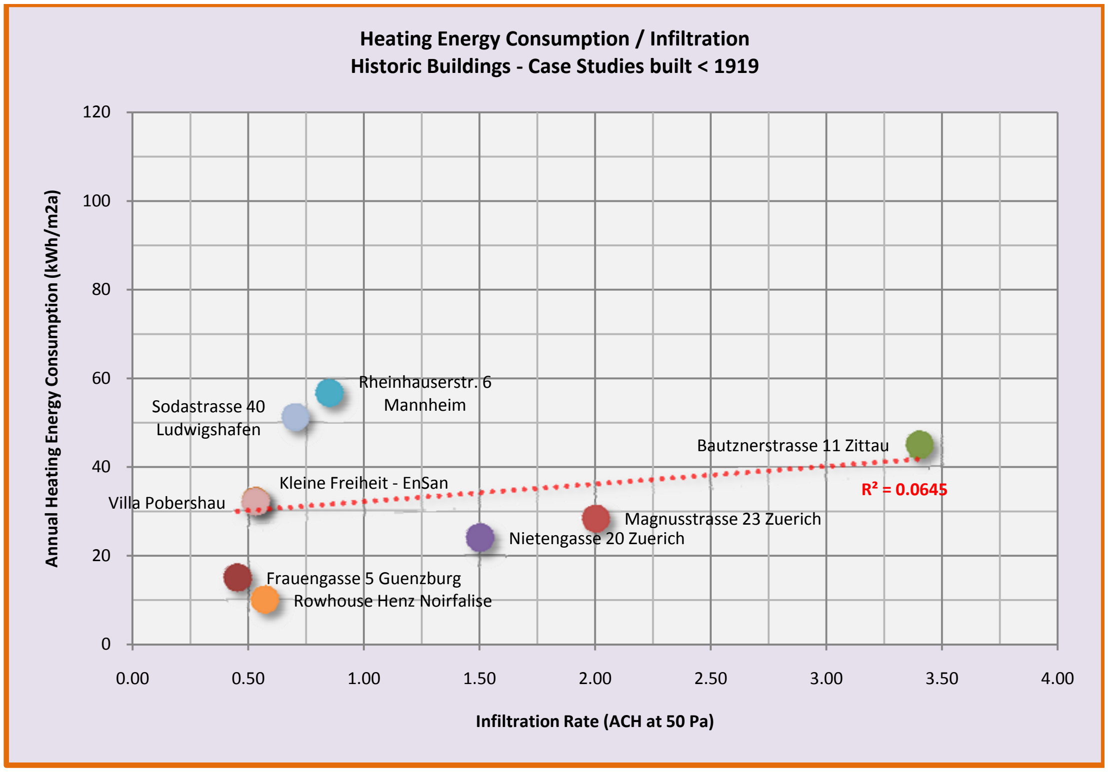


Figure 102 Heating Energy Consumption / Infiltration - Historic Buildings (< 1919)

7.5. Conclusions of the Case Study Analysis of Historic Buildings

Retrofitting historic buildings is more challenging than retrofitting non historic constructions. The various limitations limit the possible performance of the projects. Nevertheless, the improvements registered by the cases gathered within this report register significant performance increases. On average the performance could be improved by more than 80%, and the results were well below the current standards for new construction. The analysis shows that walls are the most important part of the thermal envelope, followed by the slabs and the windows.

Retrofitting historic buildings must certainly be an option for reducing the energy consumption of the building stock.

8. Recommendations for Retrofitting Historic Buildings

The energetic retrofit of existing buildings is necessary, in order to improve the efficiency and reduce the energy consumption of the residential building stock. 56% of the residential buildings in Central and Northern Europe were built before energy efficiency regulations for new constructions were introduced. More than 2/3 of these buildings are non-historic buildings which allow for extensive retrofit measures without historic preservation limitations.

The main feature of such retrofit measures is the application of an exterior insulation layer in order to improve the insulating capacity of the wall assembly. Insulating walls from the outside is a very convenient way of carrying out energetic retrofit measures. The moisture balance inside the wall improves, with the masonry being within the thermal envelope. Not only can moisture dry out towards the interior space, but the capacity of the wall to deal with incoming moisture is also increased. Mistakes made while applying external insulation can be accepted as long as they don't have a serious impact and thermal bridges can also be accounted for (Feist, 2005).

When talking about the energetic retrofit of historic buildings, the problem of historic preservation constraints on the envelope components limits the extent of the intervention measures which are applicable. Most notably these constraints relate to the walls of the buildings (walls and windows). Historic buildings can be defined as buildings built before 1919, as the construction methods and architectural styles prior to that period favored heavily the erection of ornate buildings facades and in some cases interiors. Interior insulation is in these cases the only option, if there are no constraints on the interior finish.

Unfortunately, when compared to external insulation, the use of interior insulation needs to be associated with a careful planning and execution process. The tolerance for mistakes is much lower in the case of interior insulation, because the ability of the wall to release moisture to the interior space is hindered. Moisture build up within the wall can cause interior health hazards such as mould or damage to construction elements such as beams (rotting). The Passive House Institute in Darmstadt has set two essential conditions which need to be met when retrofitting a historic building:

1. *Removal of ascending moisture:*
   As I have previously mentioned, ascending moisture from the ground or from other construction elements which contain moisture is problematic for all buildings, especially for the ones fitted with interior insulation,

where the drying capacity of the wall has been lowered. A continued source of flow into the wall can lead to mould growth or deterioration of the structure itself. The source of ascending moisture needs to be removed prior to the application of the insulation layer.

2. *Weatherproofing of the façade against driving rain:*
   Driving rain can lead to serios problems even in the case of uninsulated masonry walls. Penetrating moisture can build up within the wall structure and cause damage, especially when the wall cannot dry towards the interior. Depending on the type of wall, a water repelling or a water retarding exterior finish may be used.

8.1. Recommendations for Walls

Insulating the walls of historic buildings may prove a challenging task, given the preservation constraints imposed on the façade. Based on my case study analysis and in terms of preservation constraints, historic buildings can be split in two categories:

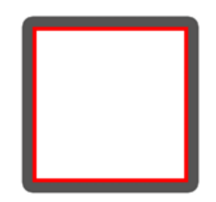


Figure 103 Diagram - Interior Insulation on all

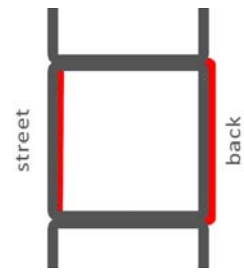


Figure 104 Diagram - Interior Insulation on

a. *Historic Buildings with all exterior facades under historic preservation*
   In this case the insulation needs to be applied on the inside of all exterior elevations and has to be thick enough to contribute to a significant improvement of the energy performance of the building. Most of these types of buildings are detached buildings, although some attached constructions may have all facades built to the same standard.

b. *Historic Buildings with only the main façade under historic preservation*
   Buildings which have only one façade under protection allow for exterior insulation to be placed on the back elevation. All of the analyzed buildings in this category are inner city buildings attached on two sides and have protected street façades. In this case, the lack of sufficient insulation on the front façade can be compensated by the exterior back insulation.

The interior insulation layer lowers or completely blocks the wall's capacity to eliminate moisture to the interior. Furthermore, the wall is in direct contact with the outside temperature, but is outside of the insulation boundary. It thus has a very low surface temperature on the inside. The possible dangers have been previously discussed in this paper. I will thus go into details regarding the potential solutions:

I. An Air Tight Construction of the insulation layer:

The air tight construction of the insulation layer is crucial in order to prevent humidity reaching the outside wall through convection. The air tight layer must be positioned on the room side. This can be achieved through the following measures:

a. ***A Continuous Layer of Plaster*** applied directly on the interior surface of the insulation panels. This solution was applied for example in the case of the Lehrstrasse project in Wiesbaden, where the insulation panels had a wood fiber coating which allows for plaster to be attached to them.

Figure 105 EPS panels with wood fibre support layer for plaster – Lehrstrasse 2 Wiesbaden (Loga, et al., 2003)

b. ***Application of OSB Panels*** on top of the insulation layer. The OSB panels need to be taped together so as not to allow any leakage through. This measure is similar to what is used in the light weight construction for passive house new construction.

Figure 106 EPS panels with plasterboard later – Sodastrasse 40 Ludwigshafen (Vogelsang, 2005)

c. ***The use of composite insulation panels*** which have a layer of insulation glued to a layer of plasterboard (towards the interior of the building). The plasterboard panels need to be taped together using a resistant tape. Such a solution was used in the case of the Sodastrasse project in Ludwigshafen. The insulation material in that case was Neopor (EPS). A second layer of plasterboard was used for the interior finish.

Figure 107 Air tight foil on the interior of the insulation – Limburgstrasse Ludwigshafen (Bergmeister, et al., 2008)

d. ***The Application of an air tight Foil*** on the interior of the insulation. The foil has to be taped to the other components of the building. Special care must be given to the areas around window openings. This method was used in the case of the Limburgstrasse project in Ludwigshafen. In that case, two types of insulation materials were used for comparison purposes (EPS and Mineral Fiber).

Potential problems in the performance of the air tight layer can come from perforations during use. A study of the Passive House Institute found that perforations from nails as they occur from normal use are not significant. Even when the nails are pulled out of the wall the infiltration is minimal. Calculations found that ther is a threshold at 8 punctures/m^2, when the infiltration becomes significant enough (Feist, et al., 2001).

II. **The Reduction of the Thermal Bridges** at the connection points of interior partition elements. The danger of thermal bridging and condensation in those areas where it occurs is high, if the insulation is suddenly interrupted. The areas most vulnerable to thermal bridging are:

a. ***window sills*** - the insulation should be carried out up to the window frame

b. ***slabs and floors*** – the insulation on top of the slab should be connected to the insulation within the slab and the insulation underneath should be carried out along the slab for approximately 300-500 mm

c. ***interior partition walls*** – just as in the case with the slabs, the insulation has to be carried out along the wall.

Figure 108 Insulation carried out along the partition wall – Lehrstrasse 2 Wiesbaden (Loga, et al., 2003)

The air tightness or vapor barriers need to be taped o very well connected in the corner areas and to the wall itself.

III. **Preventing Moisture Diffusion**

While the amounts of moisture which can reach the wall through diffusion are much smaller than those transported by convection vapor diffusion can lead to an accumulation of moisture inside the solid masonry construction, which ca cause long term problems. Protection measures against moisture buildup inside the wall due to diffusion are thus necessary. Two different concepts have been proven to be successful in dealing with diffusion:

a. ***The use of a vapor barrier or vapor retarder***, which can prohibit or reduce moisture migration. This is the so-called classical approach which can be found in most cases and has been proven to be effective in stopping vapor diffusion. The most important prerequisite is an absolutely dry wall with no other sources of moisture. The vapor barrier eliminates completely the possibility of the wall to dry towards the interior. The most important measure when applying a vapor barrier is to make sure there are no punctures or leakage areas. Indeed, in many cases, the vapor barrier can be used as an air sealing layer as well.

b. ***The Use of capillary active insulation materials*** – combined with an air sealing layer. Due to their special properties, these materials let moisture to diffuse inside, but they store it for a short period of time and then release it back into the interior environment. This property of the material eliminates the need for a vapor barrier. An air sealing layer must still be applied, in order to prevent convection. An example of such a material is calcium silicate, which has been successfully used in the cases of Bautznerstrasse Zittau and Kleine Freiheit in Hamburg. Unfortunately the thermal conductivity of calcium silicate insulation is at least 20% higher than that of mineral wool or EPS, thus requiring thicker layers of insulation to achieve the same effect.

Wall insulation material and Thickness

The themal insulation of walls on the interior has been analyzed in detail by the Pasive House Institute in Germany. Their findings suggest that the optimum thickness of conventional insulation should lie between **40 and 100 mm** (for thermal conductivity values of 0.035 – 0.04 W/mK) (Feist, 2005). If one would consider the exterior façade as an isolated element, the building's performance could be correlated directly to the thickness of the insulation used. According to Wolfgang Feist, the increase in interior insulation beyond 100 mm does not justify the material expenses due to the losses

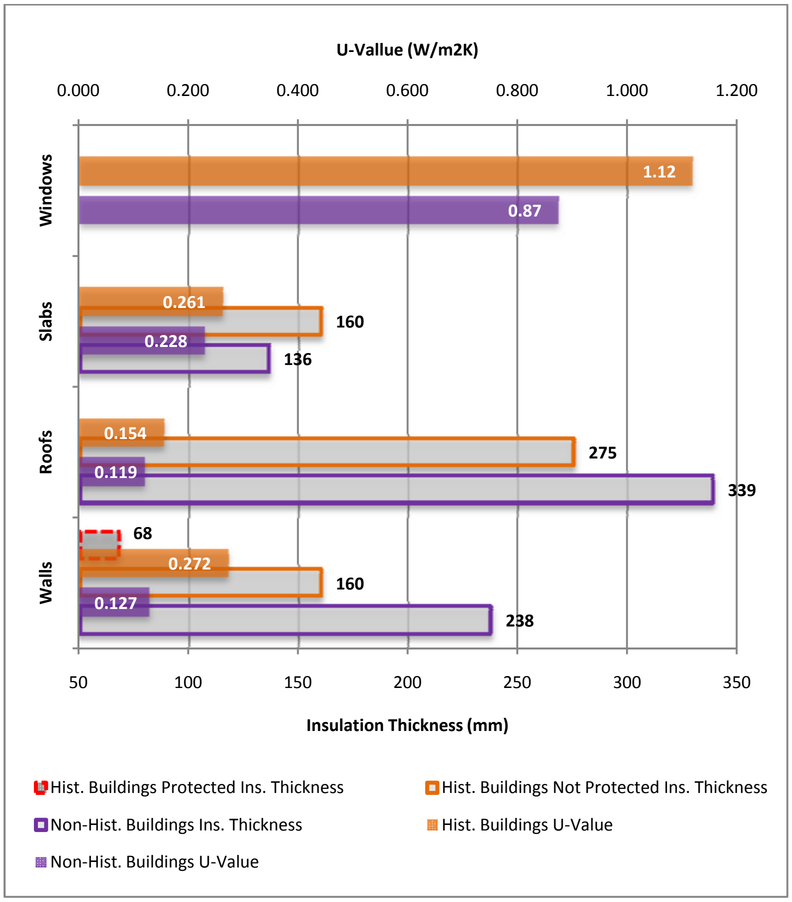


Figure 109 Comparison of U-Values and Material Thicknesses for all studied cases

incurred by thermal bridging (Feist, et al., 2001). This opinion corresponds to the findings of the present report, which has found a much weaker correlation between performance and insulation values when comparing historic retrofits with interior insulation to non historic retrofits with exterior insulation.

Even with efforts made to reduce the thermal bridging effect, it can only be eliminated in two ways, both entailing the application of a continuous layer of insulation. The easiest way is by applying the insulation on the exterior of the façade. The second option would be to apply the insulation on the interior and disconnect any constructive elements from the external façade. This has been achieved in the case of the Rowhouse Hens-Noirfalise in Eupen and the Villa in Pobershau. In both cases, exceptional levels of interior insulation were used. In Eupen, 280 mm of blown in cellulose were used within a wooden support frame built on the interior of the masonry wall, as a secondary structure. The wooden floor beams and internal partition walls were disconnected from the façade and a secondary structure was built for structural purposes. The insulation layer was installed continuously on the façades and roof.

Figure 110 Disconnected beam and contiuous internal insulation layer - Rowhouse Henz Noirfalise in Eupen (Belgian Science Policy)

In the case of the Villa in Pobershau, the wooden beams and internal walls were also disconnected from the exterior walls and a secondary lightweight wall was built parallel to the original enclosure in order to take the structural loads. An on average 185 mm thick layer of XPS loose insulation was filled into the cavity created between the original wall and the newly constructed one.

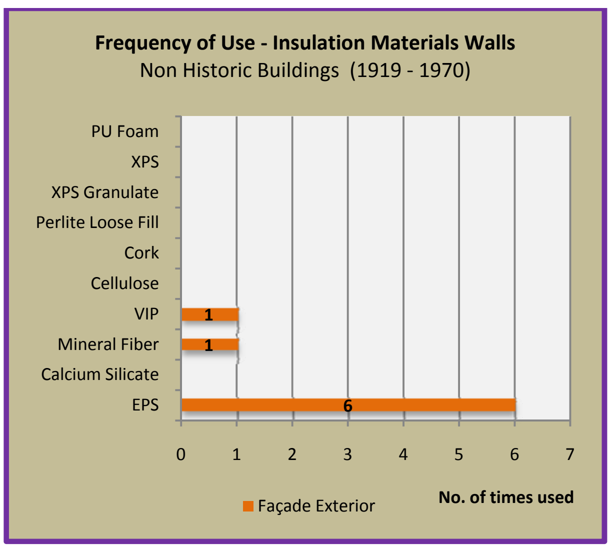
Figure 111 Disconnected internal partition wall and secondary wall structure with cavity – Villa Pobershau (ENBAUSA)

The two projects which have implemented thicker layers of interior insulation have heating energy consumption values much lower than comparable buildings. The consumption for the project in Eupen is 12 kWh/m2a, much lower than the 25-40 normal range for terraced houses and the consumption for Villa Pobershau is 32 kWh/m2a, compared to 51 in the case of Sodastrasse 40 and 57 in the case of Freihof Sulz.

The results of the case study analysis confirm the findings of the Passive House Institute. The average interior insulation thickness for protected walls is 68 mm, excluding the two instances, where the interior construction elements were disconnected from the façade and a thicker layer of insulation was used. The range of insulation thicknesses for the interior is **50 – 100 mm**, similar to the one proposed by Feist (2001). By contrast, the exterior insulation of the non restricted walls is on average 160 mm thick for historic and 238 mm thick for non historic buildings.

The types of materials used for insulating the interior are very varied. The most utilized materials are Mineral Fiber, EPS, Calcium Silicate and Cellulose. For non historic buildings the material of choice has been EPS. Except for Calcium Silicate, which has a higher thermal conductivity, all the materials are within the range **0.035 – 0.045 W/mK**.

When taking into account the experience of the analyzed cases studies, the recommended materials for interior insulation would be EPS, Mineral Fiber and Cellulose with a thickness **not bigger than 100 mm**, if a continuous layer cannot be installed. The exterior insulation could be EPS or Mineral Fiber with a thickness between **160 – 240 mm.** Increasing the thickness of the back wall external insulation seems to reduce the energy consumption considerably, although the reduction is not proportional. There are thus reasons to believe, that in the absence of a continuous layer for the front façade, the effects of increasing the back insulation are also limited.



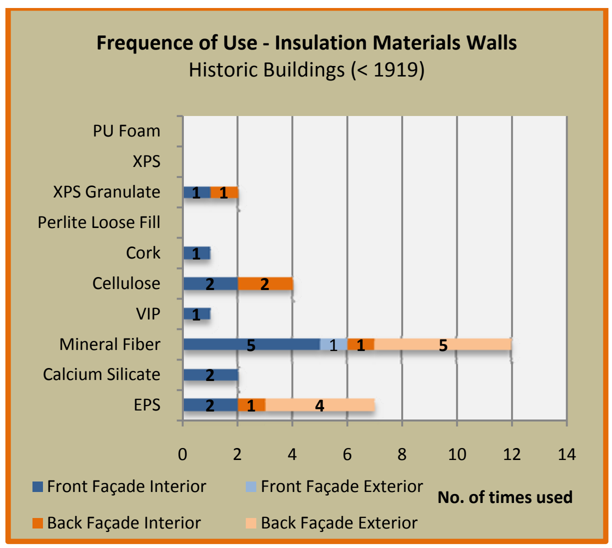


Figure 112 + 113 Frequency of use for Wall Insulation Materials (Non Historic Buildings and Historic Buildings)

8.2. Recommendations for Roofs

In all the cases studied within this paper, the roofs didn't have preservation restrictions which would hinder the retrofit measures. In most cases the external appearance and geometry of the roof had to be retained, but a replacement of the structure was possible. In the cases, where the thermal boundary is at the slab level (over the last floor) there are also no restrictions. The most used method of insulation is the cavity insulation, between the wooden beams of the roof or slab structure. The average insulation layer thickness has been **275 mm** for historic buildings and **339 mm** for non historic buildings.

The difference in insulation thickness between the two types of buildings could be attributed in my opinion to two factors:

a. *The height and geometry restrictions of the roof* limit the thickness of the insulation layer.
b. *The additional insulation would have little effect in the light of a reduced performance of the walls.*

Both arguments are my personal opinion following the analysis of the cases. The range of values for insulation thicknesses is nevertheless similar (250 – 400 mm for non historic and 150-400 mm for historic buildings).

When comparing the average U-values of the roof assemblies (0.154 – 0.119 W/m2K), both historic and non historic buildings have similar values, the difference being a reflection of the different layer thicknesses applied. The types of materials used are identical in both cases, with **Mineral Wool, Cellulose and EPS** being favored.

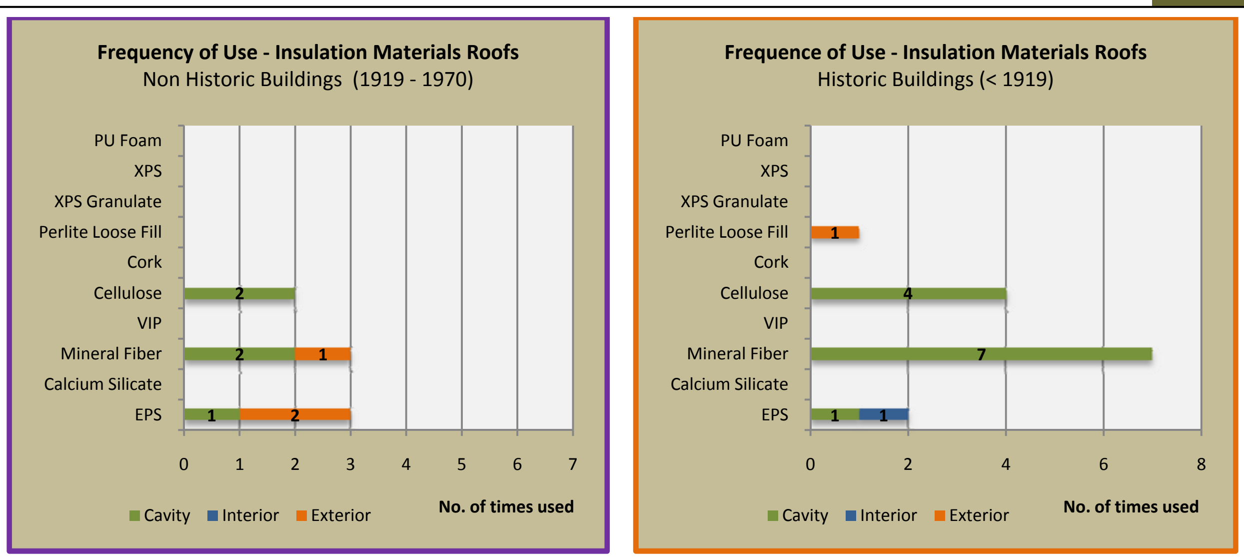


Figure 114 + 115 Frequency of use for Roof Insulation Materials (Non Historic Buildings and Historic Buildings)

Regardless of the type of insulation, a vapor barrier needs to be applied to the underside of the roof structure in order to prevent moisture build up through diffusion inside the insulation material. The vapor barrier could also serve as an air tight layer for the roof. A special problem area is represented by the knee walls, were the danger of thermal bridging has to be removed. The roof insulation needs to be connected to the wall insulation in order to form a continuous and effective thermal boundary.

8.3. Recommendations for Slabs

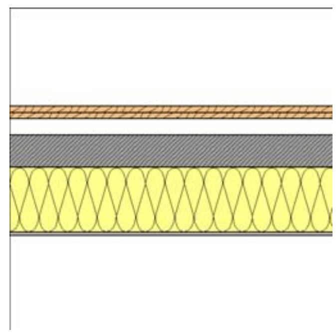


Figure 116 Exterior Slab Insulation Detail - Magnusstrasse - 200 mm

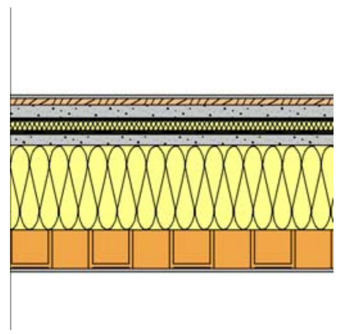


Figure 117 Interior Slab Insulation Detail - Villa Pobershau - 280 mm

The slabs of historic buildings can be upgraded using either interior or exterior insulation, the thickness of the insulation depending on the existence of height restrictions. Typically the slabs were constructed using a waste material filling for insulation purposes. This means there typically is room for application of thicker layers of insulation than in the case of non-historic buildings. If the insulation is applied to the underneath of the slab, it needs to be conducted along the basement walls in order to reduce the thermal bridging at the contact points between the slab and the walls. If the layer is on top of the slab it needs to be connected to the wall insulation and form a continuous barrier. The air tightness of the slab insulation also becomes an issue when applying it on the interior. The same measure of pouring an additional layer of screed on top is often applied. This not only forms an air barrier, but it also protects the insulation from damage.

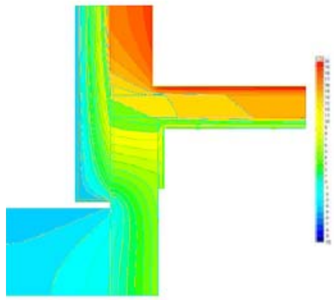


Figure 118 Minimizing thermal bridges when applying exterior insulation to slabs – The insulation is carried down along the wall – Tevesstrasse (Kaufmann, et al., 2009)

The average thickness of the slab insulation used in historic buildings is higher than for newer constructions. **160 mm** were used for projects dating before 1919 and **136 mm** were used for projects from 1919-1970. The materials used range from **PU-Foam to Mineral Wool and EPS**. The 55% correlation observed between insulation material thicknesses and energy consumption indicates the fact that the slab insulation is compensating for the lack of wall insulation. The insulation thickness should therefore be as high as possible in order to obtain a low U-value. The use of materials with a lower thermal conductivity index, such as PU-Foam (0.025 W/mK can reduce the necessary size of the layer.

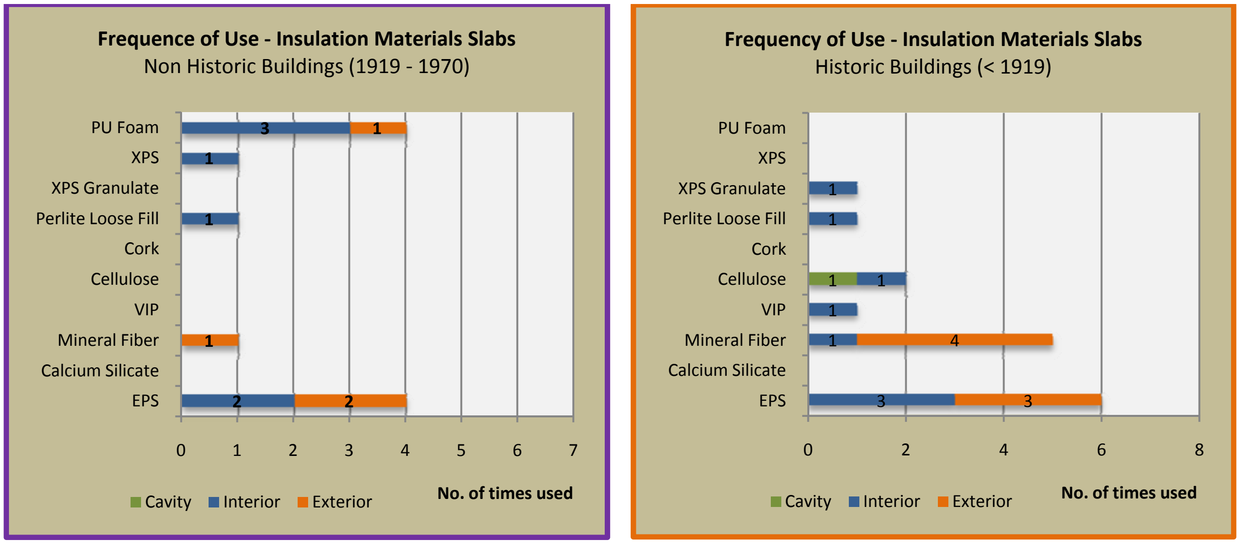


Figure 119 + 120 Frequency of use for Roof Insulation Materials (Non Historic Buildings and Historic Buildings)

8.4. Recommendations for Windows

Passive House recommended windows typically have PVC insulated frames and triple low-E glazing. The recommended U-Value for these "ideal" window assemblies is **0.8 W/m2K** and is based on the best performing This category of glazing achieves performances of about **0.6 SHGC** and U-values of around **0.6 W/m2K**, such as the Guardian Climaguard N3 glazing. The visible light transmission value is approximately 70% and the gas filling is Argon or Krypton, depending on the precise specifications.

The historic buildings nevertheless don't always allow for the use of the most efficient glazing and framing, due to preservation constraints. I have identified two different kind of situations, each with two different solutions:

I. **The original windows can be replaced** – they are replaced with:

   a. *Wood framed windows with double or triple glazing* – these types of windows need to respect the historic appearance of the original windows. The performance of the assembly is compromised by the wooden frames. Thermal bridging is a problem with these types of windows.

   b. *PVC insulated framed windows with triple glazing* – these windows are the "best case" scenario, since they are recommended for passive house new construction. The energy efficiency of these assemblies is very high.

II. **The original windows cannot be replaced** – following measures can be undertaken:

a. *The addition of a second layer of windows on the interior* – this option shows good performance characteristics, as long as the window frames are air tight. The secondary glazing is typically a type of double glazing. If air tightness is achieved, the U-Values of the assembly can be lower than the ones for the Passive House windows. This is the case for the Villa Pobershau, where the assembly U-Value of the windows is 0.56 and the infiltration rate 0.53. The disadvantage of this solution is the high thickness of the windows and the difficulties in operating two different windows.

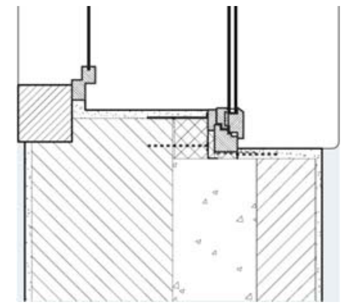


Figure 121 Window Detail - Villa Pobershau -2 layers of windows (the original to the left and the double glazed addition to the right, to the interior) (ENBAUSA)

b. *The addition of a low-E coating on the original single glazing* – this solution is the least desirable because of the poor insulating performance of the single glazed windows. It should only be applied, if there are serious interior preservation constraints which prevent the addition of a secondary window layer. The case of the Feihof in Sulz with a U-Value of 2.06 W/m2K shows this.

8.5. Recommendations for Air Tightness

The average air tightness of the historic cases analyzed is more than two times lower than that of the corresponding non historic cases. This state can be attributed in my opinion primarily to the poorer performance of the glazing and doors. The strict air tightness requirements for interior insulation mean that high standards of design and execution need to be applied in order to avoid building component damage or health hazards through mould. In the ideal case, the air tightness values should be lower than the Passive House Standard of 0.6 ACH at n50.

Experience from the analysis shows that historic buildings which benefited from more extensive interventions, including the removal of any connections between the interior structural and partition elements and the thermal envelope were able to achieve infiltration rates below 0.6 ACH. This was the case for the Villa Pobershau or the Rowhouse Henz-Noirfalise. Other buildings, with less significant interventions had higher infiltration rates. Furthermore, the non historic buildings retrofits studied in this paper were almost all pilot projets and benefited from extensive consultancy from building physicists. This leads to the conclusion that a Passive House standard for infiltration can be achieved through careful planning and on site supervision.

The low infiltration rates registered for both historic and non historic constructions are essential in achieving a high level of thermal performance. This air tightness of the envelope leads to the necessity of installing mechanical ventilation equipment with heat recovery. Heat recovery rates for this equipment is between 75 and 90%.

8.6. Special Recommendations for Thermal Envelope Integrity

The integrity of the thermal envelope is essential, especially around interior constructive elements which penetrate the internal insulation layer. An external layer of insulation would not give rise to such issues, but installing interior insulation can lead to problems related to moisture migration. In the case of historic buildings an area of particular concern is the wooden beam ends which are encased within the wall. If convection occurs around that area, moisture has the potential of penetrating the wall and can cause the wood to rot within. This can lead to significant structural problems. In addition to this, beam ends are significant areas of thermal bridging which leads to an even lower temperature around them.

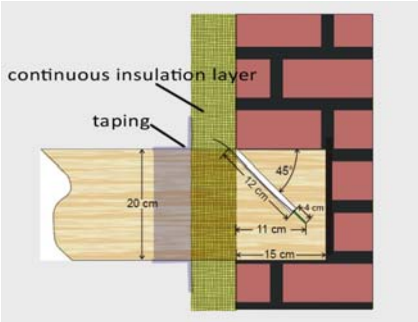


Figure 122 Beam end within the masonry wall - a measuring probe was inserted to measure moisture levels - Lehrstrasse 2 Wiesbaden (Loga, et al., 2003)

The design team which carried out the retrofit of the Lehrstrasse 2 project in Wiesbaden conducted the monitoring of the beam ends within the walls and found no significant moisture related issues. The moisture within the bulk heads was lower after retrofit, with signs of decreasing over time. The monitoring was conducted over the course of two seasons. (Loga, et al., 2003)

Figure 123 Installation of insulation between beams - Lehrstrasse 2 Wiesbaden (Loga, et al., 2003)

A prerequisite for the good moisture performance of the bulk heads is the application of one of several methods (if interior insulation is applied – there are no issues in the case of external insulation):

a. *The complete insulation of the wall around the beams and taping of gaps between the insulation and the beams.* – This measure has proven to be very effective in the documented Wiesbaden case. It requires special care and attention in the construction stage.

b. *The severing of the connection to the external wall.* – In this case the beams can be fitted with a steel connection which will connect them to the orginal load bearing wall (the original wall holds the load) such as in the case of the Kleine Freiheit project in Hamburg. Another option requires a secondary supporting structure within the thermal envelope to support the beams (Villa Pobershau and Rowhouse Henz-Noirfalise).

Figure 124 Beam ends are disconnected from the wall – beams are held in place by steel beams inside the wall – insulation layer is continuous and thermal bridges area almost eliminated – Kleine Freiheit Hamburg (Forschungszentrum Julich,

8.7. Construction Costs

The construction costs for both types of renovations are similar in magnitude. The suggested values as a result of the case study analysis are 1,247 €/m2 ($ 1,622) for historic buildings and 1,178 €/m2 ($1,531) for non historic retrofits. The difference of 5.5% between the two values indicates that retrofitting historic buildings is slightly more expensive than retrofitting newer constructions. The difference is not as high as might have been expected due, in my opinion to the lower quantities of insulation materials used. Even if the historic retrofits require more specialized labor during the construction process, the increase in cost seems to be partially offset by lower material costs.

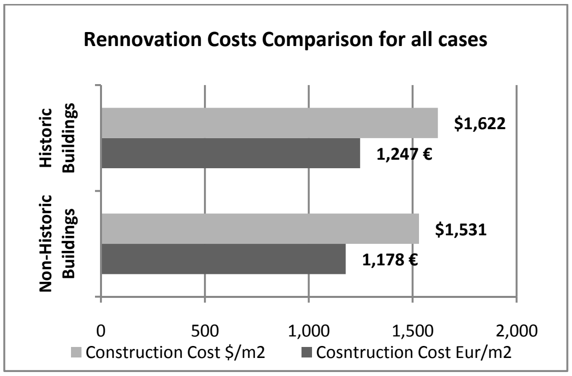


Figure 125 Renovation costs comparison for all cases

The data is based on information from 5 non historic and 6 historic buildings with ranges of 972 – 1,350 €/m2 in the first case and 951 – 1,611 €/m2 in the second case. Even with the limited cost information the values are enough to give a representation of the order of magnitude of the costs involved in retrofitting existing buildings.

9. Environmental Impact of Retrofitting Existing Buildings at a European Scale

In order to assess the environmental impact of the analyzed building retrofit projects at the Central and Northern European scale the results are extrapolated to the entire building stock of the same age group. When applying the findings and average energy reductions to the existing building stock significant improvements could be observed. In order to simplify the results, it is assumed, that all buildings of the same age group as the case studies have not been retrofitted. The results thus indicate the potential energy and emissions reductions in the case of upgrading existing buildings from a non-retrofitted to a retrofitted state. Both historic and non historic buildings have been included in this analysis.

9.1. Energy Consumption Reduction

The energy consumption reductions vary according to the size of the building stocks in the respective countries. The United Kingdom, Germany and France have the largest number of buildings and thus have the largest reductions in energy consumption by volume. The values also vary depending on the size of the building stock for the respective age group.

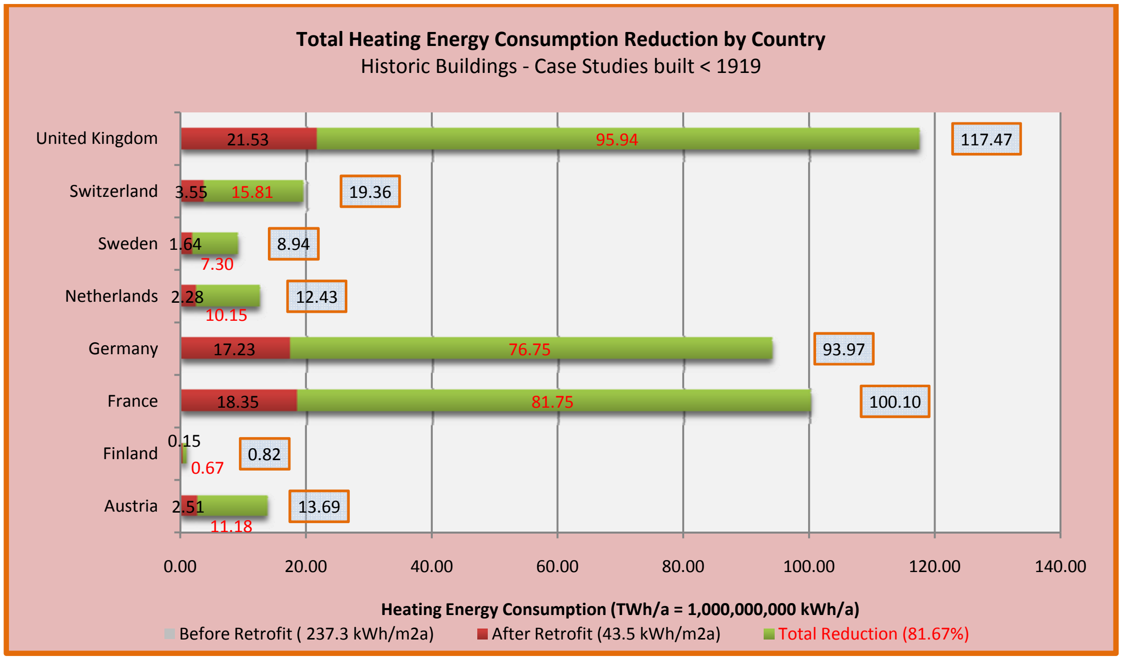


Figure 126 Total Heating Energy Consumption Reduction by Country (< 1919)

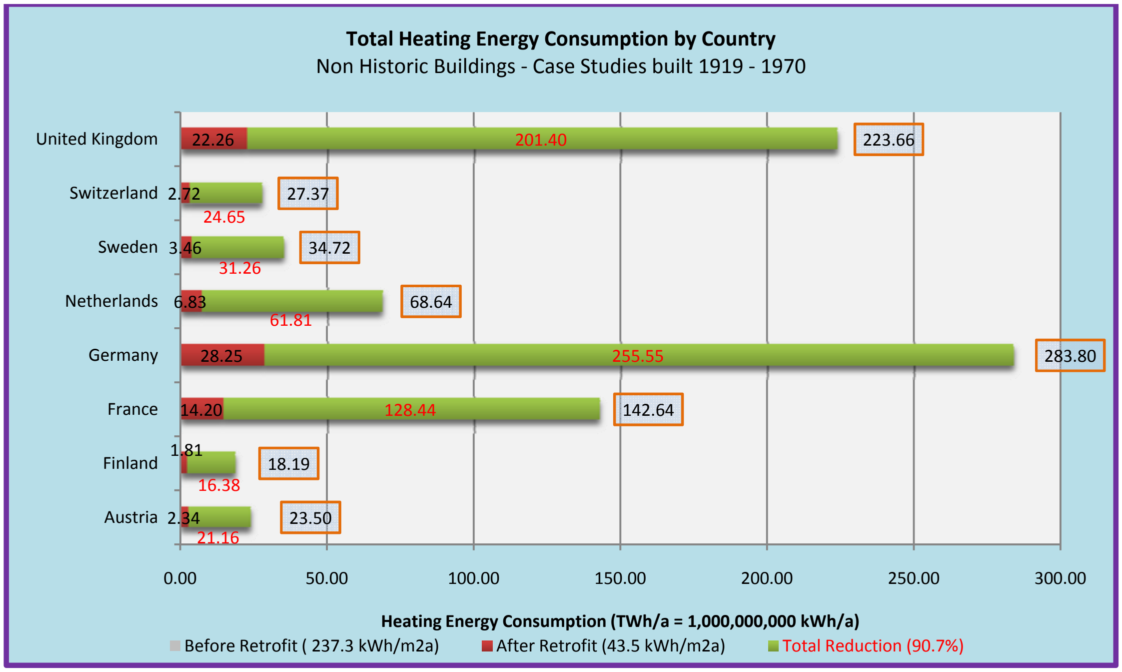


Figure 127 Total Heating Energy Consumption Reduction by Country (1919-1970)

The total energy consumption reduction due to reductions in heating energy consumption following potential rennovations across Central and Northern Europe amount to **1,040 TWh** per year. This is approximately 42 % of the total energy use of the total Residential Building Stock in Central and Northern Europe and **12 % of the total energy consumption** in the same region.

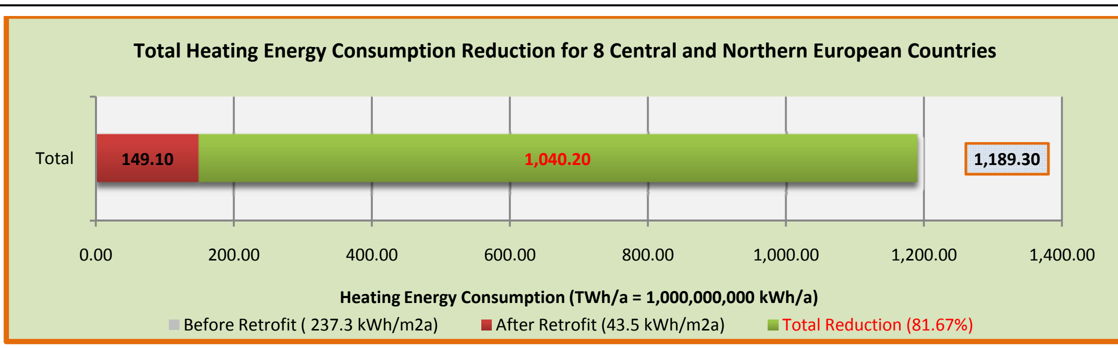


Figure 128 Total Heating Energy Consumption Reduction for 8 Countries analyzed

9.2. CO2 Emissions Reduction

In order to assess the impact of historic and non historic building retrofits on the entire building stock in terms of CO2 emissions reductions, the cases of Germany and France were analyzed. Data from Eurostat, the European Statistics agency, together with information about the building stock contained in the Itard report (2008) was used to compile the CO2 reductions diagrams.

Although the buildings stocks for the construction period before 1970 in Germany and France are similar in size (approximately 20,000 units) the emissions impact of potential retrofit measures is different. Fewer reductions in CO2 emissions can be expected in the case of France. This view is nevertheless misleading, because France has a high percentage of buildings using electric heating, but very low emissions due to electricity production. The average CO2 emissions from power generation in France are 30 % of those in Germany (190g of CO2/kWh compared to 600 g of CO2/kWh). This difference is clarified by the fuel mixture used for power generation. France has 76.3 % of its electricity coming from nuclear sources, while Germany only 38.5 %. Furthermore, the use of coal fired power plants is much more wide spread in Germany than in France. Nuclear power generation has its own sets of environmental problems which should also be taken into account.

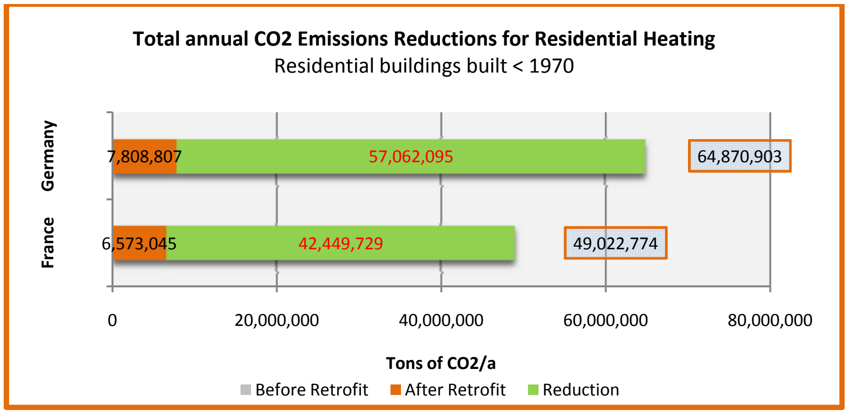


Figure 129 Total Annual Emissions Reductions for Residential Heating (Residential Buildings built before 1970)

Carbon credits are a relatively new form of putting a value on emissions reductions. The market for carbon credits has been growing in recent years, with the peak being achieved in 2008, when the average price of a ton of CO2 in form of a carbon credit was $ 24.5. Due to the economic crisis, the average price in 2009 was $ 16.6. Nevertheless the market for carbon credits is expected to grow and demand will most likely drive prices further up (Kossoy, et al., 2010).

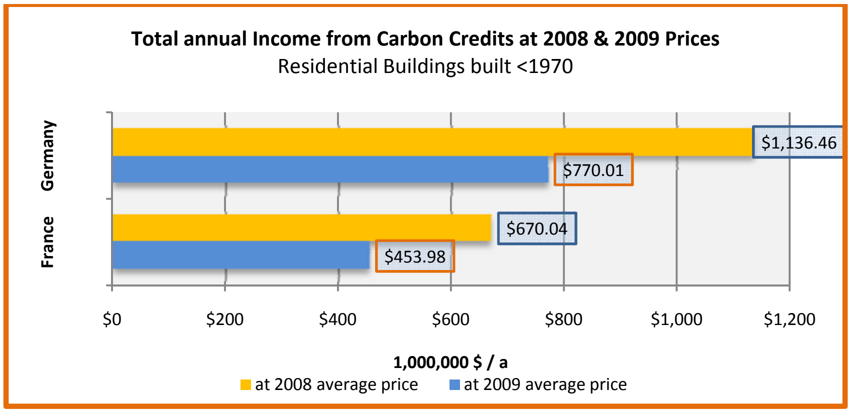


Figure 130 Total Annual Potential Income from Carbon Credits (Residential Buildings built before 1970)

In the light of the potentially large CO2 emissions reductions due to building renovation, carbon credits could be sold to account for these reductions. A framework of registering reduction on a case by case basis should be put in place to take advantage of this opportunity. The emissions reductions due to building use could be sold as carbon credits on the open market, thus providing a constant, annual flow of income for the building owners. At the scale of Germany these reductions could sum up to 1.13 billion dollars and in the case of France, to 670 million dollars per year.

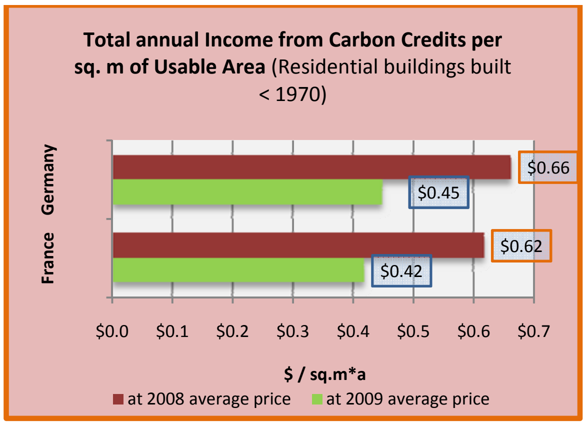


Figure 132 Total Annual Income from Carbon Credits per m^2 of Usable Area (Residential Buildings built < 1970)

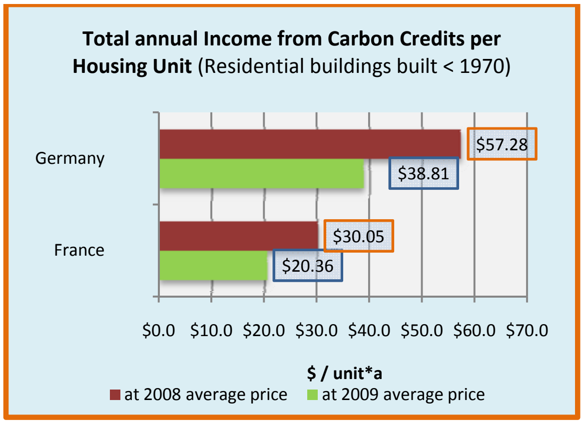


Figure 131 Total Annual Income from Carbon Credits per Housing Unit (Residential Buildings built < 1970)

On a case by case basis, the impact is less significant, but can provide a useful income which could be used towards covering the energy bill of the buildings. The values would be around $ 0.6 /m2a in the best case scenario. If prices for carbon credits increase this value should also increase. On a per unit bases anywhere between $ 30 and 40 could be expected at the credit price levels of 2008.

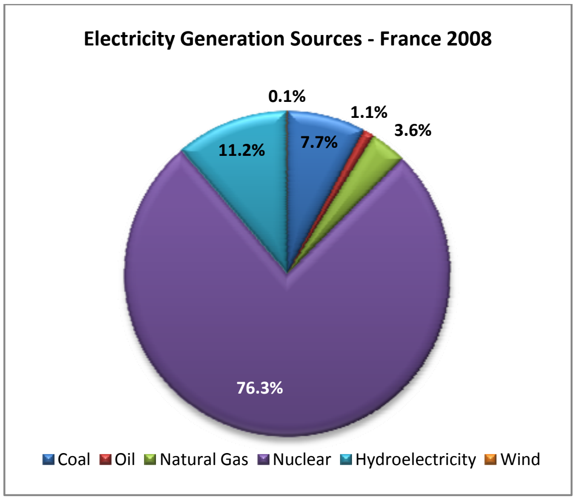


Figure 134 Sources of Electricity Generation – France

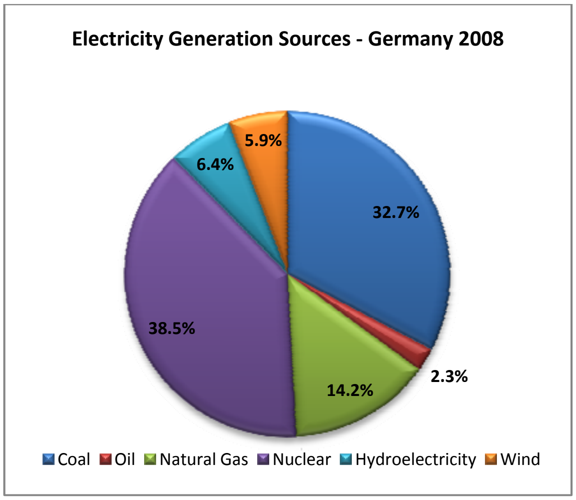


Figure 133 Sources of Electricity Generation – Germany

10. Conclusions

A thorough analysis of 22 buildings across several Central European Countries served as the basis for the present thesis. The initial assumption was, that historic masonry buildings could be retrofitted to a higher standard than current European regulations and that such improvement could reach the Passive House standard of low energy consumption. As a benchmark for current standards, the German ENEV 2009 standard for new construction and renovation was used in conjunction with the Passive House Standard and the ASHRAE 189.1-2009 standard. The strict nature of the German building code made it suitable for a best practice analysis.

Following the results of the case analysis, it has become clear that historic buildings can in fact be retrofitted in order to achieve similarly high levels of energy consumption as non historic buildings. The average consumption value indicated in the case of historic buildings is two times higher than for buildings built between 1919 and 1970, but individual cases were able to have comparable results. As expected, similar levels of insulation were used for those projects, as was used for non historic constructions.

The biggest issue when retrofitting historic buildings consists of the historically significant facades, which need to be insulated from the inside. Interior insulation can cause significant moisture related problems and needs a careful design and execution process in order to be applied efficiently. Another limiting factor in the application of sufficiently thick layers of insulation on the interior of the walls is the presence of thermal bridges at connection points between interior building elements and the thermal envelope (the exterior wall). Although such thermal bridges can be minimized as a result of the effort to reduce the danger of condensation, they still contribute significantly to a lowering of the performance of the wall assembly. It has been found that if more than 100 mm of interior insulation is applied, the thermal bridging effect cancels out some of the benefits, making the investment in additional insulation not profitable. This assumption was confirmed by the Villa Pobershau and the Rowhouse Henz-Noirfalise projects, where the partition walls and slabs were totally disconnected from the exterior wall in order to allow for a continuous thermal insulation layer. These buildings showed the best results, achieving heating energy consumption values comparable to a Passive House new construction.

The opportunity of retrofitting existing buildings can also be used to justify the sale of carbon credits. The reductions in CO_2 emissions prompted by the renovation measures are significant and can provide a continuous flow of income on an annual basis. Given current trends this income is very likely to rise over the coming years.

The best case analysis carried out in this paper has proven beyond doubt the effectiveness of building renovation and retrofit measures. It has shown that even historic buildings can achieve energetic performances comparable to standard of new construction.

11. References

1. **ASHRAE** ASHRAE Standard 189.1-2009 - Standard for the Design of High-Performance Green Buildings [Book]. - [s.l.] : ASHRAE, 2009.
2. **Belgian Science Policy** RIJWONING EUPEN [Online] // LEHR - Low Energy Housing Retrofit. - Belgian Science Policy. - 07 30, 2010. - http://lehr.be/P-Eupen/NL-EUPEN_LEHR.pdf.
3. **Bergmeister Konrad [et al.]** Überblick von Komponenten und Systemen für eine Sanierung auf Passivhausstandard des Türkenwirtes [Report]. - Vienna : Austrian Energy Agency, 2008.
4. **Bergmeister Konrad, Ertl Ulla and Grunner Roman** Uberblick von Komponenten und Systemen fur eine Sanierung auf Passihausstandard des Turkenwirtes [Report]. - Viena : Austrian Energy Agency, 2008.
5. **CCEM** Sustainable Renovation of Historical Buildings [Online] // www.ccem.ch. - Competence Center Energy and Mobility, 2008. - 07 21, 2010. - http://www.ccem.ch/MediaBoard/SuRHiB_webupdate.pdf.
6. **Darup Burkhard Schulze** Energetisch Gebaudesanierung mit Faktor 10 [Report]. - [s.l.] : Deutsche Bundesstiftung Umwelt.
7. **Darup Burkhard Schulze** Energetische Wohngebäudesanierung mit Faktor 10 - Analyse von Passivhaus-Konzepten und deren Anwendung auf die Sanierung. - Hannover : Unversitat Hannover, 2003.
8. **Darup Burkhard Schulze** Jean-Paul-Platz 4 in Nürnberg - energetische Gebäudesanierung mit Faktor 10 [Report]. - Nürnberg : Dr. Burkhard Schulze Darup, 2005.
9. **Eicker Ursula, Seeberger Peter and Fischer Heiko** Evaluierung eines im Passivhaus-Standard sanierten Bürogebäudes hinsichtlich des energetischen und raumklimatischen Verhaltens [Report]. - Stuttgart : Ingenieurbüro ebök, 2007.
10. **ENBAUSA** Energetische Vollsanierung im Denkmalschutz [Online] // ENBAUSA - Energetisch Bauen und Sanieren. - ENBAUSA. - 07 30, 2010. - http://www.enbausa.de/projekte/denkmalschutz/vollsanierung-denkmalschutz.html.
11. **Erhorn Hans [et al.]** Energetische Potentiale im Gebaudebestand [Online] // FVEE Themen 2009. - Forschungsverbund Erneuerbare Energien, 2009. - http://www.fvee.de/publikationen/publikation/download/themen-2009-forschen-fuer-globale-maerkte-erneuerbarer-energien/. - 07 21, 2010.
12. **EU Business** EU Business [Online]. - EU Business, 07 2010. - 07 21, 2010. - http://www.eubusiness.com/topics/tourism.

13. **Eurostat** Statistics [Online] // Eurostat. - European Commission, 2008. - 07 31, 2010. - http://epp.eurostat.ec.europa.eu/portal/page/portal/energy/data/main_tables.
14. **Feist Wolfgang** Protokolband 32: Faktor 4 auch bei sensiblen Altbauten: Passivhauskomponenten + Innendämmung: Zusammenfassung [Online] // Passiv Haus Institut. - 2005. - 07 22, 2010. - http://www.passiv.de/04_pub/Literatur/ProtokB/Phase_III/2004-2005/AK32/Inh_AK32/01-WF_F.htm.
15. **Feist Wolfgang, Peper Soren and Gorg Manfred** CEPHEUS-Projectinformation No. 36 - Final Technical Report [Report]. - Hannover : Enercity / Stadtewerke Hannover, 2001.
16. **Flumroc** Bauerneuerung für die Zukunft [Report]. - Flums : Flumroc AG, 2007.
17. **Forschungszentrum Julich** Abschlussbericht, Hamburg Kleine Freiheit 46-52 [Report]. - Hamburg : Ensan, 2008.
18. **Grossklos Marc [et al.]** Sanierung von drei kleinen Wohgebauden in Hofheim [Report]. - Darmstadt : Institut Wohnen und Umwelt, 2008.
19. **Itard Laure and Meijer Frits** Towards a Sustainable Northern European Housing Stock [Report]. - Delft : Delft Centre for Sustainable Urban Areas - Delft University Press, 2008.
20. **Kaufmann Berthold [et al.]** Planungsbegleitende Beratung und Qualitatssicherung Tevesstrasse Frankfurt a.M. [Report]. - Darmstadt : Passivhaus Institut, 2009.
21. **Kaufmann Berthold [et al.]** Sanierung mit Passivhauskomponenten - Planungsbegleitende Beratung und Qualitatssicherung Tevesstrasse Frankfurt a.M. [Report]. - Darmstadt : PassivHaus Institut, 2009.
22. **Kossoy Alexandre and Ambrosi Philippe** State and Trends of the Carbon Market 2010 [Report]. - Washington DC : The World Bank - Environment Department, 2010.
23. **Kunzel Hartwig M** Effect of Interior and Exterior Insulation on the Hygrothermal behaviour o exposed walls [Journal]. - [s.l.] : Materials and Structures, 1998. - March : Vol. 31.
24. **Kunzel Hartwig M.** Energetische Altbausanierung durch Innendaemmung [Article] // WTA-Journal 2. - 2004. - 2 : Vols. 4. 361-374. - pp. 361 - 374.
25. **Lober H and Bolsius J** Energetische Verbesserung der Bausubstanz, Teilkonzept 3: Sanierung von Wohngebäuden aus der Gründerzeit am Beispiel der Bautzner Straße 11 in Zittau [Report]. - [s.l.] : Ensan, 2006.
26. **Loga Tobias [et al.]** Wiesbaden - Lehrstrasse 2 - Energetische Modernisierung eines Grunderzeithauses [Report]. - Darmstadt : Institut Wohnen und Umwelt GMBH, 2003.
27. **Peper Soren and Feist Wolfgang** Gebäudesanierung „Passivhaus im Bestand“ in Ludwigshafen / Mundenheim [Report]. - Darmstadt : PassivHaus Institut, 2008.
28. **Peper Soren, Grove-Smith Jessica and Feist Wolfgang** Sanierung mit Passivhauskomponenten - Messtechnische Untersuchung und Auswertung Tevesstrasse Frankfurt a.M. [Report]. - Darmstadt : PassivHaus Institut, 2009.
29. **Pfluger Rainer [et al.]** Sanierung mit Passivhauskomponenten - Untersuchungen zu den Bestandsgebauden Tevesstrasse Frankfurt a.M. [Report]. - Darmstadt : PassivHaus Institut, 2009.
30. **Prehal Andreas and Poppe Helmut** ZSG - Zukunftsfähige Konzepte in der Stadt- und Gebäudesanierung – Trollmannkaserne Steyr [Report]. - Vienna : Bundesministerium für Verkehr, Innovation und Technologie, 2004.

31. **Reuther Stefan and Weber Christian** Energetische Modernisierung von Wohngebauden - Eine Chance fur Veranderung [Report]. - Darmstadt : Institut Wohnen und Umwelt, 2008.
32. **Schmidt Michael [et al.]** Entwicklung eines Konzepts für energetische Modernisierungen kleiner Wohngebäude auf 3-Liter-Haus-Niveau in Mannheim-Gartenstadt [Report]. - Stuttgart : Institut für GebäudeEnergetik, 2007.
33. **Schnieders Jurgen and Hermelink Andreas** CEPHEUS results: measurement and occupants satisfaction provide evidence for Passive Houses being an option for sustainable building [Journal] // Energy Policy 34. - 2006. - pp. 151-171.
34. **Schnieders Jurgen** CEPHEUS – measurement results from more than 100 dwelling units in passive houses [Journal] // ECEE Summer Study - Time to Turn Down Energy Demand. - 2003. - pp. 341-351.
35. **Sonderegger Andrea [et al.]** Sanierung ökologischer Freihof Sulz [Report]. - Vienna : Bundesministerium für Verkehr, Innovation und Technologie, 2007.
36. **Straube John and Schumacher Chris** Interior Insulation of Load-Bearing Masonry Walls in Cold Climates [Article] // Journal of Green Building. - 2007. - 2 : Vols. 2. 42-56.
37. **Tuschinski Melita** Energieausweis + ENEV 2009 Energieeinsparverordnung [Report]. - Stuttgart : Institut fur Energie-Effiziente Architektur mit Internet-Medien, 2010.
38. **Viriden Karl [et al.]** P+D – Projekt Passivhaus im Umbau - Magnusstrasse 23 [Report]. - [s.l.] : Bundesamts für Energie BFE, 2003.
39. **Viriden Karl [et al.]** P+D – Projekt Umbau Nietengasse 20 mit bestehender Sichtbacksteinfassade [Report]. - Zurich : Bundesamt für Energie, 2004.
40. **Vogelsang Jorg** Sodastrasse 40 - Neue Wege mit Innendaemmung in historischer Bausubstanz [Conference] // Zukunft Haus 2005 - Strategien fur Energieeffizienz. - Berlin : [s.n.], 2005.
41. **Zelger Thomas [et al.]** Passivhaus-Sanierungsbauteilkatalog - Auswertung gebäudesanierungsbezogener HdZForschungsberichte mit konstruktiven, bauphysikalischen und bauökologischen Ergänzungen [Report]. - Vienna : Bundesministerium für Verkehr, Innovation und Technologie, 2009.

12. Appendices

Appendix 1 – 3 Liter Haus Mannheim_Case Matrix

Appendix 2 – Apartment House in Linz_Case Matrix

Appendix 3 – Jean Paul Platz_Case Matrix

Appendix 4 – Ludwigshafen Mundheim PhiB_Case Matrix

Appendix 5 – Office Building Tuebingen_Case Matrix

Appendix 6 – Tevesstrasse_Block 1_Case Matrix

Appendix 7 – Tevesstrasse_Block 2_Case Matrix

Appendix 8 – Wilhelmstrasse Hofheim_Case Matrix

Appendix 9 – Bautznerstrasse 11 Zittau_Case Matrix

Appendix 10 – Fabrikstrasse 9 Steyr_Case Matrix

Appendix 11 – Freihof Sulz_Case Matrix

Appendix 12 – Kleine Freiheit_EnSan_Case Matrix

Appendix 13 – Lehrstrasse 2 Wiesbaden_Case Matrix

Appendix 14 – Limburgstrasse Ludwigshafen_Case Matrix

Appendix 15 – Magnusstrasse 23 Zuerich_Case Matrix

Appendix 16 – Mathildenstrasse 48 Fuerth_Case Matrix

Appendix 17 – Nietengasse 20 Zuerich_Case Matrix

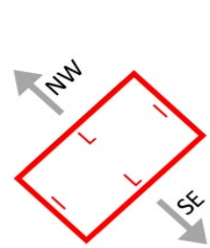
Appendix 18 – Rheinhauserstr 6 Mannheim_Case Matrix

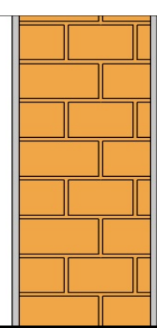
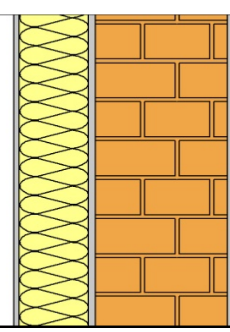
Appendix 19 – Rowhouse Henz Noirfalise_Case Matrix

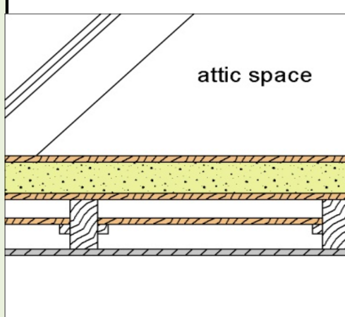
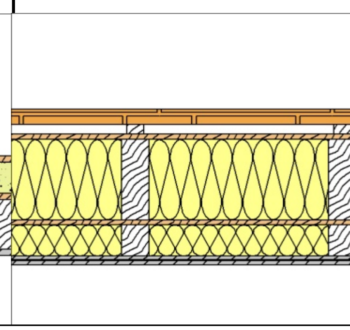
Appendix 20 – Sodastrasse 40 Ludwigshafen_Case Matrix

Appendix 21 – Villa Pobershau_Case Matrix

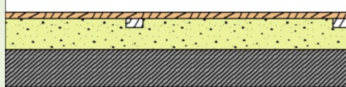
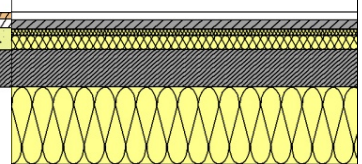
Appendix 22 – Wengistrasse 6 Zuerich_Case Matrix

Project Name:	3-Liter Haus Mannheim		
APPENDIX 1			
	before retrofit	**after retrofit**	**improvement %**
Location			
City	Mannheim		
State / Country	Baden-Wuerttemberg / Germany		
Address	Freyastrasse 42-52, 68305 Mannheim, Germany		
Location Type	suburb		
Climate			
Climate Zone	4		Ashrae 189.1 (09)
HDD (65 F)	**5,090**		(degreedays.net)
CDD (65 F)	**666**		(degreedays.net)
Notes			
Building Details			
Year of Construction	1931		
Year of Retrofit	2004		
Historic Preservation Status	none/		
Preservation Constraints Walls	none		
Preservation Constraints Roof	none		
Building Use	residential		
Building Type	detached		
L/l ratio (Length/Width)	7.8		
Orientation	NW-SE		
			
No. of Floors	2	2	
No. of Units	24	12	
Constructed Area (sq.m)	1,353	1,353	
Condition. Usable Area (sq.m)	1,150	1,150	**0.0%**
A/V ratio (cond. env. Area/V)	0.50	0.50	
Notes	the row of houses consists of 6 buildings refurbished at the same time		

	high cost of retrofit due to interior repartitioning				
Construction Costs					
Total Construction Costs (Euro)			2,645,000		
Cost (Euro/sq.m)			**2,300**		
Cost of Energy Retrofit (€/sq.m)			**600**		
Energy Consumption			middle / end		
Type of data	simulated	metered	units	metered	
Heating (kWh/sq.m*a)	**210**		**21.6 / 24.4**	**27.4**	
Heating (kBtu/sq.ft*a)	66.6		6.8 / 7.7	8.7	
Heating (kWh/sq.m*HDD)	0.0413			0.0054	**-87.0%**
Cooling (kWh/sq.m*a)					
Hot Water (kWh/sq.m*a)	12.5				
Ventilation (kWh/sq.m*a)					
Lighting (kWh/sq.m*a)					
Notes	energy consumption after - simulated for middle and end units average heating energy consumption - metered = **27.4** kWh/m2a				
Walls - Main Façade					
Insulation Type	**none**		**EPS (Neopor)**		
Insulation Location			exterior		
Insulation Thickness (mm)			200		
Insulation Conductivity (W/mK)			0.033		
Insulation U-Value (W/sq.mK)			0.165		
Insulation U-Value (Btu/hft2F)			0.029		
Assembly U-Value (W/sq.mK)	**1.280**		**0.150**		**-88.3%**
Assembly U-Value (Btu/hft2F)	0.225		0.026		
Main Layers (outside-inside)		mm		mm	
Layer 1			plaster	15	
Layer 2			EPS	200	
Layer 3	plaster	20	plaster	20	unchanged
Layer 4	solid brick	380	solid brick	380	
Layer 5	plaster	20	plaster	15	
Layer 6					
Layer 7					
Layer 8					
Total Thickness		420		630	
Construction Detail					
Notes					

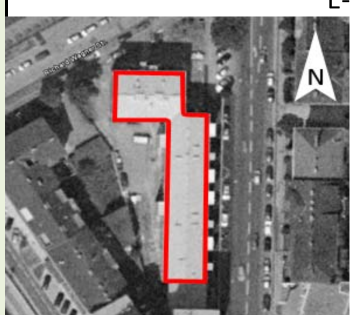
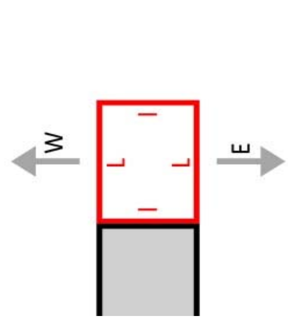
Roof					
Attic	unconditioned		conditioned		
Insulation Type	**none**		**EPS (Neopor)**		
Insulation Location			cavity		
Insulation Thickness (mm)			360		
Insulation Conductivity (W/mK)			0.033		
Insulation U-Value (W/sq.mK)			0.092		
Insulation U-Value (Btu/hft2F)			0.016		
Assembly U-Value (W/sq.mK)	**0.940**		**0.110**		**-88.3%**
Assembly U-Value (Btu/hft2F)	0.166		0.019		
Main Layers (top-bottom)		mm		mm	
Layer 1	solid wood floor	20	ceramic roof tiles		
Layer 2	sand fill	100	air layer / battens	30	
Layer 3	solid wood	20	OSB	16	
Layer 4	air layer / battens	60	EPS (Neopor)	260	
Layer 5	solid wood	20	OSB	15	
Layer 6	air layer / battens	80	EPS (Neopor)	100	
Layer 7	plasterboard	20	plasterb. + vap. bar.	12.5	
Layer 8			plasterboard	12.5	
Total Thickness		320		446	
Construction Detail					
Notes					

Floor / Slab					
Basement	unconditioned		unconditioned		
Insulation Type	**none**		**EPS (Neopor)**	**EPS**	
Insulation Location			exterior	interior	
Insulation Thickness (mm)			250	45	
Insulation Conductivity (W/mK)			0.033	0.04	
Insulation U-Value (W/sq.mK)			0.132	0.889	
Insulation U-Value (Btu/hft2F)			0.023	0.157	
Assembly U-Value (W/sq.mK)	**1.370**		**0.110**		**-92.0%**
Assembly U-Value (Btu/hft2F)	0.241		0.019		
Main Layers (top-bottom)		mm		mm	
Layer 1			flooring		
Layer 2			poured asphalt	30	
Layer 3	wood floor	20	protection plate	20	

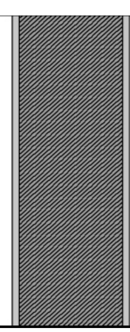
Layer 4	sand fill 100	EPS 45	
Layer 5	concrete 120	concrete 120	unchanged
Layer 6		EPS (Neopor) 250	
Layer 7			
Layer 8			
Total Thickness	240	465	
Construction Detail			
Notes			
Windows			
Glazing Type	double	triple	
Coating			
Gas filling			
Window Location		replacement	
Glazing U-Value (W/sq.mK)			
Glazing U-Value (Btu/hft2F)			
SHGC	0.80	0.60	
Assembly U-Value (W/sq.mK)	**2.6**	**0.8**	**-69.2%**
Assembly U-Value (Btu/hft2F)	0.458	0.141	
Frame Type	PVC	PVC insulated	
Infiltration Rate (ACH at 50 P)	4.2	1.2	
Notes	infiltration rate is high through partition walls between houses no cold air gets in through those walls		
Mechanical Systems			
Ventilation	natural	HRV	
Type		individual units	
Efficiency		70%	
Ventilation Rate (ACH)		0.4	
Heating	individual units	mini cogeneration plant	
Type of Fuel	coal, oil, gas	gas	
Capacity (kW)		6	
Efficiency			
Distribution System		water	
Distribution Media		air + water	
Terminal Units		air + radiators	
Cooling	no	yes (only 2 houses)	
Type of Fuel		geothermal	
Efficiency			

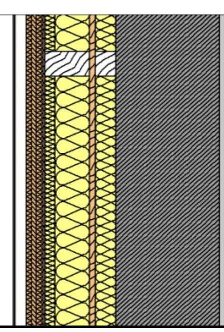
Hot Water	individual units - boilers		
Type of Fuel	electric		
Efficiency			
Storage Tanks		backup	
Capacity (liters)			
Use		heating	
Solar Thermal Collectors	no	no	
Area (sq.m)			
Capacity (kW)			
Use			
Photovoltaics	no	no	
Area (sq.m)			
Power (kW)			
Generat. Energy (kW/sq.m*a)			
Notes			

Contact Details	
Architect / Studio	
Tel	
e-mail	
Energy Consultant	
Tel	
e-mail	
Mechanical Engineer	
Tel	
e-mail	

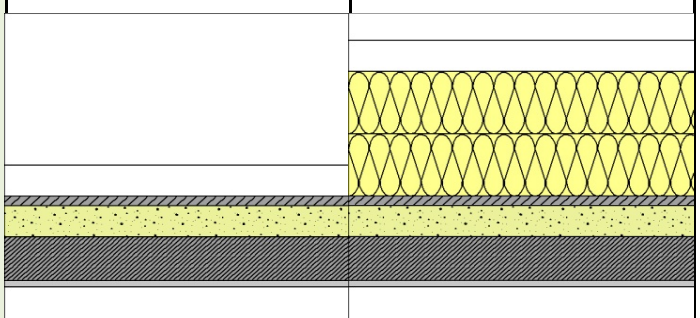
Project Name:	Apartment House in Linz		
APPENDIX 2			
	before retrofit	**after retrofit**	**improvement %**
Location			
City	Linz		
State / Country	Austria		
Address	Makartstraße 30-34, Linz, Austria		
Location Type	inner city		
Climate			
Climate Zone	5		Ashrae 189.1 (09)
HDD (65 F)	**6,271**		(degreedays.net)
CDD (65 F)	**450**		(degreedays.net)
Notes			
Building Details			
Year of Construction	1957		
Year of Retrofit	after 2000		
Historic Preservation Status	none		
Preservation Constraints Walls	none		
Preservation Constraints Roof	none		
Building Use	residential		
Building Type	attached 1 side		
L/l ratio (Length/Width)			
Orientation	E-W		
			
No. of Floors	5	5	
No. of Units	50	50	
Constructed Area (sq.m)			
Condition. Usable Area (sq.m)	2,755	3,106	**12.7%**
A/V ratio (cond. env. Area/V)			
Notes	after renovation - stair cases were included in heated area		

Construction Costs					
Total Construction Costs (Euro)			2,404,044		
Cost (Euro/sq.m)			**774**		
Cost of Energy Retrofit (€/sq.m)					
Energy Consumption					
Type of data	simulated	metered	simulated	metered	
Heating (kWh/sq.m*a)	**179**		**14.4**		
Heating (kBtu/sq.ft*a)	56.7		4.6		
Heating (kWh/sq.m*HDD)	0.0285		0.0023		**-92.0%**
Cooling (kWh/sq.m*a)					
Hot Water (kWh/sq.m*a)					
Ventilation (kWh/sq.m*a)					
Lighting (kWh/sq.m*a)					
Notes	no cooling needed in this climate				
Walls					
Insulation Type	**none**		**Mineral Wool + honeycomb**		
Insulation Location			exterior		
Insulation Thickness (mm)			190		
Insulation Conductivity (W/mK)			0.04		
Insulation U-Value (W/sq.mK)			0.211		
Insulation U-Value (Btu/hft2F)			0.037		
Assembly U-Value (W/sq.mK)	**1.200**		**0.082**	0.152	**-93.2%**
Assembly U-Value (Btu/hft2F)	0.211		0.014		
Main Layers (outside-inside)		mm		mm	
Layer 1	plaster	20	plaster	10	unchanged
Layer 2	prefab. concrete	300	prefab. concrete	300	
Layer 3	plaster	20	mineral wool	60	
Layer 4			OSB	16	
Layer 5			min. wool (100+30)	130	
Layer 6			honey comb	50	
Layer 7			air layer	31	
Layer 8			glas	5	
Total Thickness		340		602	
Construction Detail					
Notes	cellulose honey comb structure traps heat in the wall ("Gap-Solar") **U-Value for wall = 0.082 if the trapped heat is accounted for** U-Value for wall = 0.152 for the static calculation				

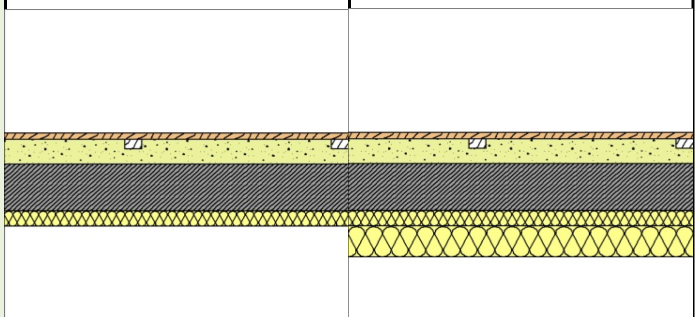




Roof					
Attic	none		none		
Insulation Type	**none**		**Mineral Wool**		
Insulation Location			exterior		
Insulation Thickness (mm)			400		
Insulation Conductivity (W/mK)			0.04		
Insulation U-Value (W/sq.mK)			0.100		
Insulation U-Value (Btu/hft2F)			0.018		
Assembly U-Value (W/sq.mK)	**0.900**		**0.093**		**-89.7%**
Assembly U-Value (Btu/hft2F)	0.159		0.016		
Main Layers (top-bottom)		mm		mm	
Layer 1			roofing layers		
Layer 2	roofing layers		Mineral Wool	400	
Layer 3	cement screed	30	cement screed	30	unchanged
Layer 4	slag fill	100	slag fill	100	
Layer 5	concrete slab	140	concrete slab	140	
Layer 6	plaster	20	plaster	20	
Layer 7					
Layer 8					
Total Thickness		290		690	
Construction Detail					
Notes					

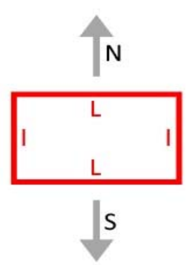


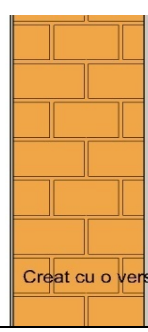
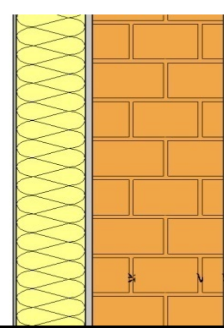
Floor / Slab					
Basement	unconditioned		unconditioned		
Insulation Type	**porous concrete (Porit)**		**porous concrete**	**min. wool**	
Insulation Location	exterior		exterior	exterior	
Insulation Thickness (mm)	50		50	100	
Insulation Conductivity (W/mK)	0.04		0.04	0.035	
Insulation U-Value (W/sq.mK)	0.800		0.800	0.350	
Insulation U-Value (Btu/hft2F)	0.141		0.141	0.062	
Assembly U-Value (W/sq.mK)	**0.700**		**0.205**		**-70.7%**
Assembly U-Value (Btu/hft2F)	0.123		0.036		
Main Layers (top-bottom)		mm		mm	
Layer 1	wood floor	20	wood floor	20	unchanged
Layer 2	slag fill	80	slag fill	80	
Layer 3	concrete slab	150	concrete slab	150	

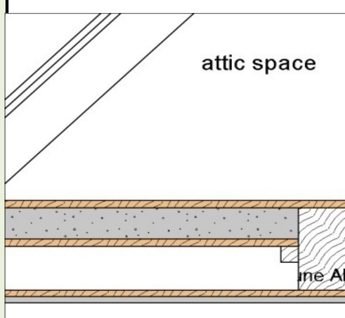
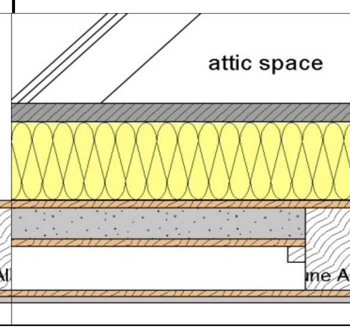
Layer 4	porous concrete plate 50	porous concrete plate 50	
Layer 5		mineral wool 100	
Layer 6			
Layer 7			
Layer 8			
Total Thickness	300	400	
Construction Detail			
Notes	porous concrete plate "Porit"		
Windows			
Glazing Type	double	triple	
Coating			
Gas filling			
Window Location		replacement	
Glazing U-Value (W/sq.mK)			
Glazing U-Value (Btu/hft2F)			
SHGC			
Assembly U-Value (W/sq.mK)	**3.00**	**0.86**	**-71.3%**
Assembly U-Value (Btu/hft2F)	0.528	0.151	
Frame Type	PVC	PVC insulated	
Infiltration Rate (ACH at 50 P)		0.6	
Notes	integrated blinds inside the glazing, btw panes		
Mechanical Systems			
Ventilation	natural	HRV	
Type		individual rooms	
Efficiency		70%	
Ventilation Rate (ACH)			
Heating	individual units		
Type of Fuel	district heating	district heating	
Capacity (kW)			
Efficiency			
Distribution System			
Distribution Media	water		
Terminal Units	radiators		
Cooling	no	no	
Type of Fuel			
Efficiency			

Hot Water			
Type of Fuel		district heating	
Efficiency			
Storage Tanks			
Capacity (liters)			
Use	heating/hot water	heating/hot water	
Solar Thermal Collectors	no	no	
Area (sq.m)			
Capacity (kW)			
Use			
Photovoltaics	no	no	
Area (sq.m)			
Power (kW)			
Generat. Energy (kW/sq.m*a)			
Notes			

Contact Details	
Architect / Studio	**Arch. DI Ingrid Domenig-Meisinger / ARCH+MORE ZT GmbH**
Tel	
e-mail	domenig@arch-more.com
Energy Consultant	
Tel	
e-mail	
Mechanical Engineer	
Tel	
e-mail	

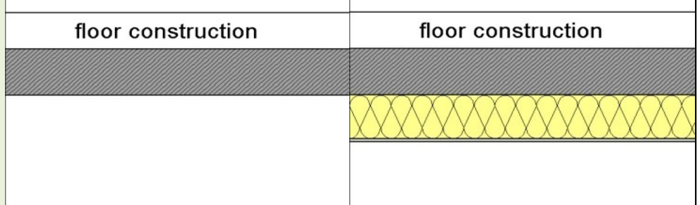
Project Name:	**Jean Paul Platz Nuernberg**		
APPENDIX 3			
	before retrofit	**after retrofit**	**improvement** %
Location			
City	Nuernberg		
State / Country	Germany		
Address	Jean-Paul-Platz 4, Nuernberg, Germany		
Location Type	suburb		
Climate			
Climate Zone	5		Ashrae 189.1 (09)
HDD (65 F)	**6325**		(degreedays.net)
CDD (65 F)	**406**		(degreedays.net)
Notes			
Building Details			
Year of Construction	1930		
Year of Retrofit	2002		
Historic Preservation Status	none		
Preservation Constraints Walls	none		
Preservation Constraints Roof	none		
Building Use	residential		
Building Type	detached		
L/l ratio (Length/Width)	2.8		
Orientation	N-S		
			
No. of Floors	3	3	
No. of Units	6	6	
Constructed Area (sq.m)			
Condition. Usable Area (sq.m)	894	894	**0.0%**
A/V ratio (cond. env. Area/V)			
Notes			

Construction Costs					
Total Construction Costs (Euro)			482,760		
Cost (Euro/sq.m)			**540**		
Cost of Energy Retrofit (€/sq.m)					
Energy Consumption					
Type of data	simulated	metered	simulated	metered	
Heating (kWh/sq.m*a)	**204**		**27**	**25.3**	
Heating (kBtu/sq.ft*a)	64.7		8.6	8.0	
Heating (kWh/sq.m*HDD)	0.0323		0.0043	0.0040	**-87.6%**
Cooling (kWh/sq.m*a)					
Hot Water (kWh/sq.m*a)					
Ventilation (kWh/sq.m*a)					
Lighting (kWh/sq.m*a)					
Notes	no cooling needed in this climate				
Walls					
Insulation Type	**none**		**EPS**		
Insulation Location			exterior		
Insulation Thickness (mm)			200		
Insulation Conductivity (W/mK)			0.035		
Insulation U-Value (W/sq.mK)			0.175		
Insulation U-Value (Btu/hft2F)			0.031		
Assembly U-Value (W/sq.mK)	**1.447**		**0.156**		**-89.2%**
Assembly U-Value (Btu/hft2F)	0.255		0.027		
Main Layers (outside-inside)		mm		mm	
Layer 1			plaster	8	
Layer 2			EPS	200	
Layer 3	plaster	8	plaster	20	unchanged
Layer 4	solid brick	380	solid brick	380	
Layer 5	plaster	15	plaster	15	
Layer 6					
Layer 7					
Layer 8					
Total Thickness		403		623	
Construction Detail					
Notes	EPS - Neopor				

Roof					
Attic	unconditioned		unconditioned		
Insulation Type	**none**		**EPS**		
Insulation Location			exterior		
Insulation Thickness (mm)			250		
Insulation Conductivity (W/mK)			0.035		
Insulation U-Value (W/sq.mK)			0.140		
Insulation U-Value (Btu/hft2F)			0.025		
Assembly U-Value (W/sq.mK)	**0.870**		**0.120**		**-86.2%**
Assembly U-Value (Btu/hft2F)	0.153		0.021		
Main Layers (top-bottom)		mm		mm	
Layer 1			cement screed on foil	60	
Layer 2			EPS	250	
Layer 3			polyethylene foil	2	
Layer 4	solid wood	24	solid wood	24	unchanged
Layer 5	fill	100	fill	100	
Layer 6	solid wood	24	solid wood	24	
Layer 7	air layer	140	air layer	140	
Layer 8	plaster supp.+plaster	40	plaster supp.+plaster	40	
Total Thickness		328		640	
Construction Detail					
Notes					

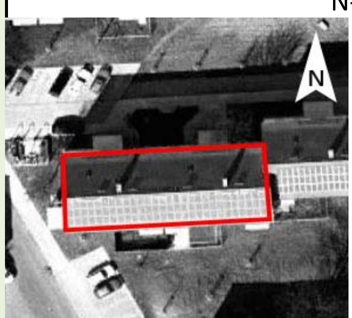
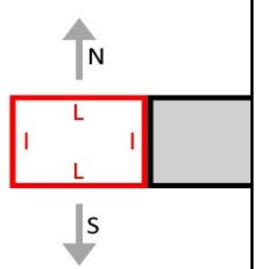
Floor / Slab					
Basement	none		none		
Insulation Type	**none**		**EPS**		
Insulation Location			exterior		
Insulation Thickness (mm)			140		
Insulation Conductivity (W/mK)			0.035		
Insulation U-Value (W/sq.mK)			0.250		
Insulation U-Value (Btu/hft2F)			0.044		
Assembly U-Value (W/sq.mK)	**0.880**		**0.190**		**-78.4%**
Assembly U-Value (Btu/hft2F)	0.155		0.033		
Main Layers (top-bottom)		mm		mm	
Layer 1	floor construction		floor construction		unchanged
Layer 2	concrete slab		concrete slab		
Layer 3			EPS	140	

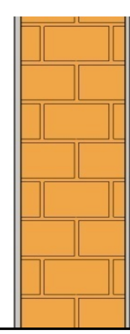
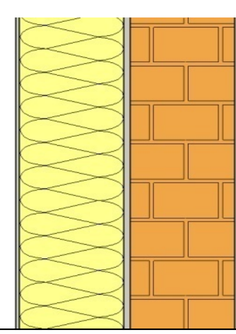
Layer 4		glas fiber plaster 10	
Layer 5			
Layer 6			
Layer 7			
Layer 8			
Total Thickness	0	150	
Construction Detail			
Notes	perimeter insulation of the basement walls		
Windows			
Glazing Type	single	triple	
Coating			
Gas filling			
Window Location		replacement	
Glazing U-Value (W/sq.mK)			
Glazing U-Value (Btu/hft2F)			
SHGC			
Assembly U-Value (W/sq.mK)		**0.8**	
Assembly U-Value (Btu/hft2F)		0.141	
Frame Type	wood	PVC insulated	
Infiltration Rate (ACH at 50 P)	4.9	0.35	
Notes			
Mechanical Systems			
Ventilation	natural	HRV	
Type		individual units	
Efficiency			
Ventilation Rate (ACH)		0.42	
Heating	iundividual units	centralized	
Type of Fuel	gas	gas	
Capacity (kW)			
Efficiency			
Distribution System			
Distribution Media		air/ water	
Terminal Units			
Cooling	no	no	
Type of Fuel			
Efficiency			



Hot Water			
Type of Fuel			
Efficiency			
Storage Tanks	**no**	**yes**	
Capacity (liters)		1000	
Use		hot water	
Solar Thermal Collectors	no	yes	
Area (sq.m)		17	
Capacity (kW)			
Use	heating/hot water	heating/hot water	
Photovoltaics	no	no	
Area (sq.m)			
Power (kW)			
Generat. Energy (kW/sq.m*a)			
Notes			

Contact Details	
Architect / Studio	**Architekturbüro Schulze Darup, Nürnberg**
Tel	
e-mail	
Energy Consultant	**Passivhaus Institut Darmstadt**
Tel	
e-mail	
Mechanical Engineer	**Ingenieurbüro VIP, Nürnberg**
Tel	
e-mail	

Project Name:	Ludwigshafen Mundenheim - PHiB		
APPENDIX 4			
	before retrofit	**after retrofit**	**improvement** %
Location			
City	Ludwigshafen		
State / Country	Germany		
Address	Hohelogstrasse 1-3, Ludwigshafen, Germany		
Location Type	suburb		
Climate			
Climate Zone	4		Ashrae 189.1 (09)
HDD (65 F)	**5,090**		(degreedays.net)
CDD (65 F)	**666**		(degreedays.net)
Notes	Central Germany		
Building Details			
Year of Construction	1965		
Year of Retrofit	2005-2006		
Historic Preservation Status	none		
Preservation Constraints Walls	none		
Preservation Constraints Roof	none		
Building Use	residential		
Building Type	attached 1 side		
L/l ratio (Length/Width)	2.3		
Orientation	N-S		
			
No. of Floors	3		
No. of Units	12	12	
Constructed Area (sq.m)			
Condition. Usable Area (sq.m)	750	750	**0.0%**
A/V ratio (cond. env. Area/V)		0.35	
Notes			

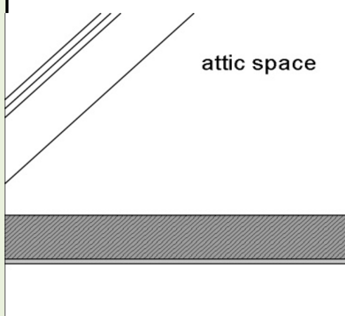
Construction Costs					
Total Construction Costs (Euro)			882,750		
Cost (Euro/sq.m)			**1,177**		
Cost of Energy Retrofit (€/sq.m)					
Energy Consumption					
Type of data	simulated	metered	simulated	metered	
Heating (kWh/sq.m*a)		**141.0**		**18.2**	
Heating (kBtu/sq.ft*a)		44.7		5.8	
Heating (kWh/sq.m*HDD)		0.0277		0.0036	**-87.1%**
Cooling (kWh/sq.m*a)					
Hot Water (kWh/sq.m*a)				24.9	
Ventilation (kWh/sq.m*a)		none		3.8	
Lighting (kWh/sq.m*a)					
Notes	before values are for an identical unretrofited neighboring build. comparison of values measured during the same heating period				
Walls					
Insulation Type	**none**		**EPS**		
Insulation Location			exterior		
Insulation Thickness (mm)			300		
Insulation Conductivity (W/mK)			0.032		
Insulation U-Value (W/sq.mK)			0.107		
Insulation U-Value (Btu/hft2F)			0.019		
Assembly U-Value (W/sq.mK)	**1.294**		**0.100**		**-92.3%**
Assembly U-Value (Btu/hft2F)	0.228		0.018		
Main Layers (outside-inside)		mm		mm	
Layer 1			mineral plaster	10	
Layer 2			EPS	300	
Layer 3	plaster	20	plaster	20	unchanged
Layer 4	honeycomb brick	300	honeycomb brick	300	
Layer 5	plaster	15	plaster	15	
Layer 6					
Layer 7					
Layer 8					
Total Thickness		335		645	
Construction Detail					
Notes					

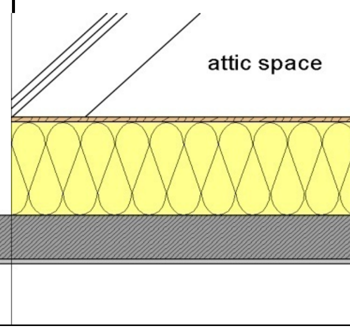
Roof

Roof			
Attic	unconditioned	unconditioned	
Insulation Type	**none**	**EPS**	
Insulation Location		exterior	
Insulation Thickness (mm)		300	
Insulation Conductivity (W/mK)		0.035	
Insulation U-Value (W/sq.mK)		0.117	
Insulation U-Value (Btu/hft2F)		0.021	
Assembly U-Value (W/sq.mK)	**0.516**	**0.114**	**-77.9%**
Assembly U-Value (Btu/hft2F)	0.091	0.020	

Main Layers (top-bottom)		mm		mm	
Layer 1			OSB	16	
Layer 2			EPS	300	
Layer 3	concrete slab	140	concrete slab	140	unchanged
Layer 4	plaster	15	plaster	15	
Layer 5					
Layer 6					
Layer 7					
Layer 8					
Total Thickness		155			

Construction Detail





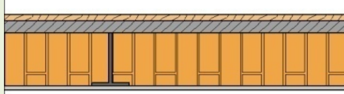
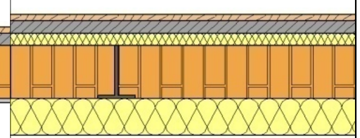
Notes

slab over the second floor is insulated / attic is not conditioned
insulation material brand ex. - Knauf Perlite **Estroperl/Staubex**

Floor / Slab

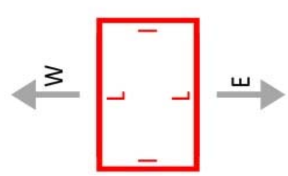
Floor / Slab				
Basement	unconditioned	unconditioned		
Insulation Type	**none**	**XPS**	**PU foam**	
Insulation Location		interior	exterior	
Insulation Thickness (mm)		40	120	
Insulation Conductivity (W/mK)		0.04	0.025	
Insulation U-Value (W/sq.mK)		1.000	0.208	
Insulation U-Value (Btu/hft2F)		0.176	0.037	
Assembly U-Value (W/sq.mK)	**0.640**	**0.170**		**-73.4%**
Assembly U-Value (Btu/hft2F)	0.113	0.030		

Main Layers (top-bottom)		mm		mm	
Layer 1			flooring	20	
Layer 2	flooring	20	screed	40	
Layer 3	screed	40	XPS (sound abs.)	40	

Layer 4	solid brick slab 170	solid brick slab 170	unchanged
Layer 5	plaster 15	PU foam 120	
Layer 6			
Layer 7			
Layer 8			
Total Thickness	245	390	
Construction Detail			
Notes	insulation material brand ex. - Knauf Perlite **Estroperl/Staubex** slab on grade construction		
Windows			
Glazing Type	single	triple	
Coating		low-E	
Gas filling		Argon	
Window Location		replacement	
Glazing U-Value (W/sq.mK)		0.6	
Glazing U-Value (Btu/hft2F)		0.106	
SHGC		0.51	
Assembly U-Value (W/sq.mK)	**2.8**	**0.83**	**-70.4%**
Assembly U-Value (Btu/hft2F)	0.493	0.146	
Frame Type	wood	PVC - insulated	
Infiltration Rate (ACH at 50 P)		0.46	
Notes	Guardian ClimaGuard N3 triple glazing Frame: Schüco, CORONA SI 82+ (U=0.89)		
Mechanical Systems			
Ventilation	natural	HRV	
Type		individual units	
Efficiency			
Ventilation Rate (ACH)		0.35 - 0.47	
Heating	district heating	district heating	
Type of Fuel		gas	
Capacity (kW)			
Efficiency			
Distribution System		water based	
Distribution Media	water	air	
Terminal Units		air reheat	
Cooling	no	no	
Type of Fuel			
Efficiency			

Hot Water			
Type of Fuel			
Efficiency			
Storage Tanks			
Capacity (liters)			
Use	heating/hot water	heating/hot water	
Solar Thermal Collectors	no	no	
Area (sq.m)			
Capacity (kW)			
Use			
Photovoltaics	no	yes	
Area (sq.m)		105	
Power (kW)		12.8	
Generat. Energy (kW/sq.m*a)		16.5	
Notes	Heating is done in the retrofit case using terminal reheat of air HRV from Vallox		

Contact Details	
Architect / Studio	**GAG Ludwigshafen**
Tel	
e-mail	
Energy Consultant	**Passivhaus Institut Sören Peper und Vahid Sariri**
Tel	
e-mail	
Mechanical Engineer	**IBB Ing. -Büro Baumgartner/ Mörlenbach**
Tel	
e-mail	

Project Name:	Office Building Tuebingen		
APPENDIX 5			
			
	before retrofit	**after retrofit**	**improvement** %
Location			
City	Tuebingen		
State / Country	Baden Wuerttemerg / Germany		
Address	Schelllingstrasse 4/2, 72072 Tuebingen, Germany		
Location Type	inner city		
Climate			
Climate Zone	5		Ashrae 189.1 (09)
HDD (65 F)	**6,089**		(degreedays.net)
CDD (65 F)	**406**		(degreedays.net)
Notes			
Building Details			
Year of Construction	1954		
Year of Retrofit	2003		
Historic Preservation Status	neighborhood		
Preservation Constraints Walls	none		
Preservation Constraints Roof	none		
Building Use	office		
Building Type	detached		
L/l ratio (Length/Width)	0.34		
Orientation	E-W		
			
No. of Floors	1	1 + 1	
No. of Units			
Constructed Area (sq.m)		986	
Condition. Usable Area (sq.m)		833	
A/V ratio (cond. env. Area/V)		0.49	
Notes	neighborhood preservation status prohibited the use of		

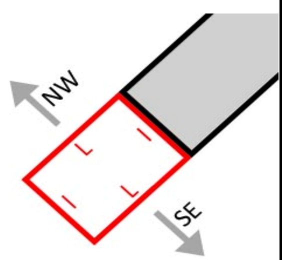
	solar thermal collectors				
Construction Costs					
Total Construction Costs (Euro)			810,000		
Cost (Euro/sq.m)			972		
Cost of Energy Retrofit (€/sq.m)					
Energy Consumption					
Type of data	simulated	metered	simulated	metered	
Heating (kWh/sq.m*a)	**1**		**22.4**	**19.3**	
Heating (kBtu/sq.ft*a)	0.3		7.1		
Heating (kWh/sq.m*HDD)	0.0002		0.0037		**2140.0%**
Cooling (kWh/sq.m*a)					
Hot Water (kWh/sq.m*a)					
Ventilation (kWh/sq.m*a)					
Lighting (kWh/sq.m*a)					
Notes	no cooling needed in this climate First Passive House Certificate for a retrofitted building (2004)				
Walls					
Insulation Type	**none**		**EPS**		
Insulation Location			exterior		
Insulation Thickness (mm)			240		
Insulation Conductivity (W/mK)			0.035		
Insulation U-Value (W/sq.mK)			0.146		
Insulation U-Value (Btu/hft2F)			0.026		
Assembly U-Value (W/sq.mK)	**1.500**		**0.136**		**-90.9%**
Assembly U-Value (Btu/hft2F)	0.264		0.024		
Main Layers (outside-inside)		mm		mm	
Layer 1					unchanged
Layer 2					
Layer 3					
Layer 4					
Layer 5					
Layer 6					
Layer 7					
Layer 8					
Total Thickness		0		0	
Construction Detail					
Notes					

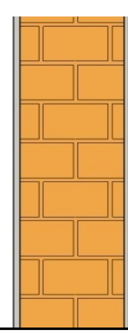
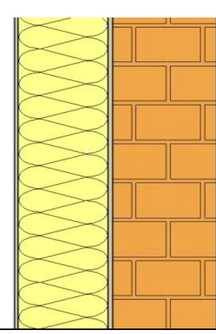
Roof			
Attic	unconditioned	conditioned	
Insulation Type	**none**	**cellulose**	
Insulation Location		cavity	
Insulation Thickness (mm)		300	
Insulation Conductivity (W/mK)		0.04	
Insulation U-Value (W/sq.mK)		0.133	
Insulation U-Value (Btu/hft2F)		0.023	
Assembly U-Value (W/sq.mK)	**1.700**	**0.138**	**-91.9%**
Assembly U-Value (Btu/hft2F)	0.299	0.024	
Main Layers (top-bottom)	mm	mm	
Layer 1			
Layer 2			
Layer 3			
Layer 4			unchanged
Layer 5			
Layer 6			
Layer 7			
Layer 8			
Total Thickness	0	0	
Construction Detail			
Notes	interior roof finish - PCM plasterboard (equivalent to 5 cm concrete)		

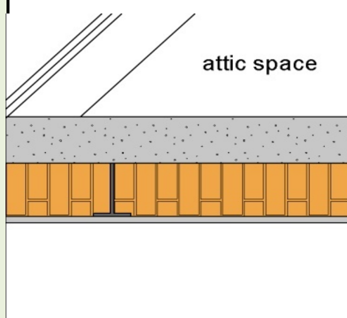
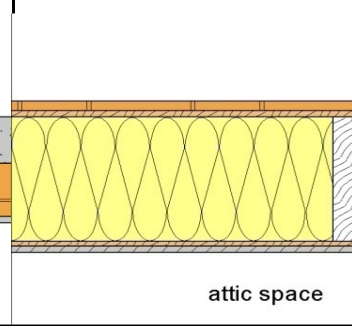
Floor / Slab				
Basement	none	none		
Insulation Type	**none**	**PU foam**	**Perlite**	
Insulation Location		interior	interior	
Insulation Thickness (mm)		45	30	
Insulation Conductivity (W/mK)		0.025	0.05	
Insulation U-Value (W/sq.mK)		0.556	1.667	
Insulation U-Value (Btu/hft2F)		0.098	0.294	
Assembly U-Value (W/sq.mK)	**2.500**	**0.350**		**-86.0%**
Assembly U-Value (Btu/hft2F)	0.440	0.062		
Main Layers (top-bottom)	mm	mm		
Layer 1				
Layer 2				
Layer 3				

Layer 4			
Layer 5			unchanged
Layer 6			
Layer 7			
Layer 8			
Total Thickness	0	0	
Construction Detail			
Notes	expanded perlite is used as a leveling layer		
Windows			
Glazing Type	single	triple	
Coating			
Gas filling			
Window Location		replacement	
Glazing U-Value (W/sq.mK)			
Glazing U-Value (Btu/hft2F)	0.000	0.000	
SHGC			
Assembly U-Value (W/sq.mK)	**2.7**	**0.8**	**-70.4%**
Assembly U-Value (Btu/hft2F)	0.476	0.141	
Frame Type	PVC	PVC insulated	
Infiltration Rate (ACH at 50 P)		0.2	
Notes	wood frames - "Striegel Ultrapur S" glazing - "Unitop"		
Mechanical Systems			
Ventilation	natural	HRV	
Type		whole house	
Efficiency		80%	
Ventilation Rate (ACH)			
Heating		whole house	
Type of Fuel		gas	
Capacity (kW)			
Efficiency			
Distribution System		water	
Distribution Media		water	
Terminal Units		radiators	
Cooling			
Type of Fuel			
Efficiency			

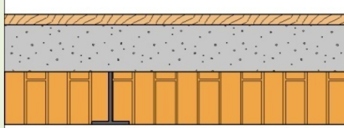
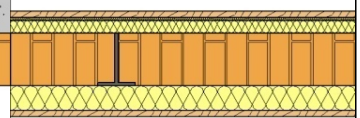
Hot Water			
Type of Fuel			
Efficiency			
Storage Tanks			
Capacity (liters)			
Use			
Solar Thermal Collectors	no	no	
Area (sq.m)			
Capacity (kW)			
Use			
Photovoltaics			
Area (sq.m)			
Power (kW)			
Generat. Energy (kW/sq.m*a)			
Notes			
Contact Details			
Architect / Studio			
Tel			
e-mail			
Energy Consultant			
Tel			
e-mail			
Mechanical Engineer			
Tel			
e-mail			

Project Name:	**Tevesstrasse Frankfurt - Block 1 - Tevesstrasse**		
APPENDIX 6			
			
	before retrofit	**after retrofit**	**improvement %**
Location			
City	Frankfurt		
State / Country	Germany		
Address	Tevesstrasse 36-46, Frankfurt, Germany		
Location Type	suburb		
Climate			
Climate Zone	5		Ashrae 189.1 (09)
HDD (65 F)	**5515**		(degreedays.net)
CDD (65 F)	**513**		(degreedays.net)
Notes	Central Germany, no cooling needed		
Building Details			
Year of Construction	1951		
Year of Retrofit	2005 - 2006		
Historic Preservation Status	none		
Preservation Constraints Walls	none		
Preservation Constraints Roof	none		
Building Use	residential		
Building Type	attached 1 side		
L/l ratio (Length/Width)			
Orientation	NW-SE		
			
No. of Floors	3	3 + 1	
No. of Units	36	33	
Constructed Area (sq.m)			
Condition. Usable Area (sq.m)	1851	2244	**21.2%**
A/V ratio (cond. env. Area/V)			
Notes	The Tevesstrasse Project consists of 2 blocks of different sizes		

	same retrofit measures for both blocks				
Construction Costs					
Total Construction Costs				3,029,400	
Cost (Euro/sq.m)				**1,350**	
Cost of Energy Retrofit (€/sq.m)					
Energy Consumption					
Type of data	simulated	metered	simulated	metered	
Heating (kWh/sq.m*a)	**283**		**14.6**	**21.0**	
Heating (kBtu/sq.ft*a)	89.7		4.6	6.7	
Heating (kWh/sq.m*HDD)	0.0513		0.0026	0.0038	**-92.6%**
Cooling (kWh/sq.m*a)					
Hot Water (kWh/sq.m*a)				15.1	
Ventilation (kWh/sq.m*a)					
Lighting (kWh/sq.m*a)					
Notes	simulated using PHPP (before - using T. of 20 C + Frankfurt climate) sim. & meter. (retrofit) - adjusted for set T. (21.8 C) + milder winter				
Walls					
Insulation Type	**none**		**EPS**		
Insulation Location			exterior		
Insulation Thickness (mm)			260		
Insulation Conductivity (W/mK)			0.035		
Insulation U-Value (W/sq.mK)			0.135		
Insulation U-Value (Btu/hft2F)			0.024		
Assembly U-Value (W/sq.mK)	**1.300**		**0.122**		**-90.6%**
Assembly U-Value (Btu/hft2F)	0.229		0.021		
Main Layers (outside-inside)		mm		mm	
Layer 1			plaster	10	
Layer 2			EPS	260	
Layer 3	plaster	20	plaster	15	
Layer 4	hollow block	300	hollow block	300	unchanged
Layer 5	plaster	15	plaster	10	
Layer 6					
Layer 7					
Layer 8					
Total Thickness		335		595	
Construction Detail					
Notes	gable walls - insulation - 200 mm 4th floor extension - wood construction - stone wool (140 mm) + mineral wool (260 mm)				

Roof					
Attic	unconditioned		conditioned		
Insulation Type	**none**		**cellulose insulation**		
Insulation Location			cavity		
Insulation Thickness (mm)			400		
Insulation Conductivity (W/mK)			0.04		
Insulation U-Value (W/sq.mK)			0.100		
Insulation U-Value (Btu/hft2F)			0.018		
Assembly U-Value (W/sq.mK)	**1.600**		**0.106**		**-93.4%**
Assembly U-Value (Btu/hft2F)	0.282		0.019		
Main Layers (top-bottom)		mm		mm	
Layer 1	waste mat. fill		roofing material		
Layer 2	solid brick slab	170	OSB plate	20	
Layer 3	plaster	20	cellulose ins.	400	
Layer 4			OSB plate	15	
Layer 5			plasterboard	20	
Layer 6					
Layer 7					roof structure was replaced
Layer 8					
Total Thickness		190		455	
Construction Detail					
Notes	the original slab - fill layer of construction waste ("Kaiser" system) before - attic was not conditioned cellulose insulation (using 6% wood)				

Floor / Slab					
Basement	unconditioned		unconditioned		
Insulation Type	**none**		**PU - foam**		
Insulation Location			exterior		
Insulation Thickness (mm)			120		
Insulation Conductivity (W/mK)			0.025		
Insulation U-Value (W/sq.mK)			0.208		
Insulation U-Value (Btu/hft2F)			0.037		
Assembly U-Value (W/sq.mK)	**1.100**		**0.177**		**-83.9%**
Assembly U-Value (Btu/hft2F)	0.194		0.031		
Main Layers (top-bottom)		mm		mm	
Layer 1			wood floor	20	
Layer 2	solid wood floor		impact insulation	10	
Layer 3	sand filling		insulation	40	

Layer 4	solid brick slab 170	solid brick slab 170	unchanged
Layer 5		PU - foam 80	
Layer 6		OSB plate 20	
Layer 7			
Layer 8			
Total Thickness	170	340	
Construction Detail			
Notes	solid brick slab - inverted steel double T beams support solid bricks low head hight in the basement limited the thickness of insulation		

Windows

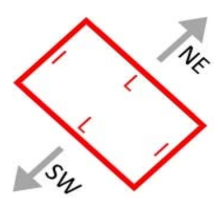
Glazing Type	single	double	triple	
Coating	none	none	low-E	
Gas filling		vacuum	Argon	
Window Location			replacement	
Glazing U-Value (W/sq.mK)			0.6	
Glazing U-Value (Btu/hft2F)			0.106	
SHGC			0.50	
Assembly U-Value (W/sq.mK)	**5.2**	**1.5**	**0.87**	**-83.3%**
Assembly U-Value (Btu/hft2F)	0.916	0.264	0.153	
Frame Type	wood	PVC - unins.	PVC-insulated	
Infiltration Rate (ACH at 50 P)	4.2		0.5	
Notes	for both buildings 8 single pane and 120 double pane windows			

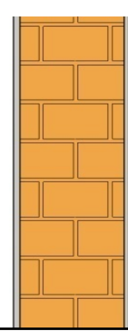
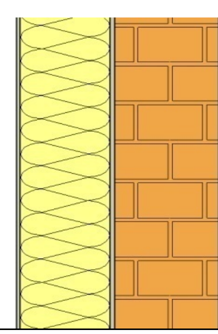
Mechanical Systems

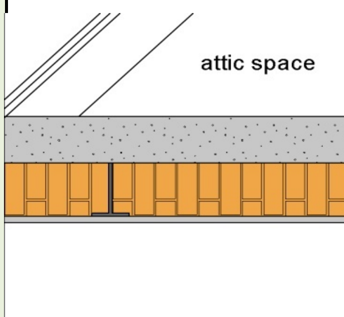
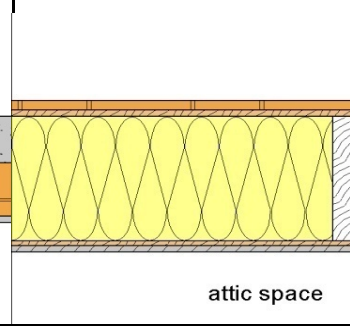
Ventilation	natural	HRV	
Type		individual units	
Efficiency		84%	
Ventilation Rate (ACH)	0.7	0.5	
Heating	individual apt heating	central system	
Type of Fuel	gas	gas	
Capacity (kW)			
Efficiency			
Distribution System		water	
Distribution Media	water	air	
Terminal Units		terminal reheat	
Cooling	no	no	
Type of Fuel			
Efficiency			

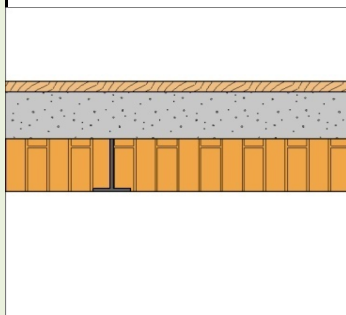
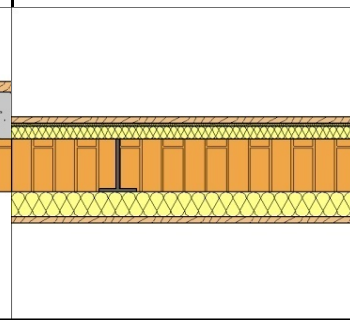
Hot Water	individual apt hot water	central system	
Type of Fuel	gas	gas	
Efficiency			
Storage Tanks			
Capacity (liters)			
Use			
Solar Thermal Collectors	no	yes	
Area (sq.m)		41.44	
Capacity (kW)			
Use		hot water	
Photovoltaics	no	no	
Area (sq.m)			
Power (kW)			
Generat. Energy (kW/sq.m*a)			
Notes	Individual apartments had different heating + hot water systems After retrofit - central heating system for both blocks		

Contact Details	
Architect / Studio	**Faktor 10, Darmstadt**
Tel	
e-mail	
Energy Consultant	**Passivhaus Institut, Darmstadt**
Tel	
e-mail	
Mechanical Engineer	**Ingenieurbüro IBB, Mörlenbach**
Tel	
e-mail	

Project Name:	Tevesstrasse Frankfurt - Block 2 - Sonderhausenstrasse		
APPENDIX 7			
	before retrofit	**after retrofit**	**improvement** %
Location			
City	Frankfurt		
State / Country	Germany		
Address	Tevesstrasse 48-54, Frankfurt, Germany		
Location Type	suburb		
Climate			
Climate Zone	5		Ashrae 189.1 (09)
HDD (65 F)	**5515**		(degreedays.net)
CDD (65 F)	**513**		(degreedays.net)
Notes	Central Germany, no cooling needed		
Building Details			
Year of Construction	1951		
Year of Retrofit	2005 - 2006		
Historic Preservation Status	none		
Preservation Constraints Walls	none		
Preservation Constraints Roof	none		
Building Use	residential		
Building Type	detached		
L/l ratio (Length/Width)			
Orientation	NE-SW		
			
No. of Floors	3	3 + 1	
No. of Units	24	20	
Constructed Area (sq.m)			
Condition. Usable Area (sq.m)	1123	1350	**20.2%**
A/V ratio (cond. env. Area/V)			
Notes	The Tevesstrasse Project consists of 2 blocks of different sizes		

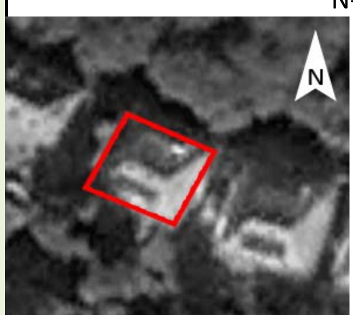
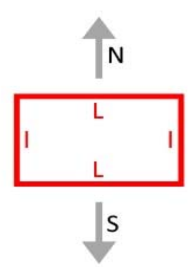
	same retrofit measures for both blocks				
Construction Costs					
Total Construction Costs				1,822,500	
Cost (Euro/sq.m)				**1,350**	
Cost of Energy Retrofit (€/sq.m)					
Energy Consumption					
Type of data	simulated	metered	simulated	metered	
Heating (kWh/sq.m*a)	**294**		**15.1**	**18.1**	
Heating (kBtu/sq.ft*a)	93.2		4.8	5.7	
Heating (kWh/sq.m*HDD)	0.0533		0.0027	0.0033	**-93.8%**
Cooling (kWh/sq.m*a)					
Hot Water (kWh/sq.m*a)				21.9	
Ventilation (kWh/sq.m*a)					
Lighting (kWh/sq.m*a)					
Notes	simulated using PHPP / before - using T. of 20 C + Frankfurt climate sim. & meter. (retrofit) - adjusted for set T. (21.8 C) + milder winter				
Walls					
Insulation Type	**none**		**EPS**		
Insulation Location			exterior		
Insulation Thickness (mm)			260		
Insulation Conductivity (W/mK)			0.035		
Insulation U-Value (W/sq.mK)			0.135		
Insulation U-Value (Btu/hft2F)			0.024		
Assembly U-Value (W/sq.mK)	**1.300**		**0.122**		**-90.6%**
Assembly U-Value (Btu/hft2F)	0.229		0.021		
Main Layers (outside-inside)		mm		mm	
Layer 1			plaster	10	
Layer 2			EPS	260	
Layer 3	plaster	20	plaster	15	
Layer 4	hollow block	300	hollow block	300	unchanged
Layer 5	plaster	15	plater	10	
Layer 6					
Layer 7					
Layer 8					
Total Thickness		335		595	
Construction Detail					
Notes	gable walls - insulation - 200 mm 4th floor extension - wood construction - stone wool (140 mm) + mineral wool (260 mm)				

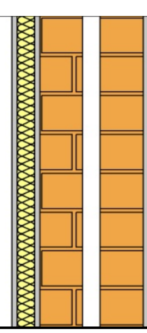
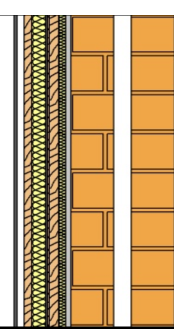
Roof					
Attic	unconditioned		conditioned		
Insulation Type	**none**		**cellulose insulation**		
Insulation Location			cavity		
Insulation Thickness (mm)			400		
Insulation Conductivity (W/mK)			0.04		
Insulation U-Value (W/sq.mK)			0.100		
Insulation U-Value (Btu/hft2F)			0.018		
Assembly U-Value (W/sq.mK)	**1.600**		**0.106**		**-93.4%**
Assembly U-Value (Btu/hft2F)	0.282		0.019		
Main Layers (top-bottom)		mm		mm	
Layer 1	waste mat. fill		roofing material		
Layer 2	solid brick slab	170	OSB plate	20	
Layer 3	plaster	20	cellulose ins.	400	
Layer 4			OSB plate	15	
Layer 5			plasterboard	20	
Layer 6					
Layer 7					roof structure
Layer 8					was replaced
Total Thickness		190		455	
Construction Detail					
Notes	the original slab - fill layer of construction waste ("Kaiser" system) cellulose insulation (using 6% wood)				
Floor / Slab					
Basement	unconditioned		unconditioned		
Insulation Type	**none**		**PU - foam**		
Insulation Location			exterior		
Insulation Thickness (mm)			120		
Insulation Conductivity (W/mK)			0.025		
Insulation U-Value (W/sq.mK)			0.208		
Insulation U-Value (Btu/hft2F)			0.037		
Assembly U-Value (W/sq.mK)	**1.100**		**0.177**		**-83.9%**
Assembly U-Value (Btu/hft2F)	0.194		0.031		
Main Layers (top-bottom)		mm		mm	
Layer 1	solid wood floor		wood floor	20	
Layer 2	sand filling		impact insulation	10	
Layer 3	waste mat. fill		insulation	40	

Layer 4	solid brick slab 170		solid brick slab 170	unchanged
Layer 5			PU - foam 80	
Layer 6			OSB plate 20	
Layer 7				
Layer 8				
Total Thickness	170		340	
Construction Detail				
Notes	solid brick slab - inverted steel double T beams support solid bricks low head hight in the basement limited the thickness of insulation			
Windows				
Glazing Type	single	double	triple	
Coating	none	none	low-E	
Gas filling		vacuum	Argon	
Window Location			replacement	
Glazing U-Value (W/sq.mK)			0.6	
Glazing U-Value (Btu/hft2F)			0.106	
SHGC			0.50	
Assembly U-Value (W/sq.mK)	**5.2**	**1.5**	**0.87**	**-83.3%**
Assembly U-Value (Btu/hft2F)	0.916	0.264	0.153	
Frame Type	wood	PVC-unins.	PVC-insulated	
Infiltration Rate (ACH at 50 P)	5.0		0..5	
Notes	for both buildings 8 single pane and 120 double pane windows triple glazing - UNIGLAS TOP 0,60/ frame - Rehau, Clima Design			
Mechanical Systems				
Ventilation	natural		HRV	
Type			individual units	
Efficiency			84%	
Ventilation Rate (ACH)				
Heating	individual apt heating		central system	
Type of Fuel	gas		gas	
Capacity (kW)				
Efficiency				
Distribution System			water	
Distribution Media	water		air	
Terminal Units			terminal reheat	
Cooling	no		no	
Type of Fuel				
Efficiency				

Hot Water	individual apt hot water		
Type of Fuel	gas		
Efficiency			
Storage Tanks			
Capacity (liters)			
Use			
Solar Thermal Collectors	no	yes	
Area (sq.m)		23.00	
Capacity (kW)			
Use		hot water	
Photovoltaics	no	no	
Area (sq.m)			
Power (kW)			
Generat. Energy (kW/sq.m*a)			
Notes	Individual apartments had different heating + hot water systems After retrofit - central heating system for both blocks		

Contact Details	
Architect / Studio	**Faktor 10, Darmstadt**
Tel	
e-mail	
Energy Consultant	**Passivhaus Institut, Darmstadt**
Tel	
e-mail	
Mechanical Engineer	**Ingenieurbüro IBB, Mörlenbach**
Tel	
e-mail	

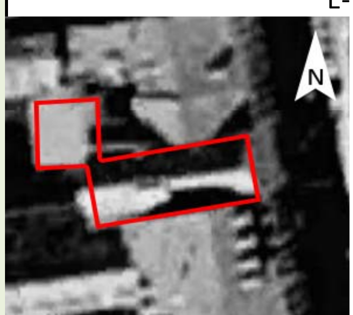
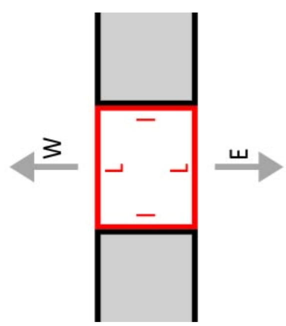
Project Name:	**Wilhelmstrasse Hofheim**		
APPENDIX 8			
			
	before retrofit	**after retrofit**	**improvement** %
Location			
City	Hofheim		
State / Country	Hessen / Germany		
Address	Wilhelmstrasse 39, 65719 Hofheim, Germany		
Location Type	suburb		
Climate			
Climate Zone	5		Ashrae 189.1 (09)
HDD (65 F)	**5,515**		(degreedays.net)
CDD (65 F)	**513**		(degreedays.net)
Notes	Central Germany, no cooling needed		
Building Details			
Year of Construction	1927		
Year of Retrofit	2006		
Historic Preservation Status	none		
Preservation Constraints Walls	none		
Preservation Constraints Roof	none		
Building Use	residential		
Building Type	detached		
L/l ratio (Length/Width)	1		
Orientation	N-S		
			
No. of Floors	2	2 + 1	
No. of Units	2	2	
Constructed Area (sq.m)			
Condition. Usable Area (sq.m)		273	**#DIV/0!**
A/V ratio (cond. env. Area/V)	0.77	0.64	
Notes			

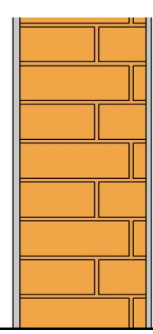
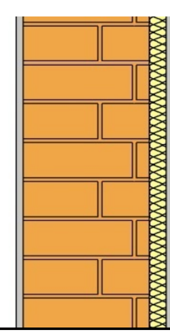
Construction Costs					
Total Construction Costs (Euro)			283,736		
Cost (Euro/sq.m)			**1,039**		
Cost of Energy Retrofit (€/sq.m)					
Energy Consumption					
Type of data	simulated	metered	simulated	metered	
Heating (kWh/sq.m*a)	**194**		**28**	**27.4**	
Heating (kBtu/sq.ft*a)	61.5		8.9	8.7	
Heating (kWh/sq.m*HDD)	0.0352		0.0051	0.0050	**-85.9%**
Cooling (kWh/sq.m*a)					
Hot Water (kWh/sq.m*a)			19.1	25.0	
Ventilation (kWh/sq.m*a)					
Lighting (kWh/sq.m*a)					
Notes	no cooling needed in this climate				
Walls - Street Façade					
Insulation Type	**EPS**		**Vacuum Insulated Panels**		
Insulation Location	exterior		exterior		
Insulation Thickness (mm)	50		40		
Insulation Conductivity (W/mK)	0.04		0.007		
Insulation U-Value (W/sq.mK)	0.800		0.175		
Insulation U-Value (Btu/hft2F)	0.141		0.031		
Assembly U-Value (W/sq.mK)	**0.700**		**0.190**		**-72.9%**
Assembly U-Value (Btu/hft2F)	0.123		0.033		
Main Layers (outside-inside)		mm		mm	
Layer 1			air (20) + composit plates (8)	28	
Layer 2			support plates (5+18)	23	
Layer 3			Al foil + VIP	40	
Layer 4			support plates (27+5)	32	
Layer 5			mineral wool	20	
Layer 6	plaster	15	plaster	15	unchanged
Layer 7	brick (125 + air(50) + brick(125)	300	brick (125 + air(50) + brick(125)	300	
Layer 8	plaster	20	plaster	15	
Total Thickness		335		473	
Construction Detail					
Notes	Prefabricated elements with VIP were chosen due to small thickness				

Roof			
Attic	unconditioned	unconditioned	
Insulation Type	**none**	**Mineral Wool**	
Insulation Location		cavity	
Insulation Thickness (mm)		300	
Insulation Conductivity (W/mK)		0.045	
Insulation U-Value (W/sq.mK)		0.150	
Insulation U-Value (Btu/hft2F)		0.026	
Assembly U-Value (W/sq.mK)	**0.800**	**0.162**	**-79.8%**
Assembly U-Value (Btu/hft2F)	0.141	0.029	
Main Layers (top-bottom)	mm	mm	
Layer 1			
Layer 2			
Layer 3			
Layer 4			
Layer 5			
Layer 6			
Layer 7			
Layer 8			
Total Thickness	0	0	
Construction Detail			
Notes			
Floor / Slab			
Basement	uninsulated	uninsulated	
Insulation Type	**none**	**EPS (Neopor)**	
Insulation Location			
Insulation Thickness (mm)		60	
Insulation Conductivity (W/mK)		0.032	
Insulation U-Value (W/sq.mK)		0.533	
Insulation U-Value (Btu/hft2F)		0.094	
Assembly U-Value (W/sq.mK)	**1.900**	**0.445**	**-76.6%**
Assembly U-Value (Btu/hft2F)	0.335	0.078	
Main Layers (top-bottom)	mm	mm	
Layer 1			

Layer 2			
Layer 3			
Layer 4			
Layer 5			
Layer 6			
Layer 7			
Layer 8			
Total Thickness	0	0	
Construction Detail			
Notes			
Windows			
Glazing Type	single	triple	
Coating			
Gas filling			
Window Location		replacement	
Glazing U-Value (W/sq.mK)			
Glazing U-Value (Btu/hft2F)			
SHGC			
Assembly U-Value (W/sq.mK)	**2.8**	**1.16**	**-58.6%**
Assembly U-Value (Btu/hft2F)	0.493	0.204	
Frame Type	PVC	PVC insulated	
Infiltration Rate (ACH at 50 P)			
Notes			
Mechanical Systems			
Ventilation	natural	HRV	
Type		individual units	
Efficiency			
Ventilation Rate (ACH)			
Heating	whole house boiler	whole house boiler	
Type of Fuel	gas	wood pellets	
Capacity (kW)			
Efficiency			
Distribution System			
Distribution Media	water		
Terminal Units			
Cooling	no	no	

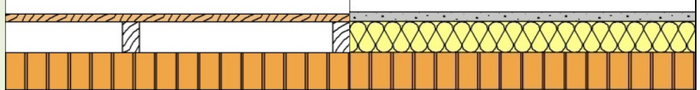
Type of Fuel			
Efficiency			
Hot Water	whole house boiler		
Type of Fuel	gas		
Efficiency			
Storage Tanks			
Capacity (liters)			
Use			
Solar Thermal Collectors	no	no	
Area (sq.m)			
Capacity (kW)			
Use			
Photovoltaics	no	no	
Area (sq.m)			
Power (kW)			
Generat. Energy (kW/sq.m*a)			
Notes			
Contact Details			
Architect / Studio			
Tel			
e-mail			
Energy Consultant			
Tel			
e-mail			
Mechanical Engineer			
Tel			
e-mail			

Project Name:	Bautznerstrasse 11 Zittau		
APPENDIX 9	 before retrofit	 after retrofit	improvement %
Location			
City	Zittau		
State / Country	Sachsen / Germany		
Address	Bautznerstrasse 11, Zittau, Germany		
Location Type	inner city		
Climate			
Climate Zone	5		Ashrae 189.1 (09)
HDD (65 F)	**6,313**		(degreedays.net)
CDD (65 F)	**363**		(degreedays.net)
Notes			
Building Details			
Year of Construction	1880 - 1910		
Year of Retrofit	2004		
Historic Preservation Status	building + neighborhood		
Preservation Constraints Walls	outside		
Preservation Constraints Roof	outside		
Building Use	residential + ground floor commercial		
Building Type	attached 2 sides		
L/l ratio (Length/Width)	0.45		
Orientation	E-W		
			
No. of Floors	4 + 1	4 + 1	
No. of Units	11 + commercial GF	11 + commercial GF	
Constructed Area (sq.m)			
Condition. Usable Area (sq.m)	1,200	1,247	**3.9%**
A/V ratio (cond. env. Area/V)			
Notes			

Construction Costs					
Total Construction Costs (Euro)					
Cost (Euro/sq.m)					
Cost of Energy Retrofit (€/sq.m)					
Energy Consumption					
Type of data	simulated	metered	simulated	metered	
Heating (kWh/sq.m*a)	**176**		**45**		
Heating (kBtu/sq.ft*a)	55.8		14.3		
Heating (kWh/sq.m*HDD)	0.0279		0.0071		**-74.4%**
Cooling (kWh/sq.m*a)					
Hot Water (kWh/sq.m*a)	16.0		6.1		**-61.9%**
Ventilation (kWh/sq.m*a)					
Lighting (kWh/sq.m*a)					
Notes	no cooling needed in this climate				
Walls - Street Façade					
Insulation Type	**none**		**Calcium Silicate**		
Insulation Location			interior		
Insulation Thickness (mm)			50		
Insulation Conductivity (W/mK)			0.065		
Insulation U-Value (W/sq.mK)			1.300		
Insulation U-Value (Btu/hft2F)			0.229		
Assembly U-Value (W/sq.mK)	**1.510**		**0.500**		**-66.9%**
Assembly U-Value (Btu/hft2F)	0.266		0.088		
Main Layers (outside-inside)		mm		mm	
Layer 1	plaster	20	plaster	20	unchanged
Layer 2	solid brick	365	solid brick	365	
Layer 3	plaster	15	Calcium Silicate	50	
Layer 4			plaster	15	
Layer 5					
Layer 6					
Layer 7					
Layer 8					
Total Thickness		400		450	
Construction Detail					
Notes					

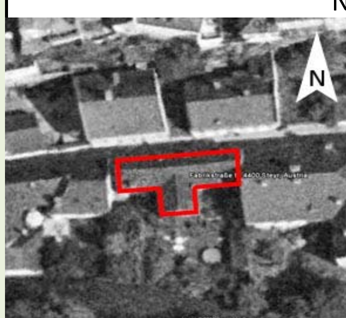
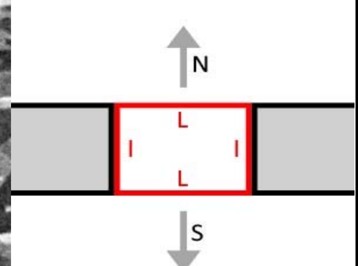
Roof - Gable Roof (Main Body of the House)					
Attic	unconditioned		conditioned		
Insulation Type			**mineral fibre**		
Insulation Location			cavity		
Insulation Thickness (mm)			180		
Insulation Conductivity (W/mK)			0.04		
Insulation U-Value (W/sq.mK)			0.222		
Insulation U-Value (Btu/hft2F)			0.039		
Assembly U-Value (W/sq.mK)	**1.100**		**0.240**		**-78.2%**
Assembly U-Value (Btu/hft2F)	0.194		0.042		
Main Layers (top-bottom)		mm		mm	
Layer 1					
Layer 2					
Layer 3					
Layer 4					new roof
Layer 5					structure
Layer 6					
Layer 7					
Layer 8					
Total Thickness		0		0	
Construction Detail					
Notes	before - uninsulated roof and attic floor with waste material fill				

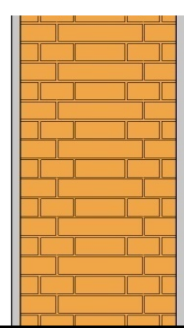
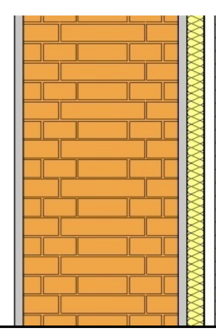
Floor / Slab					
Basement	none		none		
Insulation Type	**none**		**EPS**		
Insulation Location			interior		
Insulation Thickness (mm)			100		
Insulation Conductivity (W/mK)			0.035		
Insulation U-Value (W/sq.mK)			0.350		
Insulation U-Value (Btu/hft2F)			0.062		
Assembly U-Value (W/sq.mK)	**1.110**		**0.660**		**-40.5%**
Assembly U-Value (Btu/hft2F)	0.195		0.116		
Main Layers (top-bottom)		mm		mm	
Layer 1	wood flooring	25	cement screed	30	
Layer 2	air layer	100	EPS	100	
Layer 3	solid brick slab	120	solid brick slab	120	unchanged

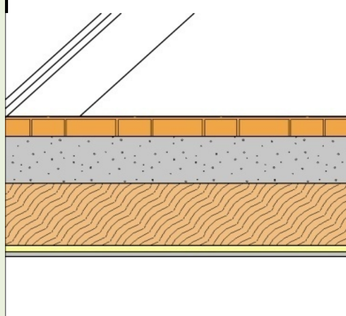
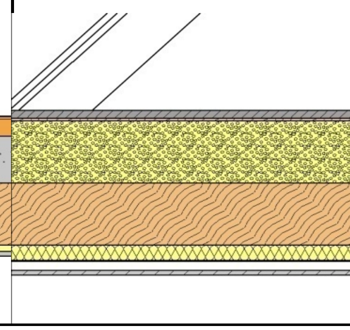
Layer 4			
Layer 5			
Layer 6			
Layer 7			
Layer 8			
Total Thickness	245	250	
Construction Detail			
Notes			
Windows			
Glazing Type	single	single + double	
Coating			
Gas filling		Argon	
Window Location		replacement	
Glazing U-Value (W/sq.mK)			
Glazing U-Value (Btu/hft2F)	0.000	0.000	
SHGC			
Assembly U-Value (W/sq.mK)	**2.5**	**1.0**	**-60.0%**
Assembly U-Value (Btu/hft2F)	0.440	0.176	
Frame Type	wood	wood	
Infiltration Rate (ACH at 50 P)		3.4	
Notes	"Zuluft Kastenfenster" - casement windows with air intake		
Mechanical Systems			
Ventilation	natural	exhaust fan	
Type		whole house	
Efficiency			
Ventilation Rate (ACH)			
Heating	stoves (individual units)	gas boiler	
Type of Fuel	coal	gas	
Capacity (kW)		120	
Efficiency			
Distribution System			
Distribution Media	direct	water + air (ground floor)	
Terminal Units		radiators + under floor	
Cooling	no	no	
Type of Fuel			
Efficiency			

Hot Water	individual boilers	gas boiler	
Type of Fuel	electric	gas	
Efficiency			
Storage Tanks			
Capacity (liters)			
Use			
Solar Thermal Collectors	no	no	
Area (sq.m)			
Capacity (kW)			
Use			
Photovoltaics	no	no	
Area (sq.m)			
Power (kW)			
Generat. Energy (kW/sq.m*a)			
Notes	the exhaust air is used to heat the hot water supply ground floor commercial unit - underfloor heating		

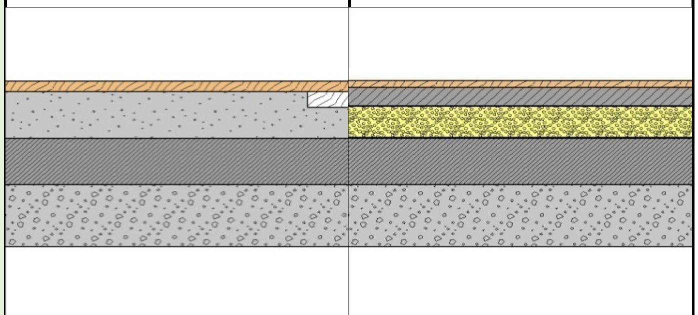
Contact Details	
Architect / Studio	
Tel	
e-mail	
Energy Consultant	
Tel	
e-mail	
Mechanical Engineer	
Tel	
e-mail	

Project Name:	Fabrikstrasse 9 Steyr		
APPENDIX 10			
	before retrofit	**after retrofit**	**improvement %**
Location			
City	Steyr		
State / Country	Austria		
Address	Fabrikstrasse 9, 4400 Steyr, Austria		
Location Type	inner city		
Climate			
Climate Zone	5		Ashrae 189.1 (09)
HDD (65 F)	**6,141**		(degreedays.net)
CDD (65 F)	**488**		(degreedays.net)
Notes			
Building Details			
Year of Construction	before 1918		
Year of Retrofit			
Historic Preservation Status	building + neighborhood		
Preservation Constraints Walls	outside		
Preservation Constraints Roof	outside		
Building Use	residential		
Building Type	attached 2 sides		
L/l ratio (Length/Width)	1.7		
Orientation	N-S		
			
No. of Floors	2		
No. of Units	1	1	
Constructed Area (sq.m)			
Condition. Usable Area (sq.m)	300	219	**-27.0%**
A/V ratio (cond. env. Area/V)			
Notes			

Construction Costs					
Total Construction Costs (Euro)					
Cost (Euro/sq.m)					
Cost of Energy Retrofit (€/sq.m)					
Energy Consumption					
Type of data	simulated	metered	simulated	metered	
Heating (kWh/sq.m*a)	**308**		**108**		
Heating (kBtu/sq.ft*a)	97.6		34.2		
Heating (kWh/sq.m*HDD)	0.0502		0.0176		**-64.9%**
Cooling (kWh/sq.m*a)					
Hot Water (kWh/sq.m*a)					
Ventilation (kWh/sq.m*a)					
Lighting (kWh/sq.m*a)					
Notes	no cooling needed in this climate				
Walls					
Insulation Type	**none**		**mineral fiber**		
Insulation Location			interior		
Insulation Thickness (mm)			50		
Insulation Conductivity (W/mK)			0.04		
Insulation U-Value (W/sq.mK)			0.800		
Insulation U-Value (Btu/hft2F)			0.141		
Assembly U-Value (W/sq.mK)	**1.220**		**0.486**		**-60.2%**
Assembly U-Value (Btu/hft2F)	0.215		0.086		
Main Layers (outside-inside)		mm		mm	
Layer 1	plaster	25	plaster	25	unchanged
Layer 2	solid brick	450	solid brick	450	
Layer 3	plaster	25	plaster	25	
Layer 4			mineral fiber ins.	50	
Layer 5			vapor barier		
Layer 6			air space/battens	30	
Layer 7			plasterboard	15	
Layer 8					
Total Thickness		500		595	
Construction Detail					
Notes					

Roof					
Attic	unconditioned		unconditioned		
Insulation Type	**none**		**perlite loose fill**		
Insulation Location			exterior		
Insulation Thickness (mm)			200		
Insulation Conductivity (W/mK)			0.04		
Insulation U-Value (W/sq.mK)			0.200		
Insulation U-Value (Btu/hft2F)			0.035		
Assembly U-Value (W/sq.mK)	**0.374**		**0.112**		**-70.1%**
Assembly U-Value (Btu/hft2F)	0.066		0.020		
Main Layers (top-bottom)		mm		mm	
Layer 1			screed	25	
Layer 2	brick	65	OSB	8	
Layer 3	fill	150	perlite	200	
Layer 4	solid wood slab	200	solid wood slab	200	unchanged
Layer 5	rush mat	20	mineral wool	50	
Layer 6	plaster	15	vapor barrier		
Layer 7			air space	30	
Layer 8			plaster board	15	
Total Thickness		450		528	
Construction Detail					
Notes	slab over the second floor is insulated / attic is not conditioned insulation material brand ex. - Knauf Perlite **Estroperl/Staubex**				

Floor / Slab					
Basement	none		none		
Insulation Type	**none**		**perlite**		
Insulation Location			interior		
Insulation Thickness (mm)			100		
Insulation Conductivity (W/mK)			0.04		
Insulation U-Value (W/sq.mK)			0.400		
Insulation U-Value (Btu/hft2F)			0.070		
Assembly U-Value (W/sq.mK)	**0.852**		**0.340**		**-60.1%**
Assembly U-Value (Btu/hft2F)	0.150		0.060		
Main Layers (top-bottom)		mm		mm	
Layer 1			flooring	22	
Layer 2			screed	60	
Layer 3	solid wood floor	34	PE foil		

Layer 4	fill btw beams 5/8	150	perlite	100	
Layer 5	concrete slab	150	concrete slab	150	unchanged
Layer 6	compacted layer	200	compacted layer	200	
Layer 7					
Layer 8					
Total Thickness		534		532	
Construction Detail					
Notes	insulation material brand ex. - Knauf Perlite **Estroperl/Staubex** slab on grade construction				
Windows					
Glazing Type	single				
Coating					
Gas filling					
Window Location			replacement		
Glazing U-Value (W/sq.mK)					
Glazing U-Value (Btu/hft2F)					
SHGC					
Assembly U-Value (W/sq.mK)	**2.5**		**1.4**		**-44.0%**
Assembly U-Value (Btu/hft2F)	0.440		0.247		
Frame Type	wood				
Infiltration Rate (ACH at 50 P)					
Notes					
Mechanical Systems					
Ventilation	natural		ERV		
Type			whole house		
Efficiency			75%		
Ventilation Rate (ACH)					
Heating					
Type of Fuel					
Capacity (kW)					
Efficiency					
Distribution System					
Distribution Media					
Terminal Units					
Cooling	no		no		
Type of Fuel					
Efficiency					

Hot Water			
Type of Fuel			
Efficiency			
Storage Tanks			
Capacity (liters)			
Use			
Solar Thermal Collectors	no	no	
Area (sq.m)			
Capacity (kW)			
Use			
Photovoltaics	no	no	
Area (sq.m)			
Power (kW)			
Generat. Energy (kW/sq.m*a)			
Notes			

Contact Details	
Architect / Studio	**Poppe Prehal Architekten** (contact person Dr. Helmut Poppe)
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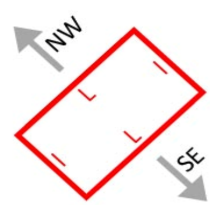
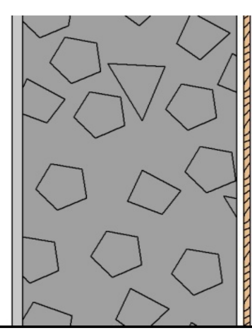
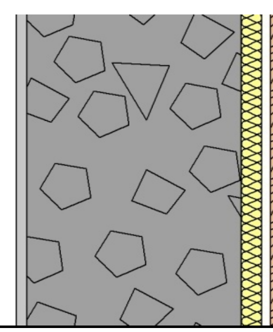
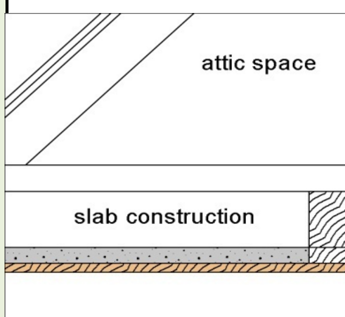
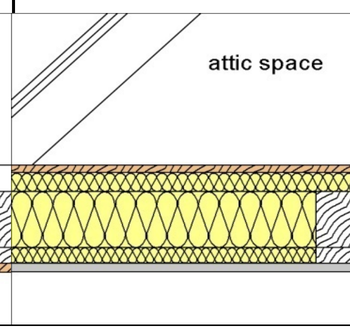
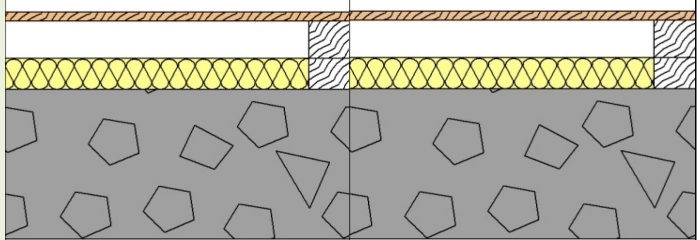
Energy Consultant	
Tel	
e-mail	
Mechanical Engineer	
Tel	
e-mail	

Project Name:	**Freihof Sulz**		
APPENDIX 11			
	before retrofit	**after retrofit**	**improvement %**
Location			
City	Sulz		
State / Country	Austria		
Address	Schuetzenstrasse 14, 6832 Sulz, Austria		
Location Type	suburb		
Climate			
Climate Zone	5		Ashrae 189.1 (09)
HDD (65 F)	**5,149**		(degreedays.net)
CDD (65 F)	**697**		(degreedays.net)
Notes			
Building Details			
Year of Construction	1899		
Year of Retrofit	2004		
Historic Preservation Status	building		
Preservation Constraints Walls	outside + inside		
Preservation Constraints Roof	outside		
Building Use	residential (hotel)		
Building Type	detached		
L/l ratio (Length/Width)	1.8		
Orientation	NW-SE		
			
No. of Floors	3	3	
No. of Units	1	1	
Constructed Area (sq.m)	1,180	1,180	
Condition. Usable Area (sq.m)	1,018	1,018	**0.0%**
A/V ratio (cond. env. Area/V)	0.30	0.30	
Notes	vaulted basement - built in 1796		

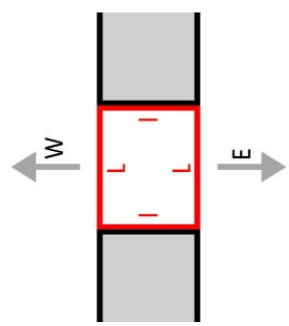
Construction Costs					
Total Construction Costs (Euro)					
Cost (Euro/sq.m)					
Cost of Energy Retrofit (€/sq.m)					
Energy Consumption					
Type of data	simulated	metered	simulated	metered	
Heating (kWh/sq.m*a)	**160**		**57.55**		
Heating (kBtu/sq.ft*a)	50.7		18.2		
Heating (kWh/sq.m*HDD)	0.0311		0.0112		**-64.0%**
Cooling (kWh/sq.m*a)					
Hot Water (kWh/sq.m*a)					
Ventilation (kWh/sq.m*a)					
Lighting (kWh/sq.m*a)					
Notes	no cooling needed in this climate				
Walls - AW 02 - Exterior Wall with interior insulation					
Insulation Type	**none**		**wood fiber board**		
Insulation Location			interior		
Insulation Thickness (mm)			60		
Insulation Conductivity (W/mK)			0.042		
Insulation U-Value (W/sq.mK)			0.700		
Insulation U-Value (Btu/hft2F)			0.123		
Assembly U-Value (W/sq.mK)	**1.259**		**0.452**		**-64.1%**
Assembly U-Value (Btu/hft2F)	0.222		0.080		
Main Layers (outside-inside)		mm		mm	
Layer 1	plaster	30	plaster	30	unchanged
Layer 2	stone wall	620	stone wall	620	
Layer 3			wood fiber board	60	
Layer 4	air layer (still)	20	air layer (still)	25	
Layer 5	solid wood	20	solid wood	20	
Layer 6					
Layer 7					
Layer 8					
Total Thickness		690		755	
Construction Detail					
Notes	The rest of the extrerior walls are not insulated				
Area (m2)	436.7	84.64%	436.7	84.64%	
Total Area Walls (m2)	515.93	100.00%	515.93	100.00%	

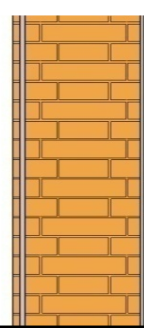
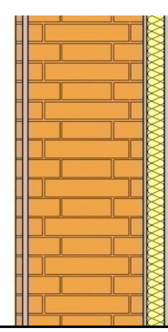
Roof - AD01 - Slab towards the unconditioned attic					
Attic	unconditioned		unconditioned		
Insulation Type	**none**		**flax fiber board**		
Insulation Location			cavity		
Insulation Thickness (mm)			310		
Insulation Conductivity (W/mK)			0.042		
Insulation U-Value (W/sq.mK)			0.135		
Insulation U-Value (Btu/hft2F)			0.024		
Assembly U-Value (W/sq.mK)			**0.144**		
Assembly U-Value (Btu/hft2F)			0.025		
Main Layers (top-bottom)		mm		mm	
Layer 1	solid wood	24	solid wood	24	unchanged
Layer 2	air layer btw joists	310	flax fibre board	80	
Layer 3			flax fibre board	180	
Layer 4			flax fibre board	50	
Layer 5			plasterboard	27	
Layer 6					
Layer 7					
Layer 8					
Total Thickness		334		361	
Construction Detail					
Notes					

Floor / Slab - KD01 - Slab over unconditioned basement					
Basement	unconditioned		unconditioned		
Insulation Type	**wood fibers**		**wood fibers**		
Insulation Location	interior		interior		
Insulation Thickness (mm)	100		100		
Insulation Conductivity (W/mK)	0.042		0.042		
Insulation U-Value (W/sq.mK)	0.420		0.420		
Insulation U-Value (Btu/hft2F)	0.074		0.074		
Assembly U-Value (W/sq.mK)	**0.407**		**0.407**		**0.0%**
Assembly U-Value (Btu/hft2F)	0.072		0.072		
Main Layers (top-bottom)		mm		mm	
Layer 1	solid wood	30	solid wood	30	unchanged
Layer 2	air layer	120	air layer	120	
Layer 3	wood fibres	100	wood fibres	100	

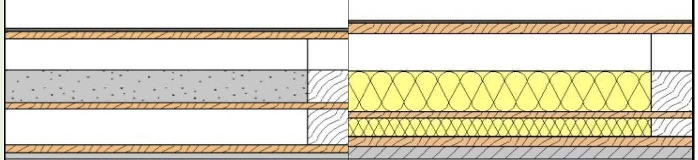
Layer 4	natural stone slab	1000	natural stone slab	1000	
Layer 5					
Layer 6					
Layer 7					
Layer 8					
Total Thickness		1250		1250	
Construction Detail					
Notes	Slab of the main body of the house (3 stories)				
Area (m2)	282.9	75.46%	282.9	75.46%	
Total Area Walls (m2)	374.9	100.00%	374.9	100.00%	
Windows					
Glazing Type	single		single		
Coating			low-E		
Gas filling					
Window Location					
Glazing U-Value (W/sq.mK)			1.900		
Glazing U-Value (Btu/hft2F)			0.335		
SHGC			0.630		
			2.06		
Assembly U-Value (Btu/hft2F)			0.363		
Frame Type	wood		wood		
Infiltration Rate (ACH at 50 P)			2 (to 3)		
Notes	original windows were refurbished using a low-E coating				
Mechanical Systems					
Ventilation	natural		HRV		
Type			kitchen and dining room		
Efficiency			65%		
Ventilation Rate (ACH)			17 (11)		
Heating			pellet boiler		
Type of Fuel			pellets		
Capacity (kW)					
Efficiency					
Distribution System					
Distribution Media			water		
Terminal Units			radiators/ walls/ ceilings		
Cooling			no		
Type of Fuel					
Efficiency					

Hot Water			
Type of Fuel			
Efficiency			
Storage Tanks		yes	
Capacity (liters)		4400	
Use		heating/hot water	
Solar Thermal Collectors	no	yes	
Area (sq.m)		52	
Capacity (kW)			
Use		heating/hot water	
Photovoltaics	no	no	
Area (sq.m)			
Power (kW)			
Generat. Energy (kW/sq.m*a)			
Notes	Ventilation - only for kitchen and ating area		
Contact Details			
Architect / Studio			
Tel			
e-mail			
Energy Consultant			
Tel			
e-mail			
Mechanical Engineer			
Tel			
e-mail			

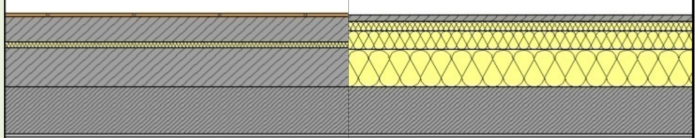
Project Name:	**Kleine Freiheit - EnSan Building (Southern Half)**		
APPENDIX 12			
			
	before retrofit	**after retrofit**	**improvement %**
Location			
City	Hamburg		
State / Country	Germany		
Address	Kleine Freiheit 46-48, Hamburg, Germany		
Location Type	inner city		
Climate			
Climate Zone	5		Ashrae 189.1 (09)
HDD (65 F)	**6,011**		(degreedays.net)
CDD (65 F)	**269**		(degreedays.net)
Notes	Northern Germany, close to the North Sea coast		
Building Details			
Year of Construction	1907		
Year of Retrofit	2006		
Historic Preservation Status	building		
Preservation Constraints Walls	outside (street façade)		
Preservation Constraints Roof	outside		
Building Use	residential + commercial (ground floor)		
Building Type	attached 2 sides		
L/l ratio (Length/Width)	0.66		
Orientation	E-W		
			
No. of Floors	4+1	4+1	
No. of Units	7 res./2 com.	7 res./2 com..	
Constructed Area (sq.m)			
Condition. Usable Area (sq.m)	647	696	**7.6%**
A/V ratio (cond. env. Area/V)	0.40	0.35	
Notes	two identical attached buildings - retrofited to different standards		

	total no. of units - 14 / cond. usable A - **1294** (before), **1391** (after)				
Construction Costs					
Total Construction Costs			1,121,256		
Total Cost (Euro/sq.m)			**1,611**		
Cost of Energy Retrofit (€/sq.m)			**820**		
Energy Consumption					
Type of data	simulated	metered	simulated	metered	
Heating (kWh/sq.m*a)		**261**		**32.3**	
Heating (kBtu/sq.ft*a)		82.7		10.2	
Heating (kWh/sq.m*HDD)		0.0434		0.0054	**-87.6%**
Cooling (kWh/sq.m*a)					
Hot Water (kWh/sq.m*a)		39.5		24.8	
Ventilation (kWh/sq.m*a)				2.3	
Lighting (kWh/sq.m*a)					
Notes	Retrofit of the Southern Half using EnSan Best Practices				
	Hot Water Energy is higher than HH Building due to higher occupancy				
Wall 1 - Street Elevation - Floors 2-4					
Insulation Type	**none**		**calcium silicate plates**		
Insulation Location			interior		
Insulation Thickness (mm)			50		
Insulation Conductivity (W/mK)			0.05		
Insulation U-Value (W/sq.mK)			1.000		
Insulation U-Value (Btu/hft2F)			0.176		
Assembly U-Value (W/sq.mK)	**1.615**		**0.613**		**-62.0%**
Assembly U-Value (Btu/hft2F)	0.284		0.108		
Main Layers (outside-inside)		mm		mm	
Layer 1	clinker	20	clinker	20	unchanged
Layer 2	mortar	15	mortar	15	
Layer 3	solid brick	335	solid brick	335	
Layer 4	plaster	10	plaster	10	
Layer 5			calcium silicate	50	
Layer 6			plaster	15	
Layer 7					
Layer 8					
Total Thickness		380		445	
Construction Detail					
Notes: total area walls (sq. m)	532.98	100%	440.38	100%	
Area for this assembly (sq.m)	82.85	16%	82.85	19%	

avg. U-Value Walls (W/sq.mK)	**1.554**		**0.306**		**-80.3%**
Roof 1 - Tilted Roof over Main Living Rooms					
Attic	conditioned + uncond.		conditioned + uncond.		
Insulation Type	**none**		**mineral wool + min. foam**		
Insulation Location			cavtiy		
Insulation Thickness (mm)			190		
Insulation Conductivity (W/mK)			0.04		
Insulation U-Value (W/sq.mK)			0.211		
Insulation U-Value (Btu/hft2F)			0.037		
Assembly U-Value (W/sq.mK)	**0.761**		**0.175**		**-77.0%**
Assembly U-Value (Btu/hft2F)	0.134		0.031		
Main Layers (top-bottom)		mm		mm	
Layer 1	bitumen	10	bitumen	8	
Layer 2	solid wood	25	plywood	35	
Layer 3	air layer	100	air layer	120	
Layer 4	loose fill (sand)	105	mineral wool	130	
Layer 5	solid wood	20	solid wood	20	
Layer 6	air layer	115	mineral foam	60	roof
Layer 7	solid wood	25	polyethylen h. dens.	2	structure
Layer 8	plaster	20	wood + plaster board	70	replaced
Total Thickness		420		445	
Construction Detail					



Notes: total area roofs (sq. m)	163.56	100%	175.9	100%	
Area for this assembly (sq.m)	52.97	32%	56.31	32%	
avg. U-Value Roofs (W/sq.mK)	**1.097**		**0.200**		**-81.8%**
Floor / Slab 1 - Slab over Unconditioned Basement					
Basement	unconditioned		unconditioned		
Insulation Type	**none**		**min. fiber**	**EPS foam**	
Insulation Location			interior	interior	
Insulation Thickness (mm)			30	180	
Insulation Conductivity (W/mK)			0.035	0.04	
Insulation U-Value (W/sq.mK)			1.167	0.222	
Insulation U-Value (Btu/hft2F)			0.205	0.039	
Assembly U-Value (W/sq.mK)	**0.838**		**0.177**		**-78.9%**
Assembly U-Value (Btu/hft2F)	0.148		0.031		
Main Layers (top-bottom)		mm		mm	
Layer 1	ceramic plates	10	cement screed	20	
Layer 2	cement screed	80	mineral fiber	30	

Layer 3	mineral fiber	20	EPS foam	60	
Layer 4	light concrete	125	EPS foam	120	
Layer 5	reinforced concrete	150	reinforced concrete	110	unchanged
Layer 6	plaster	10			
Layer 7					
Layer 8					
Total Thickness		395		340	
Construction Detail					
Notes: total area slabs (sq. m)	191.67	100%	198.78	100%	
Area for this assembly (sq.m)	35.86	19%	40.77	21%	
avg. U-Value Slabs (W/sq.mK)	**1.193**		**0.228**		**-80.9%**
Windows					
Glazing Type	single		double		
Coating					
Gas filling					
Window Location			replacement		
Glazing U-Value (W/sq.mK)					
Glazing U-Value (Btu/hft2F)					
SHGC					
Assembly U-Value (W/sq.mK)	**4.388**		**1.300**		**-70.4%**
Assembly U-Value (Btu/hft2F)	0.773		0.229		
Frame Type	wood		wood		
Infiltration Rate (ACH at 50 P)	10.35				
Notes	Infiltration measured in 2 units: 1st Fl (9.8), 3rd Fl (11.7) avg=10.35				
Mechanical Systems					
Ventilation	**natural**		**HRV**		
Type			individual units		
Efficiency					
Ventilation Rate (ACH)					
Heating	**individual units**		**gas boiler**		
Type of Fuel	electrical/gas/coal+wood		gas		
Capacity (kW)	variable		60		
Efficiency					
Distribution System			water		
Distribution Media	air+water		water		
Terminal Units			radiators		
Cooling	**no**		**no**		
Type of Fuel					

Efficiency			
Hot Water	**individual units**	**gas boiler (backup)**	
Type of Fuel	electrical/gas		
Efficiency			
Storage Tanks	**depending on units**	**yes**	
Capacity (liters)		2 x 1000	
Use		heating + hot water	
Solar Thermal Collectors	**no**	**yes**	
Area (sq.m)		30	
Capacity (kW)		24	
Use		heating + hot water	
Photovoltaics	**no**	**no**	
Area (sq.m)			
Power (kW)			
Generat. Energy (kW/sq.m*a)			
Notes	heating systems before: coal-6 units, gas-7 units, electric-4 units hot water: electric boiler-6 units, electric instant-7 units, gas instant-4 unit mechanical systems are used in common by both buildings		
Contact Details			
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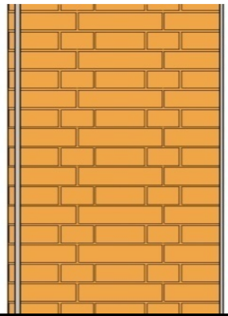
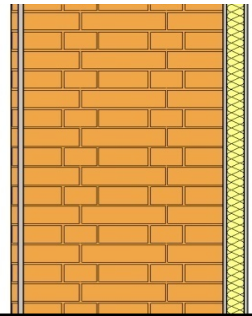
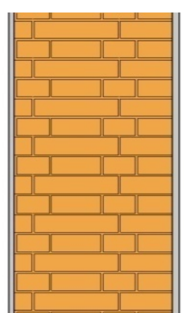
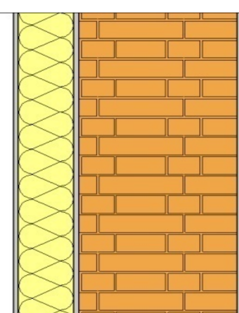
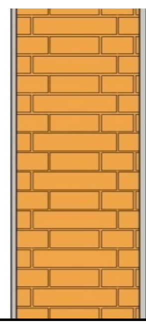
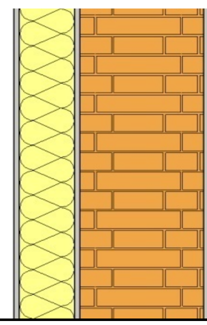
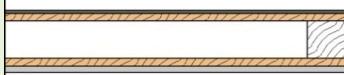
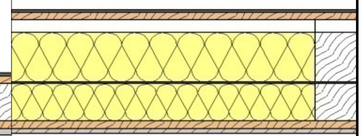
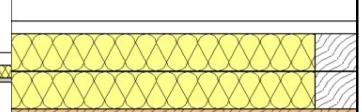
Energy Consultant	**T.U. Hamburg Harburg** (contact person Prof. Dr.-Ing. H.-J. Holle)		
Tel	+49 40 428784041		
e-mail	h-j.holle@tuhh.de		
Mechanical Engineer	**innovaTec Energusysteme GmbH** (contact: Dipl.-Ing. Joachim Otte)		
Tel	+49 5609 80920		
e-mail	info@innovatec-web.de		

Wall 2 - Street Elevation - Ground Floor					
Insulation Type	**none**		**calcium silcate plates**		
Insulation Location			interior		
Insulation Thickness (mm)			50		
Insulation Conductivity (W/mK)			0.05		
Insulation U-Value (W/sq.mK)			1.000		
Insulation U-Value (Btu/hft2F)			0.176		
Assembly U-Value (W/sq.mK)	**1.102**		**0.521**		**-52.7%**
Assembly U-Value (Btu/hft2F)	0.194		0.092		
Main Layers (outside-inside)		mm		mm	
Layer 1	clinker	20	clinker	20	unchanged
Layer 2	mortar	15	mortar	15	
Layer 3	solid brick	580	solid brick	580	
Layer 4	plaster	20	plaster	20	
Layer 5			calcium silicate	50	
Layer 6			plaster	10	
Layer 7					
Layer 8					
Total Thickness		635		695	

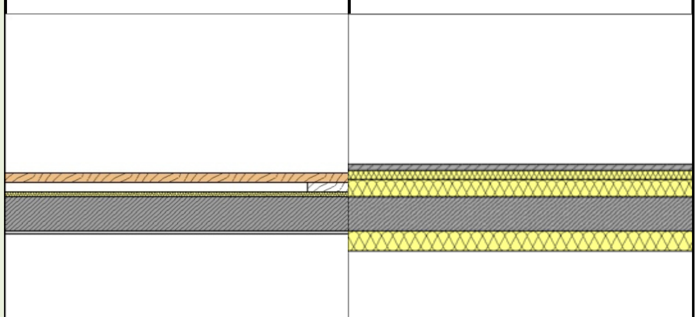
Construction Detail					
Notes: total area walls (sq. m)	532.98	100%	440.38	100%	
Area for this assembly (sq.m)	17.32	3%	18.98	4%	
avg. U-Value Walls (W/sq.mK)	**1.554**		**0.306**		**-80.3%**
Wall 3 - Back Yard Elevation - Ground Floor					
Insulation Type	**none**		**mineral fiber**		
Insulation Location			exterior		
Insulation Thickness (mm)			160		
Insulation Conductivity (W/mK)			0.035		
Insulation U-Value (W/sq.mK)			0.219		
Insulation U-Value (Btu/hft2F)			0.039		
Assembly U-Value (W/sq.mK)	**1.342**		**0.188**		**-86.0%**
Assembly U-Value (Btu/hft2F)	0.236		0.033		
Main Layers (outside-inside)		mm		mm	
Layer 1			plaster	10	
Layer 2			mineral fiber	160	
Layer 3	plaster	15	plaster	15	unchanged
Layer 4	solid brick	460	solid brick	460	
Layer 5	plaster	20	plaster	20	
Layer 6					
Layer 7					
Layer 8					
Total Thickness		495		665	
Construction Detail					
Notes: total area walls (sq. m)	532.98	100%	440.38	100%	
Area for this assembly (sq.m)	119.58	22%	83.97	19%	
avg. U-Value Walls (W/sq.mK)	**1.554**		**0.306**		**-80.3%**
Wall 4 - Back Yard Elevation - Floors 2-4					
Insulation Type	**none**		**mineral fiber**		
Insulation Location			exterior		
Insulation Thickness (mm)			160		

Insulation Conductivity (W/mK)			0.035		
Insulation U-Value (W/sq.mK)			0.219		
Insulation U-Value (Btu/hft2F)			0.039		
Assembly U-Value (W/sq.mK)	**1.593**		**0.192**		**-87.9%**
Assembly U-Value (Btu/hft2F)	0.281		0.034		
Main Layers (outside-inside)		mm		mm	
Layer 1			plaster	10	
Layer 2			mineral fiber	160	
Layer 3	plaster	15	plaster	15	unchanged
Layer 4	solid brick	360	solid brick	360	
Layer 5	plaster	20	plaster	20	
Layer 6					
Layer 7					
Layer 8					
Total Thickness		395		565	
Construction Detail					w
Notes: total area walls (sq. m)	532.98	100%	440.38	100%	
Area for this assembly (sq.m)	284.63	53%	203.73	46%	
avg. U-Value Walls (W/sq.mK)	**1.554**		**0.306**		**-80.3%**
Roof 2 - Flat Roof over Kitchen, Bathroom and Corridor					
Attic	conditioned+uncond.		conditioned+uncond.		
Insulation Type	**none**		**mineral wool**		
Insulation Location			cavtiy		
Insulation Thickness (mm)			280		
Insulation Conductivity (W/mK)			0.04		
Insulation U-Value (W/sq.mK)			0.143		
Insulation U-Value (Btu/hft2F)			0.025		
Assembly U-Value (W/sq.mK)	**1.227**		**0.158**		**-87.1%**
Assembly U-Value (Btu/hft2F)	0.216		0.028		
Main Layers (top-bottom)		mm		mm	
Layer 1			bitumen	8	
Layer 2			plywood	25	
Layer 3			air layer	40	
Layer 4	bitumen	10	mineral wool	160	
Layer 5	solid wood	25	polyethylen h. dens.	5	
Layer 6	air layer	120	mineral wool	120	unchanged
Layer 7	solid wood	25	solid wood	25	roof structure
Layer 8	plaster	20	plasterboard	15	

Total Thickness		200		398	
Construction Detail					
Notes: total area roofs (sq. m)	163.56	100%	175.9	100%	
Area for this assembly (sq.m)	46.12	28%	46.12	26%	
avg. U-Value Roofs (W/sq.mK)	**1.097**		**0.200**		**-81.8%**
Roof 3 - Steep Roof towards the Street					
Attic	conditioned+uncond.		conditioned+uncond.		
Insulation Type	**wood wool plates**		**mineral wool**		
Insulation Location			cavtiy + interior		
Insulation Thickness (mm)	40		240		
Insulation Conductivity (W/mK)	0.08		0.04		
Insulation U-Value (W/sq.mK)	2.000		0.167		
Insulation U-Value (Btu/hft2F)	0.352		0.029		
Assembly U-Value (W/sq.mK)	**1.522**		**0.182**		**-88.0%**
Assembly U-Value (Btu/hft2F)	0.268		0.032		
Main Layers (top-bottom)		mm		mm	
Layer 1	exterior finish		exterior finish		
Layer 2	wood wool plates	40	mineral wool	120	
Layer 3	plaster	15	polyethylen h. dens.	2	
Layer 4			mineral wool	120	
Layer 5			solid wood	20	
Layer 6			plasterboard	15	roof
Layer 7					structure
Layer 8					replaced
Total Thickness		55		277	
Construction Detail					
Notes: total area roofs (sq. m)	163.56	100%	175.9	100%	
Area for this assembly (sq.m)	43.02	26%	33.42	19%	
avg. U-Value Roofs (W/sq.mK)	**1.097**		**0.200**		**-81.8%**
Floor / Slab 2 - Slab over Unconditioned Basement					

Basement	unconditioned		unconditioned		
Insulation Type	**torf plates**		**mineral fiber + EPS foam**		
Insulation Location	interior		interior	exterior	
Insulation Thickness (mm)	15		85	65	
Insulation Conductivity (W/mK)	0.05		0.035	0.04	
Insulation U-Value (W/sq.mK)	3.333		0.412	0.615	
Insulation U-Value (Btu/hft2F)	0.587		0.073	0.108	
Assembly U-Value (W/sq.mK)	**1.076**		**0.231**		**-78.5%**
Assembly U-Value (Btu/hft2F)	0.190		0.041		
Main Layers (top-bottom)		mm		mm	
Layer 1	solid wood floor	30	cement screed	20	
Layer 2	air layer	30	mineral fiber	30	
Layer 3	turf plates	15	EPS foam	55	
Layer 4	reinforced concrete	110	reinforced concrete	110	unchanged
Layer 5	plaster	10	EPS foam	65	
Layer 6					
Layer 7					
Layer 8					
Total Thickness		195		280	

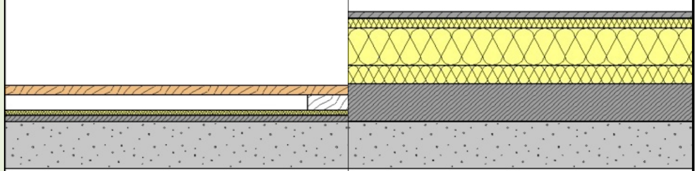
Construction Detail

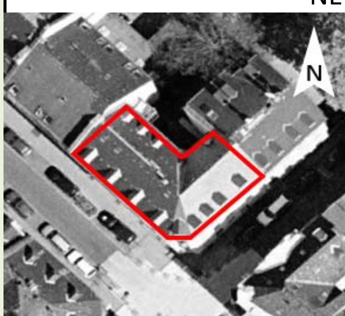
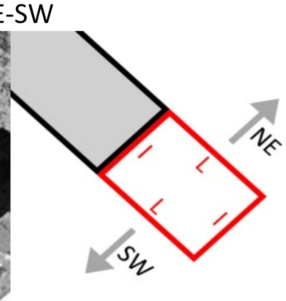


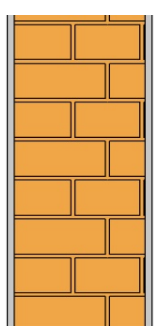
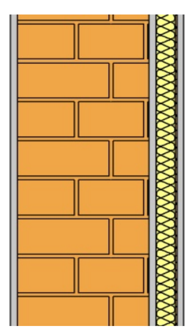
Notes: total area slabs (sq. m)	191.67	100%	198.78	100%	
Area for this assembly (sq.m)	77.74	41%	80.76	41%	
avg. U-Value Slabs (W/sq.mK)	**1.193**		**0.228**		**-80.9%**

Floor / Slab 3 - Slab on Grade

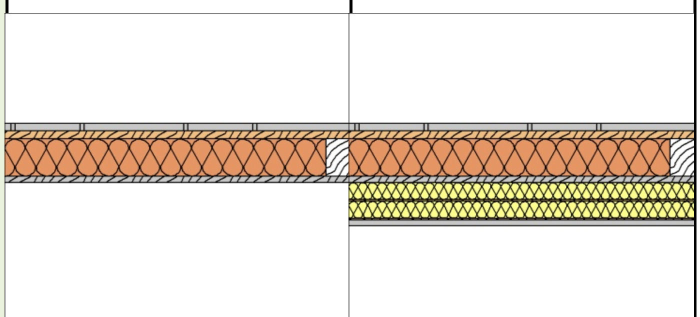
Basement	unconditioned		unconditioned		
Insulation Type	**turf plates**		**mineral fiber + EPS foam**		
Insulation Location	interior		interior		
Insulation Thickness (mm)	15		210		
Insulation Conductivity (W/mK)	0.05		0.04		
Insulation U-Value (W/sq.mK)	3.333		0.190		
Insulation U-Value (Btu/hft2F)	0.587		0.034		
Assembly U-Value (W/sq.mK)	**0.857**		**0.176**		**-79.5%**
Assembly U-Value (Btu/hft2F)	0.151		0.031		
Main Layers (top-bottom)		mm		mm	
Layer 1			cement screed	20	
Layer 2	solid wood floor	30	polyethylene foil	2	
Layer 3	air layer	50	mineral fiber	30	
Layer 4	turf plates	15	EPS foam x 2	180	
Layer 5	bitumen	2	reinforced concrete	120	

Layer 6	reinforced concrete	20	polyethylen h. dens.	2	
Layer 7	sand/rock fill	150	sand/rock fill	150	unchanged
Total Thickness		267		504	
Construction Detail					
Notes: total area slabs (sq. m)	191.67	100%	198.78	100%	
Area for this assembly (sq.m)	54.66	29%	48.42	24%	
avg. U-Value Slabs (W/sq.mK)	**1.193**		**0.228**		**-80.9%**

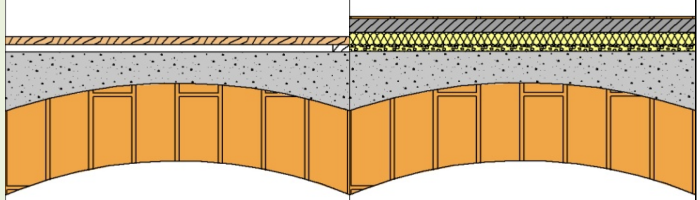
Project Name:	**Lehrstrasse 2 Wiesbaden**		
APPENDIX 13			
	before retrofit	**after retrofit**	**improvement** %
Location			
City	Wiesbaden		
State / Country	Hessen / Germany		
Address	Lehrstrasse 2, Wiesbaden, Germany		
Location Type	inner city		
Climate			
Climate Zone	5		Ashrae 189.1 (09)
HDD (65 F)	**5,638**		(degreedays.net)
CDD (65 F)	**481**		(degreedays.net)
Notes			
Building Details			
Year of Construction	1880 - 1890		
Year of Retrofit	2002		
Historic Preservation Status	building		
Preservation Constraints Walls	outside		
Preservation Constraints Roof	outside		
Building Use	residential		
Building Type	attached 2 sides - corner building		
L/l ratio (Length/Width)	1.8		
Orientation	NE-SW		
			
No. of Floors	3 +1	3 +1	
No. of Units			
Constructed Area (sq.m)		680	
Condition. Usable Area (sq.m)		646	
A/V ratio (cond. env. Area/V)			
Notes			

Construction Costs					
Total Construction Costs (Euro)			919,904		
Cost (Euro/sq.m)			**1,424**		
Cost of Energy Retrofit (€/sq.m)					
Energy Consumption					
Type of data	simulated	metered	simulated	metered	
Heating (kWh/sq.m*a)	**219.4**		**94.7**		
Heating (kBtu/sq.ft*a)	69.5		30.0		
Heating (kWh/sq.m*HDD)	0.0389		0.0168		**-56.8%**
Cooling (kWh/sq.m*a)			`		
Hot Water (kWh/sq.m*a)					
Ventilation (kWh/sq.m*a)					
Lighting (kWh/sq.m*a)					
Notes	no cooling needed in this climate				
Walls - Street Façade					
Insulation Type	**none**		**EPS coated with wood fibers**		
Insulation Location			interior		
Insulation Thickness (mm)			55		
Insulation Conductivity (W/mK)			0.035		
Insulation U-Value (W/sq.mK)			0.636		
Insulation U-Value (Btu/hft2F)			0.112		
Assembly U-Value (W/sq.mK)	**1.620**		**0.444**		**-72.6%**
Assembly U-Value (Btu/hft2F)	0.285		0.078		
Main Layers (outside-inside)		mm		mm	
Layer 1	plaster	20	plaster	20	unchanged
Layer 2	solid brick	380	solid brick	380	
Layer 3	plaster	20	plaster	20	
Layer 4			EPS	55	
Layer 5			wood fibres coating	5	
Layer 6			plaster	20	
Layer 7					
Layer 8					
Total Thickness		420		500	
Construction Detail					
Notes	the interior plaster makes up the vapour barrier				

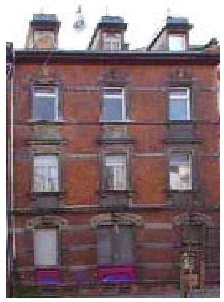
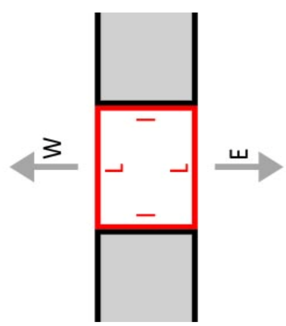
Roof - Tilted Roof (over conditioned attic)					
Attic	conditioned		conditioned		
Insulation Type	**none**		**EPS coated with wood fibres**		
Insulation Location			interior		
Insulation Thickness (mm)			110		
Insulation Conductivity (W/mK)			0.035		
Insulation U-Value (W/sq.mK)			0.318		
Insulation U-Value (Btu/hft2F)			0.056		
Assembly U-Value (W/sq.mK)	**1.261**		**0.272**		**-78.4%**
Assembly U-Value (Btu/hft2F)	0.222		0.048		
Main Layers (top-bottom)		mm		mm	
Layer 1	tiling + solid wood	50	tiling + solid wood	50	unchanged
Layer 2	puddled clay	120	puddled clay	120	
Layer 3	clay plaster/ reed net	20	clay plaster/ reed net	20	
Layer 4			EPS	55	
Layer 5			wood fibres coating	5	
Layer 6			EPS	55	
Layer 7			wood fibres coating	5	
Layer 8			plaster	20	
Total Thickness		190		330	
Construction Detail					
Notes	puddled clay used as insulation between 120 mm rafters the interior plaster makes up the vapour barrier				

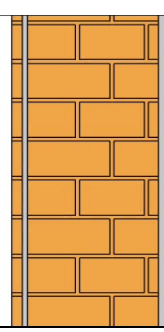
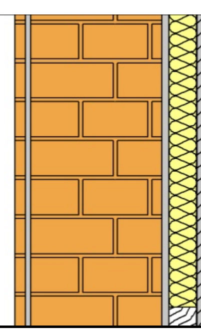


Floor / Slab					
Basement	unconditioned		unconditioned		
Insulation Type	**none**		**EPS**	**fermacell**	
Insulation Location	`		interior	interior	
Insulation Thickness (mm)			40	20	
Insulation Conductivity (W/mK)			0.035	0.05	
Insulation U-Value (W/sq.mK)			0.875	2.500	
Insulation U-Value (Btu/hft2F)			0.154	0.440	
Assembly U-Value (W/sq.mK)	**0.949**		**0.444**		**-53.2%**
Assembly U-Value (Btu/hft2F)	0.167		0.078		
Main Layers (top-bottom)		mm		mm	
Layer 1			ceramic tiles	6	
Layer 2			screed	45	
Layer 3	solid wood floor	25	EPS	40	

Layer 4	air layer 24	fermacell leveling 20	
Layer 5	sand filling 100	sand filling 100	unchanged
Layer 6	solid brick vaults 250	solid brick vaults 250	
Layer 7			
Layer 8			
Total Thickness	399	461	
Construction Detail			
Notes	fermacell leveling compound - used to level the floor		
Windows			
Glazing Type	single and double	triple	
Coating			
Gas filling			
Window Location		replacement	
Glazing U-Value (W/sq.mK)			
Glazing U-Value (Btu/hft2F)	0.000	0.000	
SHGC	0.86	0.60	
Assembly U-Value (W/sq.mK)	**5.0**	**1.7**	**-66.0%**
Assembly U-Value (Btu/hft2F)	0.881	0.299	
Frame Type	wood and PVC	wood	
Infiltration Rate (ACH at 50 P)			
Notes	new windows with wooden frames to imitate historic frames		
Mechanical Systems			
Ventilation	natural	HRV	
Type			
Efficiency			
Ventilation Rate (ACH)			
Heating	coal and oil	central heating	
Type of Fuel		gas	
Capacity (kW)			
Efficiency			
Distribution System			
Distribution Media			
Terminal Units			
Cooling			
Type of Fuel			
Efficiency			

Hot Water			
Type of Fuel			
Efficiency			
Storage Tanks			
Capacity (liters)			
Use			
Solar Thermal Collectors			
Area (sq.m)			
Capacity (kW)			
Use			
Photovoltaics			
Area (sq.m)			
Power (kW)			
Generat. Energy (kW/sq.m*a)			
Notes			
Contact Details			
Architect / Studio			
Tel			
e-mail			
Energy Consultant			
Tel			
e-mail			
Mechanical Engineer			
Tel			
e-mail			

Project Name:	Limburgstrasse Ludwigshafen		
APPENDIX 14			
	before retrofit	**after retrofit**	**improvement %**
Location			
City	Ludwigshafen		
State / Country	Rheinland-Pfalz / Germany		
Address	Limburgstrasse 19/21, Ludwigshafen-Hemshof, Germany		
Location Type	inner city		
Climate			
Climate Zone	4		Ashrae 189.1 (09)
HDD (65 F)	**5,090**		(degreedays.net)
CDD (65 F)	**666**		(degreedays.net)
Notes			
Building Details			
Year of Construction	1900		
Year of Retrofit	2004		
Historic Preservation Status	building		
Preservation Constraints Walls	outside		
Preservation Constraints Roof	outside		
Building Use	residential		
Building Type	attached 2 sides		
L/l ratio (Length/Width)	1.86		
Orientation	E-W		
			
No. of Floors	4	4	
No. of Units			
Constructed Area (sq.m)			
Condition. Usable Area (sq.m)		651	
A/V ratio (cond. env. Area/V)			
Notes			

Construction Costs					
Total Construction Costs (Euro)					
Cost (Euro/sq.m)					
Cost of Energy Retrofit (€/sq.m)					
Energy Consumption					
Type of data	simulated	metered	simulated	metered	
Heating (kWh/sq.m*a)	**230.2**		**35.6**		
Heating (kBtu/sq.ft*a)	73.0		11.3		
Heating (kWh/sq.m*HDD)	0.0452		0.0070		**-84.5%**
Cooling (kWh/sq.m*a)					
Hot Water (kWh/sq.m*a)					
Ventilation (kWh/sq.m*a)					
Lighting (kWh/sq.m*a)					
Notes	no cooling needed in this climate				
Walls - Front Façade					
Insulation Type	**none**		**Mineral wool / EPS**		
Insulation Location			interior		
Insulation Thickness (mm)			80		
Insulation Conductivity (W/mK)			0.035		
Insulation U-Value (W/sq.mK)			0.438		
Insulation U-Value (Btu/hft2F)			0.077		
Assembly U-Value (W/sq.mK)	**1.370**		**0.330**		
Assembly U-Value (Btu/hft2F)	0.241		0.058		
Main Layers (outside-inside)		mm		mm	
Layer 1	brick facing	30	brick facing	30	unchanged
Layer 2	plaster	15	plaster	15	
Layer 3	solid brick	380	solid brick	380	
Layer 4	plaster	20	plaster	20	
Layer 5			min. wool / EPS	80	
Layer 6			vapour barrier		
Layer 7			plasterboard	20	
Layer 8					
Total Thickness		445		545	
Construction Detail					
Notes	the vapour barrier was attached 1 m into the inner space along the interior walls and slabs interior insulation - airtightness - mechanical ventilation necessary				

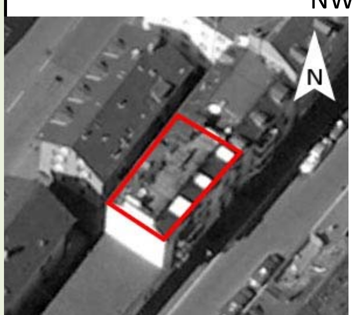
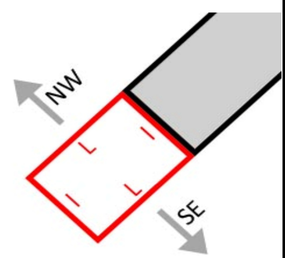
Roof			
Attic	unconditioned	unconditioned	
Insulation Type	**none**	**mineral wool**	
Insulation Location		cavity	
Insulation Thickness (mm)		200	
Insulation Conductivity (W/mK)		0.035	
Insulation U-Value (W/sq.mK)		0.175	
Insulation U-Value (Btu/hft2F)		0.031	
Assembly U-Value (W/sq.mK)		**0.180**	
Assembly U-Value (Btu/hft2F)	0.000	0.032	
Main Layers (top-bottom)	mm	mm	
Layer 1			
Layer 2			
Layer 3			
Layer 4			
Layer 5			
Layer 6			
Layer 7			
Layer 8			
Total Thickness	0	0	
Construction Detail			
Notes			

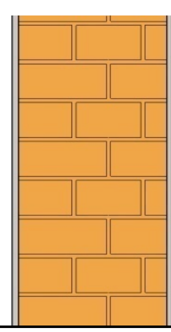
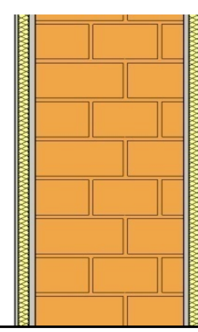
Floor / Slab			
Basement	none	none	
Insulation Type	**none**		
Insulation Location			
Insulation Thickness (mm)			
Insulation Conductivity (W/mK)			
Insulation U-Value (W/sq.mK)			
Insulation U-Value (Btu/hft2F)			
Assembly U-Value (W/sq.mK)			
Assembly U-Value (Btu/hft2F)			
Main Layers (top-bottom)	mm	mm	
Layer 1			
Layer 2			
Layer 3			

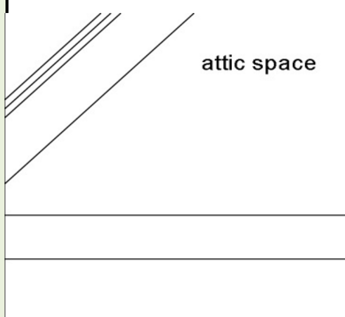
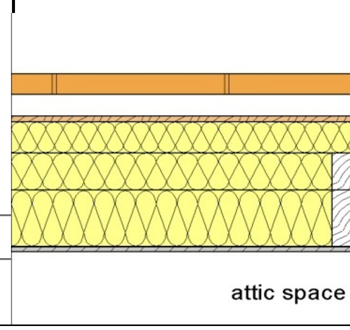
Layer 4			
Layer 5			unchanged
Layer 6			
Layer 7			
Layer 8			
Total Thickness	0	0	
Construction Detail			
Notes			
Windows			
Glazing Type	single	triple	
Coating			
Gas filling			
Window Location		replacement	
Glazing U-Value (W/sq.mK)			
Glazing U-Value (Btu/hft2F)	0.000	0.000	
SHGC			
Assembly U-Value (W/sq.mK)		**1.1**	
Assembly U-Value (Btu/hft2F)		0.194	
Frame Type	wood	wood	
Infiltration Rate (ACH at 50 P)			
Notes			
Mechanical Systems			
Ventilation	natural	HRV	
Type		individual units	
Efficiency		90%	
Ventilation Rate (ACH)			
Heating		gas	
Type of Fuel		gas	
Capacity (kW)		44	
Efficiency			
Distribution System			
Distribution Media		water	
Terminal Units			
Cooling	no	no	
Type of Fuel			
Efficiency			

Hot Water			
Type of Fuel			
Efficiency			
Storage Tanks		yes	
Capacity (liters)		2 x 500	
Use		hot water	
Solar Thermal Collectors	no	yes	
Area (sq.m)		11	
Capacity (kW)			
Use		heating/hot water	
Photovoltaics	no	no	
Area (sq.m)			
Power (kW)			
Generat. Energy (kW/sq.m*a)			
Notes	solar thermal collectors - 60 - 65% of the hot water		

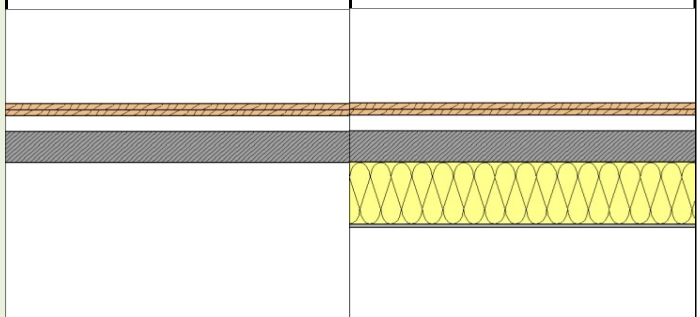
Contact Details	
Architect / Studio	
Tel	
e-mail	
Energy Consultant	
Tel	
e-mail	
Mechanical Engineer	
Tel	
e-mail	

Project Name:	**Magnusstrasse 23 Zuerich**		
APPENDIX 15			
	 **before retrofit**	 **after retrofit**	**improvement %**
Location			
City	Zuerich		
State / Country	Switzerland		
Address	Magnusstrasse 23, Zuerich, Switzerland		
Location Type	inner city		
Climate			
Climate Zone	5		Ashrae 189.1 (09)
HDD (65 F)	**6,188**		(degreedays.net)
CDD (65 F)	**444**		(degreedays.net)
Notes	Northern Switzerland		
Building Details			
Year of Construction	1894		
Year of Retrofit	2001		
Historic Preservation Status	building		
Preservation Constraints Walls	outside - street elevation		
Preservation Constraints Roof	geometry		
Building Use	residential		
Building Type	attached 1 side		
L/l ratio (Length/Width)	1.8		
Orientation	NW-SE		
			
No. of Floors	4 + 1	4 + 1	
No. of Units	4	4	
Constructed Area (sq.m)			
Condition. Usable Area (sq.m)	475	475	**0.0%**
A/V ratio (cond. env. Area/V)	0.35	0.35	
Notes			

Construction Costs					
Total Construction Costs (Euro)					
Cost (Euro/sq.m)					
Cost of Energy Retrofit (€/sq.m)					
Energy Consumption					
Type of data	simulated	metered	simulated	metered	
Heating (kWh/sq.m*a)		**122**	**17.5**	**28.4**	
Heating (kBtu/sq.ft*a)		38.7	5.5	9.0	
Heating (kWh/sq.m*HDD)		0.0197	0.0028	0.0046	**-76.7%**
Cooling (kWh/sq.m*a)					
Hot Water (kWh/sq.m*a)			13.8	13.3	
Ventilation (kWh/sq.m*a)					
Lighting (kWh/sq.m*a)					
Notes	no cooling needed in this climate heating energy after retrofit - average value for 2 years				
Wall - Street Façade					
Insulation Type	**none**		**rock wool**		
Insulation Location			interior + exterior		
Insulation Thickness (mm)			60		
Insulation Conductivity (W/mK)			0.036		
Insulation U-Value (W/sq.mK)			0.600		
Insulation U-Value (Btu/hft2F)			0.106		
Assembly U-Value (W/sq.mK)	**1.600**		**0.430**		**-73.1%**
Assembly U-Value (Btu/hft2F)	0.282		0.076		
Main Layers (outside-inside)		mm		mm	
Layer 1			plaster	10	
Layer 2			mineral wool	30	
Layer 3	plaster	20	plaster	20	unchanged
Layer 4	solid brick	430	solid brick	430	
Layer 5	plaster	15	plaster	15	
Layer 6			rock wool	30	
Layer 7			plaster	10	
Layer 8					
Total Thickness		465		545	
Construction Detail					
Notes	The street façade represents 20 % of the building envelope				
avg. U-Value Walls (W/sq.mK)	**1.600**		**0.170**		**-89.4%**

Roof					
Attic	conditioned		conditioned		
Insulation Type	**none**		**rock wool**		
Insulation Location			cavity		
Insulation Thickness (mm)			400		
Insulation Conductivity (W/mK)			0.036		
Insulation U-Value (W/sq.mK)			0.090		
Insulation U-Value (Btu/hft2F)			0.016		
Assembly U-Value (W/sq.mK)			**0.090**		
Assembly U-Value (Btu/hft2F)			0.016		
Main Layers (top-bottom)		mm		mm	
Layer 1			ceramic tile	66	
Layer 2			air layer	70	
Layer 3			particle board	18	
Layer 4			rock wool	100	
Layer 5			rock wool	120	
Layer 6			rock wool	180	roof
Layer 7			vapor barrier		structure
Layer 8			plaster board	15	replaced
Total Thickness		0		569	
Construction Detail					
Notes	prfabricated roof elements				

Floor / Slab					
Basement	unconditioned		unconditioned		
Insulation Type	**none**		**rock wool**		
Insulation Location			exterior		
Insulation Thickness (mm)			200		
Insulation Conductivity (W/mK)			0.036		
Insulation U-Value (W/sq.mK)			0.180		
Insulation U-Value (Btu/hft2F)			0.032		
Assembly U-Value (W/sq.mK)	**1.260**		**0.170**		**-86.5%**
Assembly U-Value (Btu/hft2F)	0.222		0.030		
Main Layers (top-bottom)		mm		mm	
Layer 1	wood floor	20	wood floor	20	
Layer 2	solid wood	20	solid wood	20	unchanged
Layer 3	fill	100	fill	100	

Layer 4	reinforced concrete 100	reinforced concrete 100
Layer 5		rock wool 200
Layer 6		plaster 10
Layer 7		
Layer 8		
Total Thickness	240	450
Construction Detail		
Notes		
Windows		
Glazing Type	single	triple
Coating		
Gas filling		Krypton
Window Location		replacement
Glazing U-Value (W/sq.mK)		0.5
Glazing U-Value (Btu/hft2F)		0.088
SHGC		
Assembly U-Value (W/sq.mK)		**0.75**
Assembly U-Value (Btu/hft2F)		0.132
Frame Type	wood	wood + PVC
Infiltration Rate (ACH at 50 P)		2
Notes	higher infiltration rate due to leakages in the roof and slab areas	
Mechanical Systems		
Ventilation	natural	HRV
Type		individual units
Efficiency		1%
Ventilation Rate (ACH)		
Heating	individual units	whole house
Type of Fuel	oil and electric	electric heat pump
Capacity (kW)		9
Efficiency		
Distribution System		water to air (term reheat)
Distribution Media	none	water
Terminal Units	stoves	air
Cooling	no	yes
Type of Fuel		
Efficiency		

Hot Water		boiler	
Type of Fuel		gas	
Efficiency			
Storage Tanks	**no**	**yes**	
Capacity (liters)		2600	
Use		heating/hot water	
Solar Thermal Collectors	no	yes	
Area (sq.m)		15.5	
Capacity (kW)			
Use		heating/hot water	
Photovoltaics	no	no	
Area (sq.m)			
Power (kW)			
Generat. Energy (kW/sq.m*a)			
Notes	**wood stoves are used as backup heating in the individual units** wood stoves are used for 20 % of the heating need		

Contact Details	
Architect / Studio	**Viriden + Partner, contact person - Karl Viriden**
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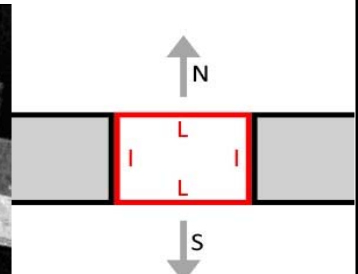
e-mail	viriden@viriden-partner.ch
Energy Consultant	
Tel	
e-mail	
Mechanical Engineer	
Tel	
e-mail	

Project Name:	Mathildenstrasse 48 Fuerth		
APPENDIX 16			
	before retrofit	**after retrofit**	**improvement %**
Location			
City	Fuerth		
State / Country	Bayern / Germany		
Address	Mathildenstrasse 48 Fuerth, Germany		
Location Type	inner city/ suburb		
Climate			
Climate Zone	5		Ashrae 189.1 (09)
HDD (65 F)	**6,441**		(degreedays.net)
CDD (65 F)	**382**		(degreedays.net)
Notes			
Building Details			
Year of Construction	1890		
Year of Retrofit	2002		
Historic Preservation Status	building		
Preservation Constraints Walls	outside		
Preservation Constraints Roof	outside		
Building Use	residential + office		
Building Type	attached 2 sides		
L/l ratio (Length/Width)	1.13		
Orientation	N-S		
			
No. of Floors	5	5	
No. of Units	5	5	
Constructed Area (sq.m)			
Condition. Usable Area (sq.m)	404	520	
A/V ratio (cond. env. Area/V)	0.34	0.28	
Notes			

Construction Costs					
Total Construction Costs (Euro)			560,560		
Cost (Euro/sq.m)			**1,078**		
Cost of Energy Retrofit (€/sq.m)			**205**		
Energy Consumption					
Type of data	simulated	metered	simulated	metered	
Heating (kWh/sq.m*a)	**254**		**44.5**		
Heating (kBtu/sq.ft*a)	80.5		14.1		
Heating (kWh/sq.m*HDD)	0.0394		0.0069		**-82.5%**
Cooling (kWh/sq.m*a)					
Hot Water (kWh/sq.m*a)					
Ventilation (kWh/sq.m*a)					
Lighting (kWh/sq.m*a)					
Notes	no cooling needed in this climate				
Walls - Street Façade					
Insulation Type	**none**		**mineral wool**		
Insulation Location			interior		
Insulation Thickness (mm)			100		
Insulation Conductivity (W/mK)			0.04		
Insulation U-Value (W/sq.mK)			0.400		
Insulation U-Value (Btu/hft2F)			0.070		
Assembly U-Value (W/sq.mK)	**1.980**		**0.450**		**-77.3%**
Assembly U-Value (Btu/hft2F)	0.349		0.079		
Main Layers (outside-inside)		mm		mm	
Layer 1					unchanged
Layer 2					
Layer 3					
Layer 4					
Layer 5					
Layer 6					
Layer 7					
Layer 8					
Total Thickness		0		0	
Construction Detail					
Notes					

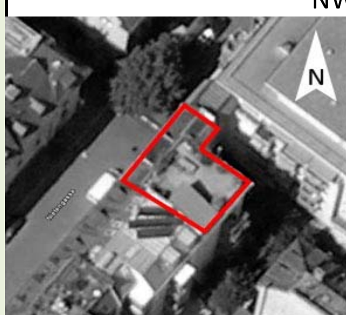
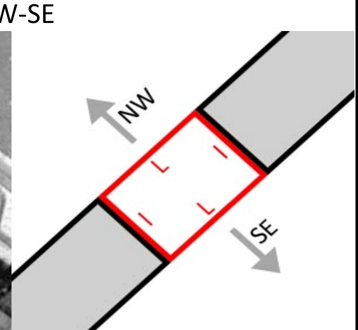
Roof			
Attic	unconditioned	unconditioned	
Insulation Type	**none**	**mineral wool**	
Insulation Location		cavity	
Insulation Thickness (mm)		360	
Insulation Conductivity (W/mK)		0.035	
Insulation U-Value (W/sq.mK)		0.097	
Insulation U-Value (Btu/hft2F)		0.017	
Assembly U-Value (W/sq.mK)	**1.050**	**0.100**	**-90.5%**
Assembly U-Value (Btu/hft2F)	0.185	0.018	
Main Layers (top-bottom)	mm	mm	
Layer 1			
Layer 2			
Layer 3			
Layer 4			unchanged
Layer 5			
Layer 6			
Layer 7			
Layer 8			
Total Thickness	0	0	
Construction Detail			
Notes			

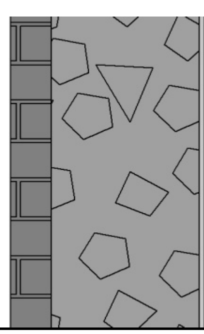
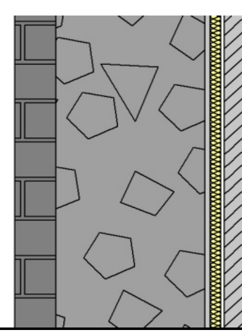
Floor / Slab			
Basement	none	none	
Insulation Type	**none**	**mineral wool**	
Insulation Location		exterior	
Insulation Thickness (mm)		150	
Insulation Conductivity (W/mK)		0.04	
Insulation U-Value (W/sq.mK)		0.267	
Insulation U-Value (Btu/hft2F)		0.047	
Assembly U-Value (W/sq.mK)	**0.870**	**0.250**	**-71.3%**
Assembly U-Value (Btu/hft2F)	0.153	0.044	
Main Layers (top-bottom)	mm	mm	
Layer 1			
Layer 2			
Layer 3			

Layer 4				
Layer 5				unchanged
Layer 6				
Layer 7				
Layer 8				
Total Thickness	0	0		
Construction Detail				
Notes				
Windows				
Glazing Type	double	triple		
Coating				
Gas filling		Argon		
Window Location		replacement		
Glazing U-Value (W/sq.mK)		0.6	0.6	
Glazing U-Value (Btu/hft2F)	0.000	0.106	0.106	
SHGC		0.50	0.50	
Assembly U-Value (W/sq.mK)	**2.8**	**0.8**	**1.1**	**-72.9%**
Assembly U-Value (Btu/hft2F)	0.493	0.134	0.194	
Frame Type	PVC	PVC insulated	wood	
Infiltration Rate (ACH at 50 P)				
Notes	some of the windows were single pane (Back Façade) - U=5.6 W/sq.mK street windows - wood frames/ back windows - PVC insulated frames			
Mechanical Systems				
Ventilation	natural	HRV		
Type		individual units		
Efficiency		85%		
Ventilation Rate (ACH)				
Heating		whole building furnace		
Type of Fuel		gas		
Capacity (kW)				
Efficiency				
Distribution System				
Distribution Media				
Terminal Units				
Cooling				
Type of Fuel				
Efficiency				

Hot Water			
Type of Fuel			
Efficiency			
Storage Tanks			
Capacity (liters)			
Use			
Solar Thermal Collectors	no	yes	
Area (sq.m)			
Capacity (kW)			
Use			
Photovoltaics			
Area (sq.m)			
Power (kW)			
Generat. Energy (kW/sq.m*a)			
Notes	solar thermal collectors cover 60 % of the yearly hot water demand		

Contact Details	
Architect / Studio	
Tel	
e-mail	
Energy Consultant	
Tel	
e-mail	
Mechanical Engineer	
Tel	
e-mail	

Project Name:	Nietengasse 20 Zuerich		
APPENDIX 17			
	before retrofit	**after retrofit**	**improvement** %
Location			
City	Zuerich		
State / Country	Switzerland		
Address	Nietengasse 20, Zuerich, Switzerland		
Location Type	inner city		
Climate			
Climate Zone	5		Ashrae 189.1 (09)
HDD (65 F)	**6,188**		(degreedays.net)
CDD (65 F)	**444**		(degreedays.net)
Notes	Northern Switzerland		
Building Details			
Year of Construction	1907		
Year of Retrofit	2002		
Historic Preservation Status	building		
Preservation Constraints Walls	outside (street façade)		
Preservation Constraints Roof	none		
Building Use	residential		
Building Type	attached 2 sides		
L/l ratio (Length/Width)			
Orientation	NW-SE		
			
No. of Floors	4+1	4+1	
No. of Units	5	3	
Constructed Area (sq.m)			
Condition. Usable Area (sq.m)		574	
A/V ratio (cond. env. Area/V)		0.45	
Notes			

Construction Costs					
Total Construction Costs (Euro)					
Cost (Euro/sq.m)					
Cost of Energy Retrofit (€/sq.m)					
Energy Consumption					
Type of data	simulated	metered	simulated	metered	
Heating (kWh/sq.m*a)			**17.5**	**24**	
Heating (kBtu/sq.ft*a)			5.5	7.6	
Heating (kWh/sq.m*HDD)			0.0028	0.0039	
Cooling (kWh/sq.m*a)					
Hot Water (kWh/sq.m*a)			20.8	13.6	
Ventilation (kWh/sq.m*a)				1.8	
Lighting (kWh/sq.m*a)					
Notes	no cooling needed in this climate the measured year had 94 % of the HDD of an average year				
Walls - Street Façade - Ground Floor					
Insulation Type	**none**		**Vacuum Insulated Panels**		
Insulation Location			interior		
Insulation Thickness (mm)			30		
Insulation Conductivity (W/mK)			0.007		
Insulation U-Value (W/sq.mK)			0.233		
Insulation U-Value (Btu/hft2F)			0.041		
Assembly U-Value (W/sq.mK)	**3.600**		**0.160**		**95.6%**
Assembly U-Value (Btu/hft2F)	0.634		0.028		
Main Layers (outside-inside)		mm		mm	
Layer 1	natural stone facing	120	natural stone facing	120	unchanged
Layer 2	quarry stone	430	quarry stone	430	
Layer 3	plaster	15	plaster	15	
Layer 4			VIP panels	30	
Layer 5			air layer	10	
Layer 6			solid gipsum board	60	
Layer 7			plaster	5	
Layer 8					
Total Thickness		565		670	
Construction Detail					
Notes					

Roof			
Attic	unconditioned	unconditioned	
Insulation Type	**none**	**rock wool**	
Insulation Location		cavity	
Insulation Thickness (mm)		360	
Insulation Conductivity (W/mK)		0.036	
Insulation U-Value (W/sq.mK)		0.100	
Insulation U-Value (Btu/hft2F)		0.018	
Assembly U-Value (W/sq.mK)		**0.090**	
Assembly U-Value (Btu/hft2F)		0.016	
Main Layers (top-bottom)	mm	mm	
Layer 1			
Layer 2			
Layer 3			
Layer 4			
Layer 5			
Layer 6			
Layer 7			
Layer 8			
Total Thickness	0	0	
Construction Detail			
Notes			

Floor / Slab			
Basement	none	none	
Insulation Type	**none**	**rock wool**	
Insulation Location		exterior	
Insulation Thickness (mm)		200	
Insulation Conductivity (W/mK)		0.036	
Insulation U-Value (W/sq.mK)		0.180	
Insulation U-Value (Btu/hft2F)		0.032	
Assembly U-Value (W/sq.mK)		**0.160**	
Assembly U-Value (Btu/hft2F)		0.028	
Main Layers (top-bottom)	mm	mm	
Layer 1			
Layer 2			
Layer 3			

Layer 4			
Layer 5			
Layer 6			
Layer 7			
Layer 8			
Total Thickness	0	0	
Construction Detail			
Notes			
Windows			
Glazing Type	single	triple	
Coating			
Gas filling			
Window Location		replacement	
Glazing U-Value (W/sq.mK)		0.05	
Glazing U-Value (Btu/hft2F)		0.009	
SHGC			
Assembly U-Value (W/sq.mK)		**0.9**	
Assembly U-Value (Btu/hft2F)		0.159	
Frame Type	wood	PVC	
Infiltration Rate (ACH at 50 P)		1.5	
Notes			
Mechanical Systems			
Ventilation	natural	ERV	
Type		individual units	
Efficiency		75%	
Ventilation Rate (ACH)			
Heating		mini cogeneration unit	
Type of Fuel		gas	
Capacity (kW)		10	
Efficiency			
Distribution System			
Distribution Media		water	
Terminal Units		terminal reheat	
Cooling	no	no	
Type of Fuel			
Efficiency			

Hot Water		mini cogeneration unit	
Type of Fuel		gas	
Efficiency			
Storage Tanks		**yes**	
Capacity (liters)		1200	
Use		hot water	
Solar Thermal Collectors	no	no	
Area (sq.m)			
Capacity (kW)			
Use			
Photovoltaics	no	no	
Area (sq.m)			
Power (kW)			
Generat. Energy (kW/sq.m*a)			
Notes			

Contact Details	
Architect / Studio	**Viriden + Partner, contact person - Karl Viriden**
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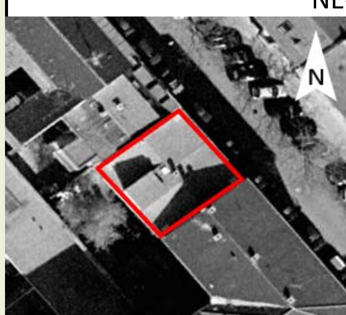
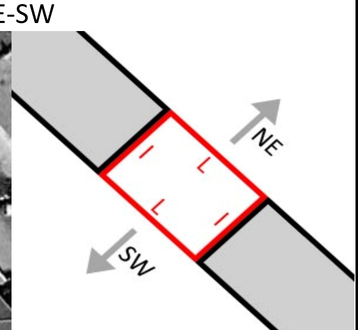
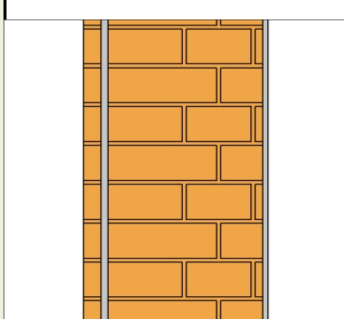
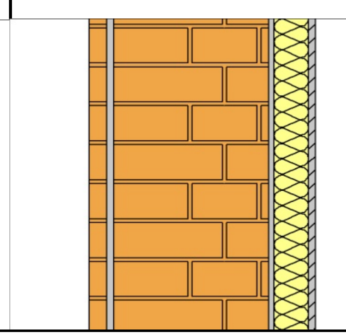
Energy Consultant	
Tel	
e-mail	
Mechanical Engineer	
Tel	
e-mail	

Project Name:	Rheinhauserstrasse 6 Mannheim		
APPENDIX 18			
	before retrofit	**after retrofit**	**improvement %**
Location			
City	Mannheim		
State / Country	Baden Wurtemberg / Germany		
Address	Rheinhäuserstr 6, 68165 Mannheim, Germany		
Location Type	inner city		
Climate			
Climate Zone	4		Ashrae 189.1 (09)
HDD (65 F)	**5,090**		(degreedays.net)
CDD (65 F)	**666**		(degreedays.net)
Notes			
Building Details			
Year of Construction	1901		
Year of Retrofit	2007		
Historic Preservation Status	building		
Preservation Constraints Walls	outside		
Preservation Constraints Roof	none		
Building Use	residential		
Building Type	attached 2 sides		
L/l ratio (Length/Width)	1		
Orientation	NE-SW		
			
No. of Floors	4	5	
No. of Units	7	6	
Constructed Area (sq.m)			
Condition. Usable Area (sq.m)	385	560	
A/V ratio (cond. env. Area/V)		0.30	
Notes			

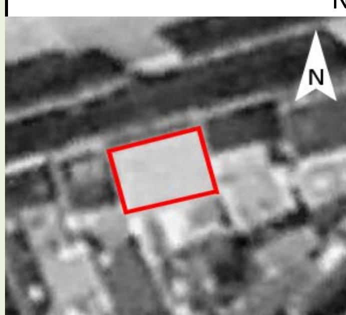
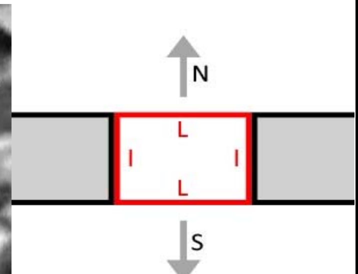
Construction Costs					
Total Construction Costs (Euro)			677,660		
Cost (Euro/sq.m)			**1,210**		
Cost of Energy Retrofit (€/sq.m)			**363**		
Energy Consumption					
Type of data	simulated	metered	simulated	metered	
Heating (kWh/sq.m*a)	**251.85**		**56.74**		
Heating (kBtu/sq.ft*a)	79.8		18.0		
Heating (kWh/sq.m*HDD)	0.0495		0.0111		**-77.5%**
Cooling (kWh/sq.m*a)					
Hot Water (kWh/sq.m*a)					
Ventilation (kWh/sq.m*a)					
Lighting (kWh/sq.m*a)					
Notes	no cooling needed in this climate				
Walls					
Insulation Type	**none**		**mineral wool**		
Insulation Location			interior		
Insulation Thickness (mm)			100		
Insulation Conductivity (W/mK)			0.035		
Insulation U-Value (W/sq.mK)			0.350		
Insulation U-Value (Btu/hft2F)			0.062		
Assembly U-Value (W/sq.mK)	**1.700**		**0.267**		**-84.3%**
Assembly U-Value (Btu/hft2F)	0.299		0.047		
Main Layers (outside-inside)		mm		mm	
Layer 1	brick facing	50	brick facing	50	unchanged
Layer 2	mortar	20	mortar	20	
Layer 3	solid brick	450	solid brick	450	
Layer 4	plaster	15	plaster	15	
Layer 5			mineral wool	100	
Layer 6			plasterboard	20	
Layer 7					
Layer 8					
Total Thickness		535		655	
Construction Detail					
Notes					

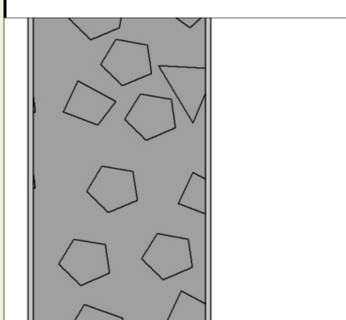
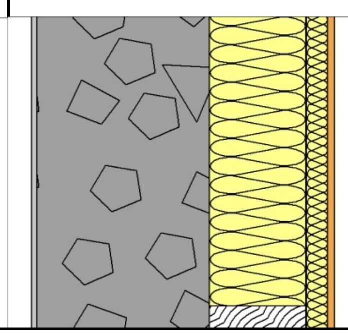
Roof			
Attic	none	conditioned	
Insulation Type	**none**	**mineral wool**	
Insulation Location		cavity	
Insulation Thickness (mm)		240	
Insulation Conductivity (W/mK)		0.035	
Insulation U-Value (W/sq.mK)		0.146	
Insulation U-Value (Btu/hft2F)		0.026	
Assembly U-Value (W/sq.mK)		**0.200**	
Assembly U-Value (Btu/hft2F)		0.035	
Main Layers (top-bottom)	mm	mm	
Layer 1			
Layer 2			
Layer 3			
Layer 4			
Layer 5			
Layer 6			
Layer 7			
Layer 8			
Total Thickness	0	0	
Construction Detail			
Notes			

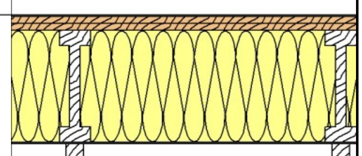
Floor / Slab			
Basement	unconditioned	unconditioned	
Insulation Type	**none**	**EPS**	
Insulation Location		exterior	
Insulation Thickness (mm)		100	
Insulation Conductivity (W/mK)		0.035	
Insulation U-Value (W/sq.mK)		0.350	
Insulation U-Value (Btu/hft2F)		0.062	
Assembly U-Value (W/sq.mK)			
Assembly U-Value (Btu/hft2F)			
Main Layers (top-bottom)	mm	mm	
Layer 1			
Layer 2			
Layer 3			

Layer 4			
Layer 5			
Layer 6			
Layer 7			
Layer 8			
Total Thickness	0	0	
Construction Detail			
Notes			
Windows			
Glazing Type	single	double	
Coating			
Gas filling			
Window Location		replacement	
Glazing U-Value (W/sq.mK)		1.1	
Glazing U-Value (Btu/hft2F)		0.194	
SHGC			
Assembly U-Value (W/sq.mK)	**2.9**	**1.3**	**-55.2%**
Assembly U-Value (Btu/hft2F)	0.511	0.229	
Frame Type	PVC	wood	
Infiltration Rate (ACH at 50 P)		0.85	
Notes			
Mechanical Systems			
Ventilation	natural	HRV	
Type		individual units	
Efficiency		79%	
Ventilation Rate (ACH)			
Heating	gas boiler		
Type of Fuel	gas	district heating	
Capacity (kW)			
Efficiency			
Distribution System			
Distribution Media	water	water	
Terminal Units			
Cooling	no	no	
Type of Fuel			
Efficiency			

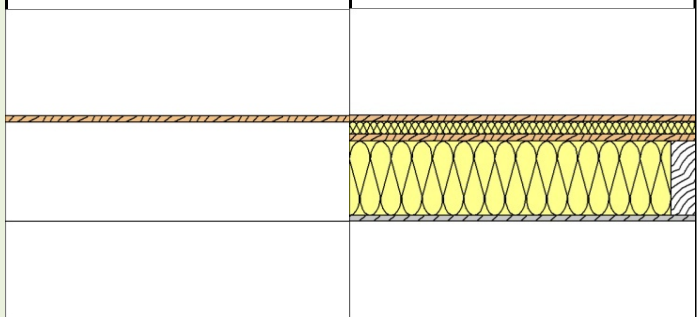
Hot Water	individual units	whole house	
Type of Fuel			
Efficiency			
Storage Tanks			
Capacity (liters)			
Use			
Solar Thermal Collectors	no	no	
Area (sq.m)			
Capacity (kW)			
Use			
Photovoltaics	no	no	
Area (sq.m)			
Power (kW)			
Generat. Energy (kW/sq.m*a)			
Notes			
Contact Details			
Architect / Studio			
Tel			
e-mail			
Energy Consultant			
Tel			
e-mail			
Mechanical Engineer			
Tel			
e-mail			

Project Name:	**Rowhouse Henz-Noirfalise**		
APPENDIX 19			
	before retrofit	**after retrofit**	**improvement %**
Location			
City	Eupen		
State / Country	Belgium		
Address	Heggenstrasse 59, 4700 Eupen, Belgium		
Location Type	inner city		
Climate			
Climate Zone	5		Ashrae 189.1 (09)
HDD (65 F)	**5,720**		(degreedays.net)
CDD (65 F)	**272**		(degreedays.net)
Notes			
Building Details			
Year of Construction	1850		
Year of Retrofit	2006		
Historic Preservation Status	building		
Preservation Constraints Walls	outside		
Preservation Constraints Roof	none		
Building Use	residential		
Building Type	attached 2 sides		
L/l ratio (Length/Width)	1.27		
Orientation	N-S		
			
No. of Floors	2 + 1	2 + 1	
No. of Units	1	1	
Constructed Area (sq.m)			
Condition. Usable Area (sq.m)	130	180	**38.5%**
A/V ratio (cond. env. Area/V)		0.55	
Notes	preservation constraints street façade only		

Construction Costs					
Total Construction Costs (Euro)			171,240		
Cost (Euro/sq.m)			**951**		
Cost of Energy Retrofit (€/sq.m)					
Energy Consumption					
Type of data	simulated	metered	simulated	metered	
Heating (kWh/sq.m*a)	**300**		**12**		
Heating (kBtu/sq.ft*a)	95.1		3.8		
Heating (kWh/sq.m*HDD)	0.0524		0.0021		**-96.0%**
Cooling (kWh/sq.m*a)					
Hot Water (kWh/sq.m*a)					
Ventilation (kWh/sq.m*a)					
Lighting (kWh/sq.m*a)					
Notes	no cooling needed in this climate				
Walls					
Insulation Type	**none**		**blown in cellulose**		
Insulation Location			interior		
Insulation Thickness (mm)			280		
Insulation Conductivity (W/mK)			0.04		
Insulation U-Value (W/sq.mK)			0.143		
Insulation U-Value (Btu/hft2F)			0.025		
Assembly U-Value (W/sq.mK)	**3.140**		**0.135**		**-95.7%**
Assembly U-Value (Btu/hft2F)	0.553		0.024		
Main Layers (outside-inside)		mm		mm	
Layer 1	plaster	15	plaster	15	unchanged
Layer 2	natural stone	500	natural stone	500	
Layer 3	plaster	15	cellulose btw studs	280	
Layer 4			vapour barrier		
Layer 5			cellulose panels	60	
Layer 6			clay	20	
Layer 7					
Layer 8					
Total Thickness		530		875	
Construction Detail					
Notes					

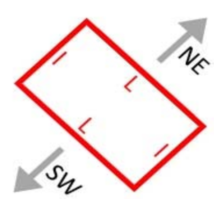
Roof					
Attic	conditioned		conditioned		
Insulation Type	**none**		**blown in cellulose**		
Insulation Location			cavity		
Insulation Thickness (mm)			360		
Insulation Conductivity (W/mK)			0.04		
Insulation U-Value (W/sq.mK)			0.111		
Insulation U-Value (Btu/hft2F)			0.020		
Assembly U-Value (W/sq.mK)	**5.500**		**0.111**		**-98.0%**
Assembly U-Value (Btu/hft2F)	0.969		0.020		
Main Layers (top-bottom)		mm		mm	
Layer 1			zinc finish	5	
Layer 2			solid wood	22	
Layer 3			bituminised OSB	22	
Layer 4			blown in cellulose	360	
Layer 5			vapour barrier		original
Layer 6			air layer / battens	48	construction
Layer 7			plasterboard	12.5	replaced
Layer 8					
Total Thickness		0		469.5	
Construction Detail					
Notes					

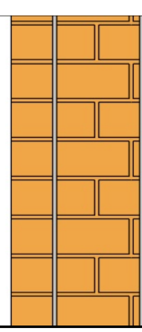
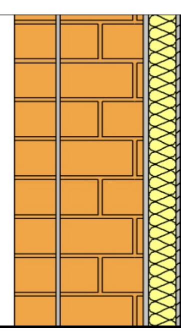
Floor / Slab					
Basement	none		none		
Insulation Type	**none**		**blown in cellulose**		
Insulation Location			cavity		
Insulation Thickness (mm)			240		
Insulation Conductivity (W/mK)			0.04		
Insulation U-Value (W/sq.mK)			0.167		
Insulation U-Value (Btu/hft2F)			0.029		
Assembly U-Value (W/sq.mK)	**2.200**		**0.165**		**-92.5%**
Assembly U-Value (Btu/hft2F)	0.387		0.029		
Main Layers (top-bottom)		mm		mm	
Layer 1	floor	20	floor	20	unchanged
Layer 2	floor structure		cellulose panels	40	
Layer 3			OSB	22	

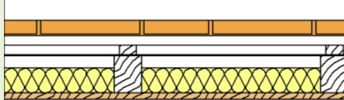
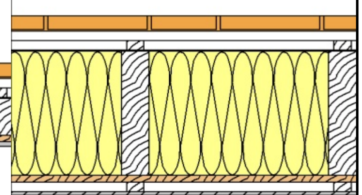
Layer 4		cellulose insulation 240	
Layer 5		fibre cement board 18	floor structure replaced
Layer 6			
Layer 7			
Layer 8			
Total Thickness		340	
Construction Detail			
Notes	wooden I-beams used for the new structure		
Windows			
Glazing Type	single	single/double/triple	
Coating			
Gas filling		Air/ Argon/ etc.	
Window Location		interior/ replacement	
Glazing U-Value (W/sq.mK)		0.6	
Glazing U-Value (Btu/hft2F)	0.000	0.106	
SHGC			
Assembly U-Value (W/sq.mK)	**4.7**	**0.7**	**-84.5%**
Assembly U-Value (Btu/hft2F)	0.819	0.127	
Frame Type	PVC	PVC insulated	
Infiltration Rate (ACH at 50 P)		0.57	
Notes			
Mechanical Systems			
Ventilation	natural	HRV	
Type		whole house	
Efficiency		85%	
Ventilation Rate (ACH)			
Heating			
Type of Fuel		wood pellets	
Capacity (kW)			
Efficiency			
Distribution System			
Distribution Media		air	
Terminal Units		terminal reheat	
Cooling	no	no	
Type of Fuel			
Efficiency			

Hot Water			
Type of Fuel			
Efficiency			
Storage Tanks		3 plastic storage tanks	
Capacity (liters)		3 x 700	
Use		rainwater	
Solar Thermal Collectors	no	yes	
Area (sq.m)		8	
Capacity (kW)			
Use		heating + hot water	
Photovoltaics	no	no	
Area (sq.m)			
Power (kW)			
Generat. Energy (kW/sq.m*a)			
Notes	ground air heat exchanger		

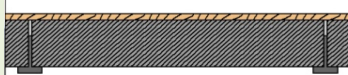
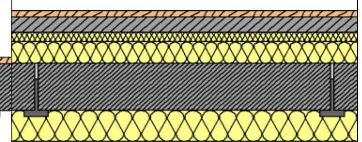
Contact Details	
Architect / Studio	
Tel	
e-mail	
Energy Consultant	
Tel	
e-mail	
Mechanical Engineer	
Tel	
e-mail	

Project Name:	**Sodastrasse 40 Ludwigshafen**		
APPENDIX 20			
	before retrofit	**after retrofit**	**improvement** %
Location			
City	Ludwigshafen		
State / Country	Germany		
Address	Sodastrasse 40, Ludwigshafen, Germany		
Location Type	suburb		
Climate			
Climate Zone	4		Ashrae 189.1 (09)
HDD (65 F)	**5,090**		(degreedays.net)
CDD (65 F)	**666**		(degreedays.net)
Notes			
Building Details			
Year of Construction	1892		
Year of Retrofit	2005		
Historic Preservation Status	building		
Preservation Constraints Walls	outside		
Preservation Constraints Roof	none		
Building Use	residential		
Building Type	detached		
L/l ratio (Length/Width)	1.35		
Orientation	NE-SW		
			
No. of Floors	2 + 1	2 + 1	
No. of Units	2	2	
Constructed Area (sq.m)			
Condition. Usable Area (sq.m)		215	
A/V ratio (cond. env. Area/V)			
Notes			

Construction Costs					
Total Construction Costs (Euro)					
Cost (Euro/sq.m)					
Cost of Energy Retrofit (€/sq.m)					
Energy Consumption					
Type of data	simulated	metered	simulated	metered	
Heating (kWh/sq.m*a)	**252.7**		**51.2**		
Heating (kBtu/sq.ft*a)	80.1		16.2		
Heating (kWh/sq.m*HDD)	0.0496		0.0101		**-79.7%**
Cooling (kWh/sq.m*a)					
Hot Water (kWh/sq.m*a)					
Ventilation (kWh/sq.m*a)					
Lighting (kWh/sq.m*a)					
Notes	no cooling needed in this climate				
Walls					
Insulation Type	**none**		**EPS (Neopor)**		
Insulation Location			interior		
Insulation Thickness (mm)			80		
Insulation Conductivity (W/mK)			0.031		
Insulation U-Value (W/sq.mK)			0.388		
Insulation U-Value (Btu/hft2F)			0.068		
Assembly U-Value (W/sq.mK)	**1.548**		**0.303**		**-80.4%**
Assembly U-Value (Btu/hft2F)	0.273		0.053		
Main Layers (outside-inside)		mm		mm	
Layer 1	brick facing	120	brick facing	120	unchanged
Layer 2	cement mortar	12	cement mortar	12	
Layer 3	solid brick	240	solid brick	240	
Layer 4	plaster	15	plaster	15	
Layer 5			EPS (Neopor)	80	
Layer 6			plasterboard	12.5	
Layer 7			vapour barrier		
Layer 8			plasterboard	12.5	
Total Thickness		387		492	
Construction Detail					
Notes	Rigitherm Doublissimo - plasterboard glued to neopor plates ext. façade weather sealed with "Siloxan" vapour barrier - moisture adaptive poliamide foil				

Roof					
Attic	conditioned		conditioned		
Insulation Type	**unknown**		**EPS (Neopor)**		
Insulation Location	cavity		cavity		
Insulation Thickness (mm)	80		400		
Insulation Conductivity (W/mK)			0.031		
Insulation U-Value (W/sq.mK)			0.078		
Insulation U-Value (Btu/hft2F)			0.014		
Assembly U-Value (W/sq.mK)	**1.314**		**0.087**		**-93.4%**
Assembly U-Value (Btu/hft2F)	0.231		0.015		
Main Layers (top-bottom)		mm		mm	
Layer 1	ceramic roof tiles		ceramic roof tiles		
Layer 2	air layer / battens	60	air layer / battens	60	
Layer 3	water membrane	3	water membrane	3	
Layer 4	air layer / studs	40	EPS (Neopor) / studs	400	new prefab.
Layer 5	insulatino / studs	80	OSB	22	roof structure
Layer 6	reed layer	20	air layer / battens	30	
Layer 7	plaster	15	plasterb. + vap. bar.	12.5	
Layer 8			PCM plasterboard	15	
Total Thickness		218		542.5	
Construction Detail					
Notes	PCM plasterboard "Micronal" is used as interior surface vapour barrier - moisture adaptive poliamide foil				

Floor / Slab					
Basement	none		none		
Insulation Type	**none**		**EPS (Neopor)**		
Insulation Location			interior + exterior		
Insulation Thickness (mm)			200		
Insulation Conductivity (W/mK)			0.031		
Insulation U-Value (W/sq.mK)			0.155		
Insulation U-Value (Btu/hft2F)			0.027		
Assembly U-Value (W/sq.mK)	**2.276**		**0.272**		**-88.0%**
Assembly U-Value (Btu/hft2F)	0.401		0.048		
Main Layers (top-bottom)		mm		mm	
Layer 1			flooring	20	
Layer 2			screed	50	
Layer 3			EPS (Neopor)	30	

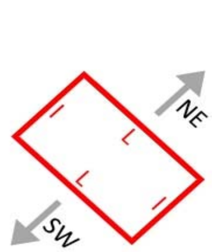
Layer 4	flooring	20	EPS (Neofloor)	70	
Layer 5	concrete slab	150	concrete slab	150	unchanged
Layer 6			Neopor (EPS)	100	
Layer 7					
Layer 8					
Total Thickness		170		420	
Construction Detail					
Notes	slab is made from unreinforced precast concrete elements set in between I beams (100 cm o.c.)				

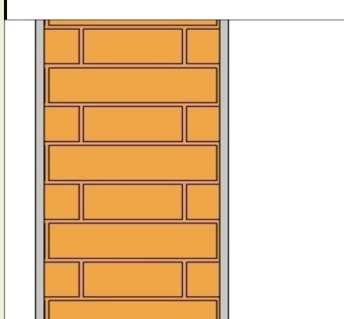
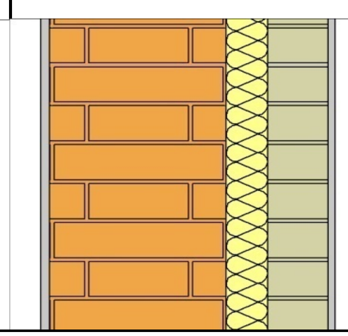
Windows			
Glazing Type	single	triple	
Coating			
Gas filling			
Window Location		replacement	
Glazing U-Value (W/sq.mK)			
Glazing U-Value (Btu/hft2F)			
SHGC			
Assembly U-Value (W/sq.mK)		**1.17**	
Assembly U-Value (Btu/hft2F)		0.206	
Frame Type		PVC insulated	
Infiltration Rate (ACH at 50 P)		0.7	
Notes			

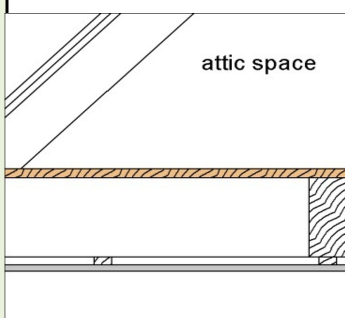
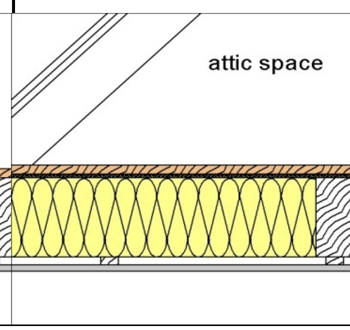
Mechanical Systems			
Ventilation	natural	HRV	
Type		individual units	
Efficiency		80%	
Ventilation Rate (ACH)		0.5 - 0.7	
Heating	boiler	boiler	
Type of Fuel	gas	gas	
Capacity (kW)		24	
Efficiency			
Distribution System			
Distribution Media	water	air + water	
Terminal Units		radiator (bath) + term reheat	
Cooling	no	no	
Type of Fuel			
Efficiency			

Hot Water			
Type of Fuel			
Efficiency			
Storage Tanks		**yes**	
Capacity (liters)			
Use		hot water	
Solar Thermal Collectors	no	yes	
Area (sq.m)		10	
Capacity (kW)			
Use		hot water	
Photovoltaics	no	no	
Area (sq.m)			
Power (kW)			
Generat. Energy (kW/sq.m*a)			
Notes	Solar evacuated tube collectors - Viessmann Vitosol 200 HRV - Paul, WRG 90 multi 100 DC		

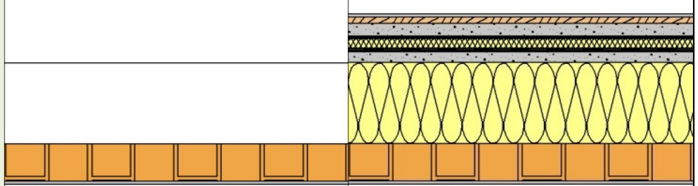
Contact Details	
Architect / Studio	
Tel	
e-mail	
Energy Consultant	
Tel	
e-mail	
Mechanical Engineer	
Tel	
e-mail	

Project Name:	**Villa Pobershau**		
APPENDIX 21			
	before retrofit	**after retrofit**	**improvement** %
Location			
City	Pobershau		
State / Country	Sachsen / Germany		
Address	AS-Dorfstraße 41, 09496 Pobershau, Germany		
Location Type	inner city/ suburb		
Climate			
Climate Zone	5		Ashrae 189.1 (09)
HDD (65 F)	**6,313**		(degreedays.net)
CDD (65 F)	**363**		(degreedays.net)
Notes			
Building Details			
Year of Construction	1882		
Year of Retrofit	2008		
Historic Preservation Status	building		
Preservation Constraints Walls	outside		
Preservation Constraints Roof	outside		
Building Use	residential		
Building Type	detached		
L/l ratio (Length/Width)	1.15		
Orientation	NE-SW		
			
No. of Floors	2	2	
No. of Units	2	2	
Constructed Area (sq.m)			
Condition. Usable Area (sq.m)	277	254	**-8.3%**
A/V ratio (cond. env. Area/V)		0.53	
Notes			

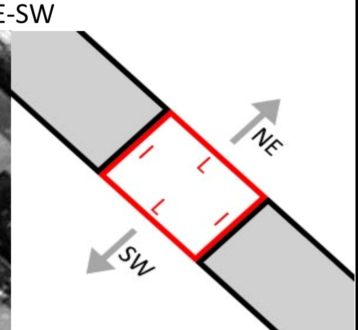
Construction Costs					
Total Construction Costs (Euro)					
Cost (Euro/sq.m)					
Cost of Energy Retrofit (€/sq.m)					
Energy Consumption					
Type of data	simulated	metered	simulated	metered	
Heating (kWh/sq.m*a)	**361.3**		**32**		
Heating (kBtu/sq.ft*a)	114.5		10.1		
Heating (kWh/sq.m*HDD)	0.0572		0.0051		**-91.1%**
Cooling (kWh/sq.m*a)					
Hot Water (kWh/sq.m*a)					
Ventilation (kWh/sq.m*a)					
Lighting (kWh/sq.m*a)					
Notes	no cooling needed in this climate				
Walls - Ground Floor					
Insulation Type	**none**		**XPS granulate**		
Insulation Location			interior (cavity)		
Insulation Thickness (mm)			120		
Insulation Conductivity (W/mK)			0.035		
Insulation U-Value (W/sq.mK)			0.292		
Insulation U-Value (Btu/hft2F)			0.051		
Assembly U-Value (W/sq.mK)	**1.200**		**0.191**		**-84.1%**
Assembly U-Value (Btu/hft2F)	0.211		0.034		
Main Layers (outside-inside)		mm		mm	
Layer 1	plaster	25	plaster	25	unchanged
Layer 2	solid brick	510	solid brick	510	
Layer 3	plaster	25	XPS granulate	120	
Layer 4			expanded clay brick	175	
Layer 5			plaster	20	
Layer 6					
Layer 7					
Layer 8					
Total Thickness		560		850	
Construction Detail					
Notes	secondary wall structure errected on the inside floor beams are resting on the secondary construction				

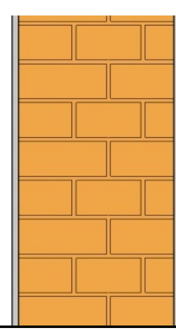
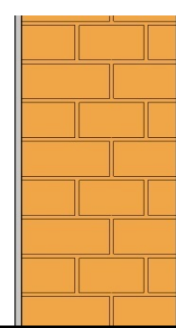
Roof					
Attic	unconditioned		unconditioned		
Insulation Type			**cellulose fill**		
Insulation Location			cavity		
Insulation Thickness (mm)			255		
Insulation Conductivity (W/mK)			0.04		
Insulation U-Value (W/sq.mK)			0.157		
Insulation U-Value (Btu/hft2F)			0.028		
Assembly U-Value (W/sq.mK)			**0.205**		
Assembly U-Value (Btu/hft2F)			0.036		
Main Layers (top-bottom)		mm		mm	
Layer 1			wood floor	28	
Layer 2	wood floor	28	levelling (EPS)	12	
Layer 3	floor structure	255	cellulose fill	255	
Layer 4	wood battens	24	wood battens	24	unchanged
Layer 5	plaster on reed	21	plaster on reed	21	
Layer 6					
Layer 7					
Layer 8					
Total Thickness		328		340	
Construction Detail					
Notes					

Floor / Slab					
Basement	none		none		
Insulation Type	**none**		**XPS fill**	**VIP**	
Insulation Location			interior	interior	
Insulation Thickness (mm)			260	30	
Insulation Conductivity (W/mK)			0.08	0.005	
Insulation U-Value (W/sq.mK)			0.308	0.167	
Insulation U-Value (Btu/hft2F)			0.054	0.029	
Assembly U-Value (W/sq.mK)			**0.095**		
Assembly U-Value (Btu/hft2F)			0.017		
Main Layers (top-bottom)		mm		mm	
Layer 1			flooring	10	
Layer 2			OSB	20	
Layer 3			dry screed	40	

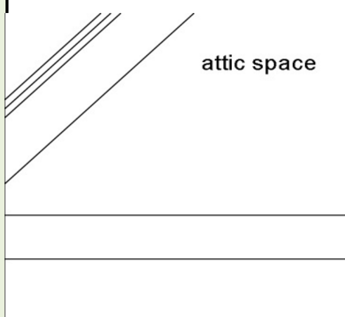
Layer 4			EPS + VIP + EPS	50	
Layer 5	floor structure		cement leveling layer	35	
Layer 6	fill		XPS fill	260	
Layer 7	solid brick vaults	120	solid brick vaults	120	unchanged
Layer 8	plaster	10	plaster	10	
Total Thickness		130		545	
Construction Detail					
Notes					
Windows					
Glazing Type	single		double	single	
Coating					
Gas filling			Krypton		
Window Location			interior	existing	
Glazing U-Value (W/sq.mK)			1		
Glazing U-Value (Btu/hft2F)			0.176		
SHGC			0.55		
Assembly U-Value (W/sq.mK)			**0.56**		
Assembly U-Value (Btu/hft2F)			0.099		
Frame Type	wood		wood		
Infiltration Rate (ACH at 50 P)			**0.53**		
Notes	original windows were kept and additional double pane windows were added to the interior				
Mechanical Systems					
Ventilation	natural		HRV		
Type			individual units		
Efficiency			82%		
Ventilation Rate (ACH)			0.6		
Heating			water/water heatpump		
Type of Fuel			electric		
Capacity (kW)			15		
Efficiency					
Distribution System					
Distribution Media			water		
Terminal Units			underfloor		
Cooling	no		no		
Type of Fuel					
Efficiency					

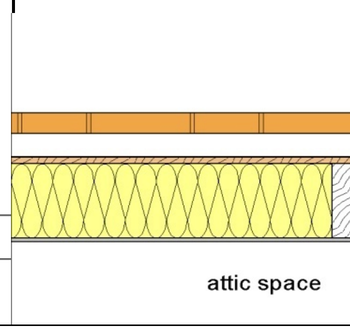
Hot Water			
Type of Fuel			
Efficiency			
Storage Tanks		yes	
Capacity (liters)		1300	
Use		hot water	
Solar Thermal Collectors	no	yes	
Area (sq.m)			
Capacity (kW)			
Use		hot water	
Photovoltaics	no	no	
Area (sq.m)		21.84	
Power (kW)			
Generat. Energy (kW/sq.m*a)			
Notes			
Contact Details			
Architect / Studio			
Tel			
e-mail			
Energy Consultant			
Tel			
e-mail			
Mechanical Engineer			
Tel			
e-mail			

Project Name:	**Wengistrasse 6 Zuerich**		
APPENDIX 22			
	before retrofit	**after retrofit**	**improvement %**
Location			
City	Zuerich		
State / Country	Switzerland		
Address	Wengistrasse 6, Zürich, Switzerland		
Location Type	inner city		
Climate			
Climate Zone	5		Ashrae 189.1 (09)
HDD (65 F)	**6,188**		(degreedays.net)
CDD (65 F)	**444**		(degreedays.net)
Notes	Northern Switzerland		
Building Details			
Year of Construction	1898		
Year of Retrofit	2006		
Historic Preservation Status	building		
Preservation Constraints Walls	outside + inside		
Preservation Constraints Roof	none		
Building Use	residential + commercial (ground floor)		
Building Type	attached 2 sides		
L/l ratio (Length/Width)	1.3		
Orientation	NE-SW		
			
No. of Floors	5 + 1	5 + 2	
No. of Units	0	0	
Constructed Area (sq.m)			
Condition. Usable Area (sq.m)	1,000	1,150	**15.0%**
A/V ratio (cond. env. Area/V)			
Notes			

Construction Costs					
Total Construction Costs (Euro)					
Cost (Euro/sq.m)					
Cost of Energy Retrofit (€/sq.m)					
Energy Consumption					
Type of data	simulated	metered	simulated	metered	
Heating (kWh/sq.m*a)	**160**		**39.5**		
Heating (kBtu/sq.ft*a)	50.7		12.5		
Heating (kWh/sq.m*HDD)	0.0259		0.0064		**-75.3%**
Cooling (kWh/sq.m*a)					
Hot Water (kWh/sq.m*a)					
Ventilation (kWh/sq.m*a)					
Lighting (kWh/sq.m*a)					
Notes	**Consumption information for space+water heating combined** no cooling needed in this climate				
Walls - Front Façade					
Insulation Type	**none**		**none**		
Insulation Location					
Insulation Thickness (mm)					
Insulation Conductivity (W/mK)					
Insulation U-Value (W/sq.mK)					
Insulation U-Value (Btu/hft2F)					
Assembly U-Value (W/sq.mK)	**1.060**		**1.060**		**0.0%**
Assembly U-Value (Btu/hft2F)	0.187		0.187		
Main Layers (outside-inside)		mm		mm	
Layer 1					
Layer 2					
Layer 3	plaster	20	plaster	20	unchanged
Layer 4	solid brick	450	solid brick	450	
Layer 5	plaster	10	plaster	10	
Layer 6					
Layer 7					
Layer 8					
Total Thickness		480		480	
Construction Detail					
Notes	**Front façade - 450 mm solid brick - historicaly protected - no insulation**				

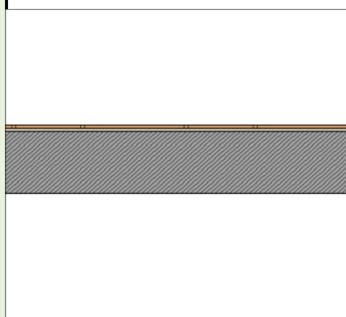
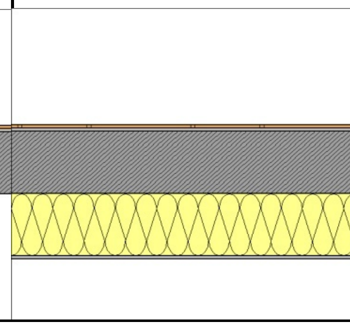
Roof					
Attic	unconditioned		conditinoed		
Insulation Type			**cellulose insulation**		
Insulation Location			cavity		
Insulation Thickness (mm)			240		
Insulation Conductivity (W/mK)			0.04		
Insulation U-Value (W/sq.mK)			0.167		
Insulation U-Value (Btu/hft2F)			0.029		
Assembly U-Value (W/sq.mK)	**1.700**		**0.150**		**-91.2%**
Assembly U-Value (Btu/hft2F)	0.299		0.026		
Main Layers (top-bottom)		mm		mm	
Layer 1			ceramic tiles	66	
Layer 2			air space	74	
Layer 3			weatherproofing	2	
Layer 4			OSB panels	20	
Layer 5			cellulose insulation	240	
Layer 6			fermacel panel	12	roof
Layer 7					structure
Layer 8					replaced
Total Thickness		0		414	
Construction Detail					





Notes	

Floor / Slab					
Basement	undonditioned		undonditioned		
Insulation Type	**none**		**mineral wool**		
Insulation Location			exterior		
Insulation Thickness (mm)			200		
Insulation Conductivity (W/mK)			0.036		
Insulation U-Value (W/sq.mK)			0.180		
Insulation U-Value (Btu/hft2F)			0.032		
Assembly U-Value (W/sq.mK)	**2.640**		**0.160**		**-93.9%**
Assembly U-Value (Btu/hft2F)	0.465		0.028		
Main Layers (top-bottom)		mm		mm	
Layer 1	ceramic panels	10	ceramic panels	10	unchanged
Layer 2	mortar	10	mortar	10	
Layer 3	reinf. concrete	200	reinf. concrete	200	

Layer 4		mineral wool 200	
Layer 5		support net 10	
Layer 6			
Layer 7			
Layer 8			
Total Thickness	220	430	
Construction Detail			
Notes			
Windows			
Glazing Type		double	
Coating			
Gas filling			
Window Location		replacement	
Glazing U-Value (W/sq.mK)		0.8	
Glazing U-Value (Btu/hft2F)		0.141	
SHGC		0.56	
Assembly U-Value (W/sq.mK)	**2.6**	**1.2**	**-53.8%**
Assembly U-Value (Btu/hft2F)	0.458	0.211	
Frame Type	wood	wood	
Infiltration Rate (ACH at 50 P)			
Notes			
Mechanical Systems			
Ventilation	natural	HRV	
Type		whole house	
Efficiency		85% - 90%	
Ventilation Rate (ACH)			
Heating	whole house	whole house	
Type of Fuel	gas	wood pellets	
Capacity (kW)	45	32	
Efficiency			
Distribution System			
Distribution Media	water	water	
Terminal Units			
Cooling	no	no	
Type of Fuel			
Efficiency			

Hot Water			
Type of Fuel			
Efficiency			
Storage Tanks		combi-tank	
Capacity (liters)		4000	
Use			
Solar Thermal Collectors	no	yes	
Area (sq.m)		28	
Capacity (kW)			
Use		heating/hot water	
Photovoltaics	no	no	
Area (sq.m)			
Power (kW)			
Generat. Energy (kW/sq.m*a)			
Notes			

Contact Details	
Architect / Studio	
Tel	
e-mail	
Energy Consultant	
Tel	
e-mail	
Mechanical Engineer	
Tel	
e-mail	