D4.6 Deep renovation guidelines

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OUTPHIT – DEEP RETROFITS MADE FASTER, CHEAPER AND MORE RELIABLE
outPHit pairs such approaches with the rigour of Passive House principles to make deep retrofits cost-effective, faster and more reliable. On the basis of case studies across Europe and in collaboration with a wide variety of stakeholders, outPHit is addressing barriers to the uptake of high quality deep retrofits while facilitating the development of high performance renovation systems, tools for decision making and quality assurance safeguards. **outphit.eu**

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DEEP RENOVATION GUIDELINES

Content

1. INTRODUCTION

ALSO AND ESPECIALLY WITH SERIAL RENOVATION: IT'S THE DETAILS THAT MATTER

Insulation quality and thermal bridges within the renovation modules are an issue that can generally be resolved. The joints between modules or between modules and windows could often be improved, which would be a challenge for the providers of prefabricated renovation systems to address. However, without any flanking measures, the connections of the modules at the base of the building or at the upper end to either the eaves or gable wall also hold the risk of high thermal bridge values. Altogether, carefully planned solutions can avoid additional heat losses of approximately 5 kWh/(m²a).

Further potentials lie in those building areas for which it is already difficult to find solutions using prefabrication concepts and which are therefore usually insulated conventionally. For example, stairwells which often penetrate the thermal building envelope to be insulated downwards into the unheated basement and up into the roof space: these are difficult to insulate and create thermal bridges as well as complicated connections in terms of airtightness. Rising or intersecting constructions such as basement walls or brick walls in the roof space, exterior basement walls or gable walls also create thermal bridges, which can be significantly mitigated through flanking measures. And finally, balconies or loggias should be mentioned: if the thermal bridges associated with these cannot be completely eliminated by cutting them off or enclosing them, they can at least be reduced somewhat through flanking measures. Even with the penetrations mentioned here, the potential for significantly reducing heat losses is 5 kWh/(m²a), if not higher, depending on the particular situation in the project.

Of course, the installation of windows in complete wall modules or in conventional EIFS renovation systems is also a connection detail that requires careful consideration and where good detailed planning can result in potential savings in the building´s heating energy demand of up to 5 kWh/(m²a). Installation in the prefabricated modules usually requires the windows to be installed in the insulation level, in which case they must also be connected to the existing reveal in an airtight manner.

Airtightness is the final challenge in renovations from the outside that are carried out as fast as possible. If the existing external plaster cannot be improved as an airtight layer, the renovation modules must be offset in an airtight way, usually by means of sealing compounds, tubular seals or swelling/waterstop tape, creating a kind of housing all around the house. However, this outer shell must be carefully bonded to the outer wall or other connecting components at the lower and upper ends and of course at the windows in order to prevent infiltration behind the airtight new outer shell. To avoid convective processes, it is also advisable to completely fill the gap behind the prefabricated modules with suitable materials.

Another topic coming up recently with deep renovation projects mainly carried out from the outside of buildings is the installation of pipes, ducts or small devices even of the new technical building equipment within the new insulation layer to avoid intrusive measures within the apartments. Furthermore, distribution heat losses by ground tubes resulting from energy generation outside of the buildings should be considered in the planning decisions making process.

TOOLBOX FOR PLANNING AND DECISION MAKING SUPPORT

With the large number of renovations that have to be carried out 'as quickly as possible', there is often a lack of awareness of the impact of these problem areas and of the potential offered by appropriate solutions. For this reason, the outPHit project provides various brief sets of instructions, checklists and tools, each dedicated to one of the above-mentioned sub-aspects which offers the person seeking advice a quick and simple understanding of the individual challenges and potential optimizations, regardless of other aspects of a building renovation.

This toolbox includes recommendations, checklists or small evaluation tools even to support planning and decision making of several aspects of deep retrofits, also facilitating entries into energy balance calculations like PHPP by recommending qualities to start with or by providing preliminary calculation values for specific situations.

To start with, for the optimization of the building envelope quality insulation and thermal bridge solutions in special areas is provided by recommendations and evaluation tools for:

Insulation and thermal bridge optimization:

- Basement accesses
- Window installation
- Perimeter insulation

Another area in which optimizations can be made during rapid and minimally invasive renovation from the outside are pipes on the outside or within the insulation, façade integration of ventilation units and suitable procedures for an airtight building envelope. Instructions and assessment tools have therefore also been developed for these aspects:

Optimization of façade integration concepts and ground distribution losses

- Pipes and ducts in the ground
- Ventilation ducts in the insulation layer
- Façade integration of small units

In the last area, the choice of either airtightness concepts or renovation components materials is supported through recommendations, checklists or component data lists with representative calculation values to work with

Airtightness and choice of renovation materials

- Checklists for airtightness concepts
- Building material list

2. INSULATION OF BASEMENT STAIRCASES

If existing buildings, especially multi-family buildings, are renovated, the building envelope (walls / roofs or top floor ceilings and basement ceilings) are insulated to achieve the component qualities required by the renovation standard and the airtightness of is improved. Internal stair cases, however usually then penetrate the thermal building envelope:

- The to be insulated basement ceiling is penetrated by the basement staircase
- The to be insulated top floor ceiling is penetrated by the attic staircase in case of pitched roof buildings with cold attics for storage or other purposes than residential

In case, the top floor ceiling will not be the new insulated thermal envelope, but instead the roof will be insulated and the roof attic will become part of the thermal envelope, the second situation described doesn´t occur. Neither does it, should the existing roof be demolished and the building extended by another story on top of the existing ones.

Whereas it isn't sure if the attic staircase needs to be considered in a deep renovation project, the basement staircase almost always needs to be addressed to minimize heat losses and airtightness problems. The careful planning and efficiency design of the basement stair case thereby should be part of every deep renovation project, because, if disregarded, insulation levels and airtightness of the renovated building will be considerably weakened by every staircase descending into the unheated basement. For the renovation of basement staircases multiple functions and goals are to be achieved. The three main goals for the renovation are:

- low thermal losses to the outside or the unheated basement
- high surface temperatures of components and thermal bridges to avoid mold
- good airtightness levels for any boundary component of the staircase
- Preservation of the main function: access to the basement

To achieve these goals, different stair case insulation concepts can be applied. The outPHit partners have identified three main ways to renovate basement access staircases:

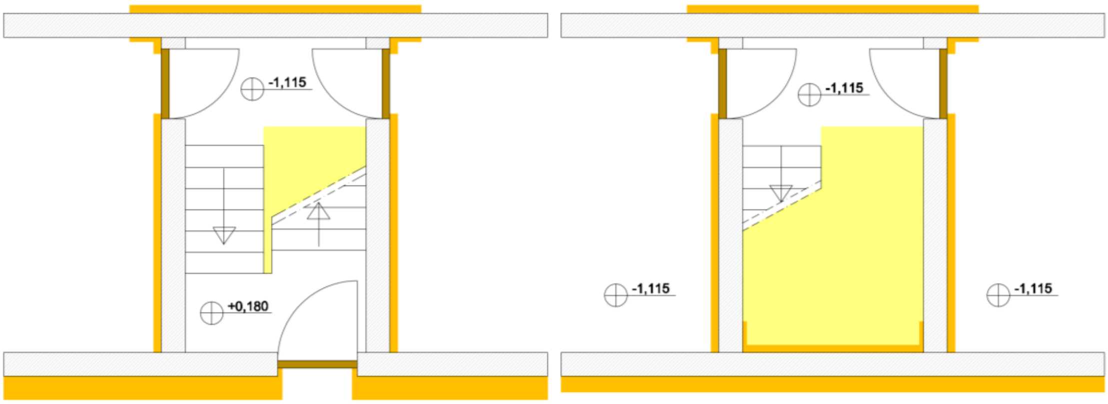
- Basement Staircase is completely encapsulated in the thermal envelope
- Encapsulation of the total volume of the basements stairs only
- Encapsulation of the building entry landing on the ground floor

In the checklists below, each of these staircase insulation options is explained more in detail, together with a short checklist of things not to forget for each of the cases.

VERSION 1: STAIRCASE COMPLETELY ENCAPSULATED IN THE THERMAL ENVELOPE

In this (optimal) case, the whole staircaes can be encapsulated in the new thermal envelope of the renovated building. If the basement rooms next to the staircase can be insulated from the unheated side of the basement, this version offers the most uncomplicated approach.

The disadvantage, however, is the insulation of the basement floor of the staircase, which has to be considered and carried out as good as possible.



Version 1: Basement staircase completely included in the thermal envelope

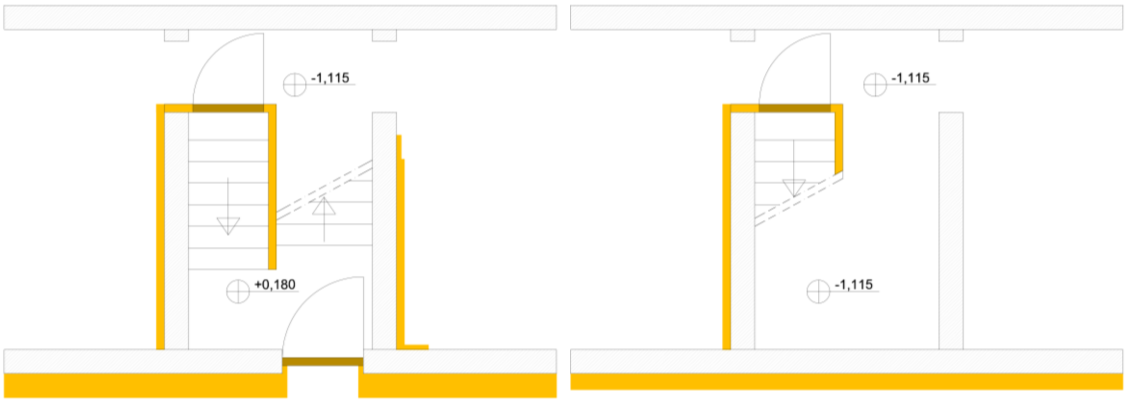
CHECKLIST FOR VERSION 1:
STAIRCASE COMPLETELY IN THE THERMAL ENVELOPE

- ☐ Insulate staircase walls in the basement from the outside (basement side) with sufficient insulation thickness (U-Values between 0,20 to 0,30 W/(m²K))
- ☐ Use high-efficiency and airtight passive house doors with low U-values (0,80 W/(m²K)) to replace the existing doors from staircase to unheated basement
- ☐ Use flanking insulation (ideally 40cm wide, 10cm thick) on all interior, exterior walls and staircase walls in the basement as shown in picture.
- ☐ On the external wall of the staircase, interior insulation or exterior insulation can be used, depending on the accessibility on the outside or the available space on the basement stair landing.
- ☐ Insulate staircase floor as much surface as possible. If floor assembly height is a concern, use insulation materials with a very low thermal conductivity like PU-foam or phenolic foam.

VERSION 2: ENCAPSULATION OF THE TOTAL BASEMENT STAIR VOLUME

Encapsulation of the basement volume on the basement floor with the basement entry door in the basement at the end of the last flight of stairs, so the whole basement stairs are included in the thermal envelope. Whether the last flight of stairs can be insulated from the inside or the outside of the staircase must be decided individually for each project. The advantage compared to Version 1 is, that the basement floor does not need to be insulated.

The disadvantage here is the encapsulation of the stair well that might be complicated, if not impossible if there is not enough space.



Version 2: Only basement stair flights encapsulated in the thermal envelope

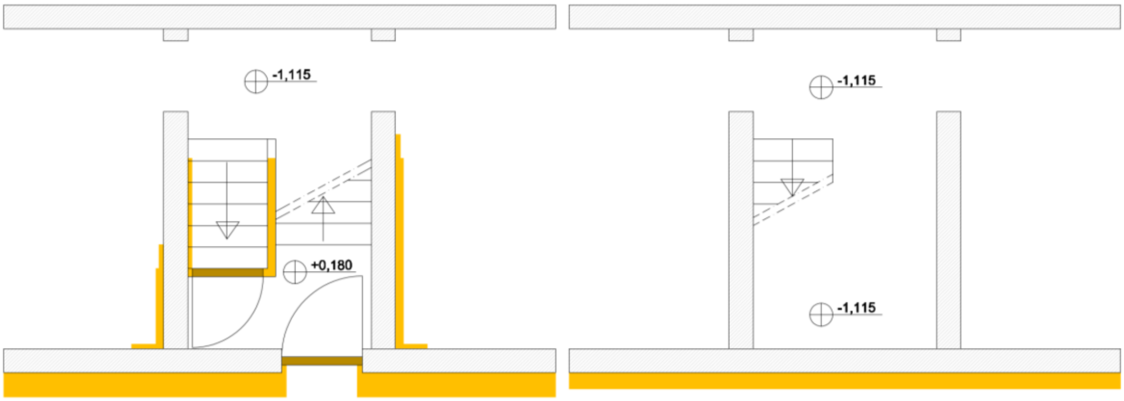
CHECKLIST FOR VERSION 2:
BASEMENT ENTRY DOOR IN THE BASEMENT

- ☐ Carefully close any holes / gaps in the walls to the unheated basement or the external wall to achieve good airtightness
- ☐ Insulate intermediate platform (in-between basement and ground floor) and both flights of stairs running from first floor to the basement from underneath with the same insulation thickness as the basement ceiling (U-Values between 0,20 to 0,30 W/(m²K))
- ☐ Use high-efficiency and airtight passive house doors with low U-values (0,80 W/(m²K))
- ☐ Use flanking insulation on all interior and exterior walls in the basement (ideally 40cm wide, 10cm thick).
- ☐ Insulate the staircase walls on the outside (basement side) in basement down to at least bottom height of the insulation underneath the intermediate platform (between basement and ground floor) and the height of the flanking insulation on top (U-Values between 0,20 to 0,30 W/(m²K))
- ☐ Build encapsulation in the stairwell connecting the door to the rising stairs from first floor to the intermediate platform (in-between ground floor and first floor) and to the rising stairs from this intermediate platform to the basement.
- ☐ If possible, use insulation on the small floor slab area underneath the flight of stairs in the basement.

VERSION 3: ENCAPSULATION OF THE BUILDING ENTRY LANDING ON THE GROUND FLOOR

Encapsulation of the basement entry landing on the ground floor with the basement entry door on above the last flight of stairs, so the basement stairs are outside the thermal envelope.

Disadvantage is the encapsulation of the stair well and the door opening onto the building entry landing that may complicate operating the door.



Version 3: Encapsulation of the building entry landing

CHECKLIST FOR VERSION 3:
BASEMENT ENTRY DOOR ON FIRST FLOOR

- ☐ Insulate intermediate platform (in-between basement and first floor) and staircase running from this platform to the basement from underneath with the same insulation thickness as the basement ceiling (U-Values between 0,20 to 0,30 W/(m²K)).
- ☐ Use flanking insulation on all interior and exterior walls in the basement.
- ☐ Use high-efficiency and airtight passive house doors with low U-values (0,80 W/(m²K))
- ☐ Insulate Staircase walls on the outside (basement side) in basement down to at least bottom height of the insulation underneath the intermediate platform (in-between basement and ground floor) and the height of the flanking insulation on top.
- ☐ Build encapsulation in the stair well connecting the door to the rising stairs from ground floor to intermediate platform (in-between ground floor and first floor) and to the rising stairs from the intermediate platform (in-between basement and ground floor) to the ground floor.
- ☐ Insulate flight of stairs going down to the basement to the outside of the staircase with low thermal conductivity insulation like PU-foam or phenolic foam to not reduce the width of the flight of stairs too much.
- ☐ Also insulate the flights of stairs going from the ground floor to first floor from under-neath (cold side) with low thermal conductivity insulation. Make sure that enough headroom is available for using the stairs.

3. WINDOW INSTALLATION Ψ-VALUE ESTIMATION TOOL

Installation of windows has a big impact on the thermal performance and comfort characteristics of the windows and the overall energy efficiency of building. The window installation is characterized through the use of the linear heat transfer coefficient $\Psi_{installation}$.

Thermal simulation were carried out to demonstrate how the position of the window within the opening of existing walls with ETICS insulation on the outside effects the installation Ψ-value. For this the linear heat transfer coefficient of the window for different situations were evaluated. The following parameter were changed:

- ETICS thermal conductivity:
  0.025 W/(mK), 0.035 W/(mK) and 0.045 W/(mK)
- ETICS thickness from 15 to 25 cm in 5 cm steps
- connections: bottom, head and side
- for side and top: with and without insulation over the frame
- position of the window in 2,5 cm steps

To explain the identification of the window positionThe reference position of the window frame as an example window position is shown in the following picture below. As can be seen, the reference window position was assumed with the window frame flush with the existing (massive) wall. Installing the windows more to the outside of the thermal envelope results in positive window positions, whereas moving the window more to the inside (for example to the existing position in the middle of the brick wall) will result in negative window positions:

Window positions that are varied though the parametric calculation

In addition to the Ψ-value for the installation the corresponding fRsi-value was calculated. With this it can be checked if condensate, or at least risk of mold growth, is going to occur or not. This value should exceed 0.7 to avoid condensation for standard interior conditions (50 % relative humidity and +20 °C).

All this information is integrated in a Microsoft-excel-based Thermal Bridge Tool.

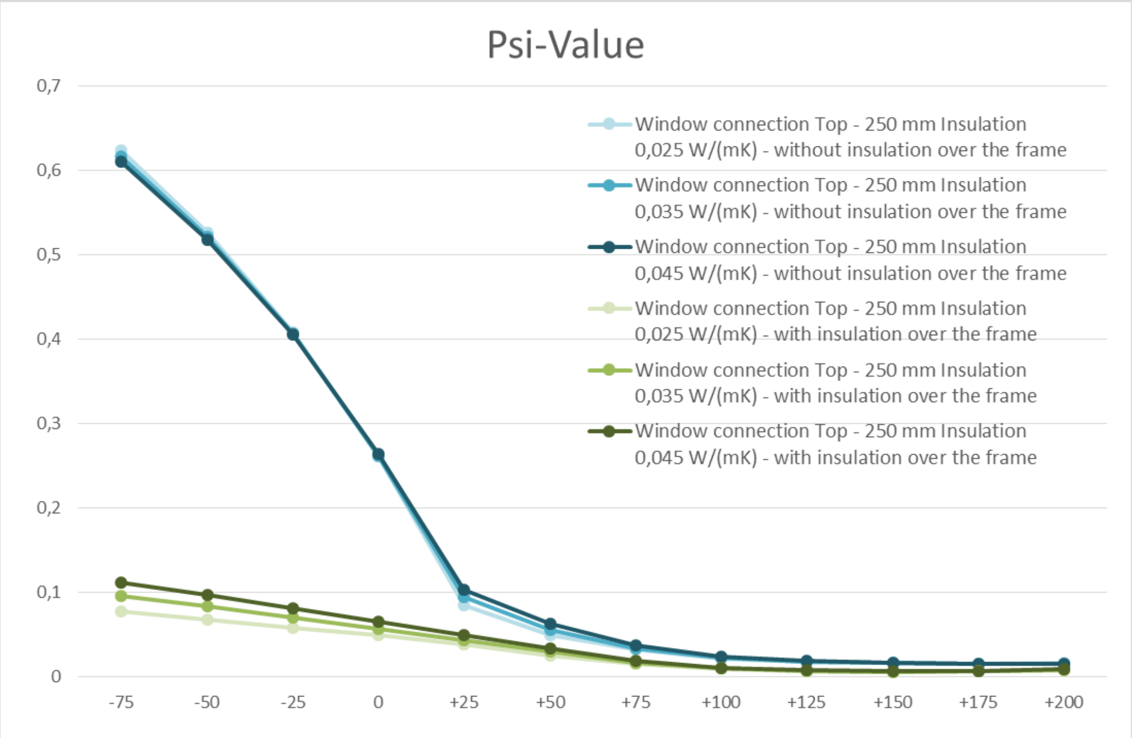
INSTALLATION GUIDELINES

Derived from the results a range for the optimal window position in the wall can be recommended. For most connections the installation heat loss coefficient for the thermal bridge is drastically reduced at the position of around +25 mm from the outside and more. After around +100 mm the value starts to plateau and can even go up again when the window is positioned more to the outside of the insulation layer.

Also it is important to note that placing insulation over the frame results in drastically reduced thermal bridge losses through the connection, in some cases even up to 80 % (e. g. for the top connection with the most inward facing position). Please not that this effect is drastically reduced if aluminum windows or windows with aluminium shells are used.

Interior surface temperatures and therefore f_{Rsi}-values are also much higher for the connections with insulation over the frame which reduces the possibility of mold growth. Also f_{Rsi}-values are highest when the window is placed roughly in the area of +25 mm to +100 mm.

It is therefore recommended to install the window protruding at least 25 mm from the wall, better around 100 mm. As can be seen in the diagram below, the installation-Psi-Values get very low, if the windows are installed within the insulation layer (0,03 W/(mK) or smaller as of a window position of 5cm beyond the old wall surface)

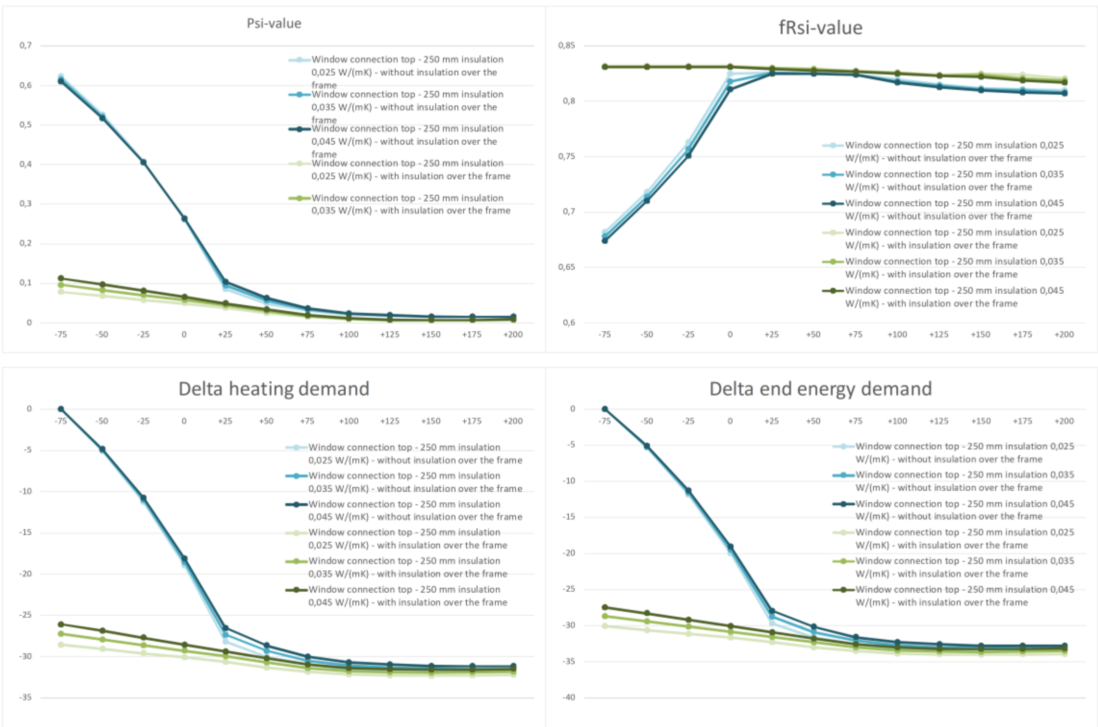


Psi-Value-Diagram of the tool with frame with or without over-insulated frames

THE WINDOW INSTALLATION Ψ-VALUE ESTIMATION TOOL

Thermal Bridge Tool – Window installation

Language:	EN	
Connection:	top	
Insulation thickness:	250	
Fensterhöhe [m]:	1,00	
Fensterbreite [m]:	1,60	
Heizsystem:	Gas boiler	
Klima:	Athen	
Heizgradtage [kKh/a]:		90



Screenshot of the whole excel tool with control menu on the top and evaluation diagrams

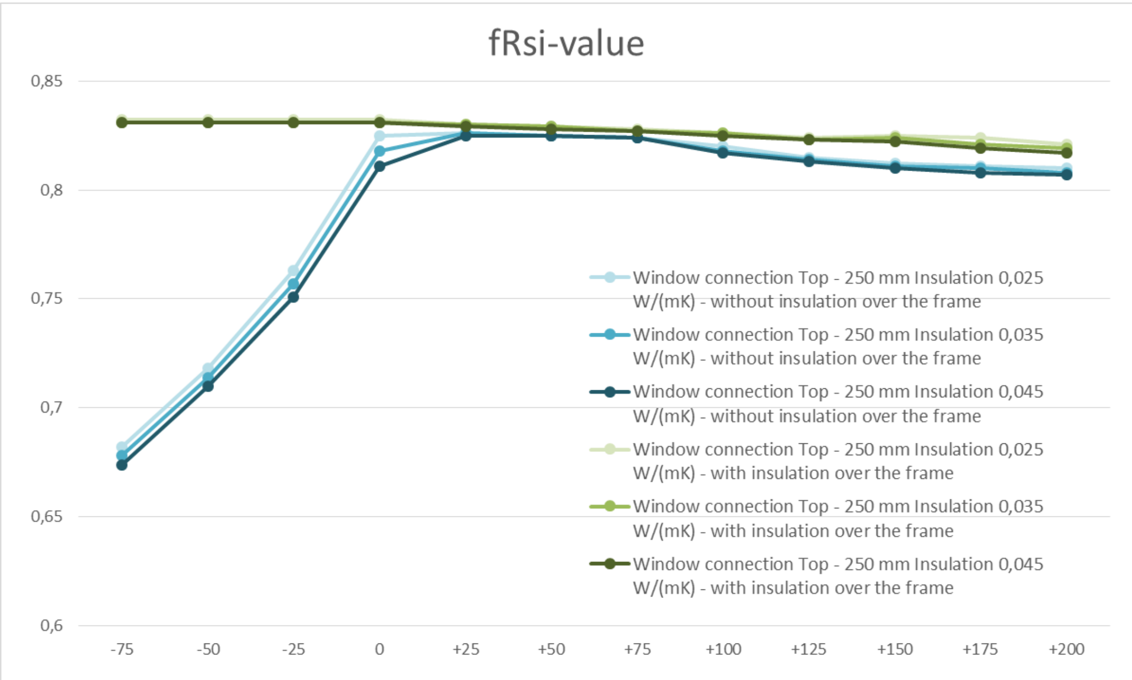
The tool consists of a small control menu at the top, were some selections must be entered: for example the side of the window to be considered or the insulation thickness for the evaluation. In order to work with the tool, the user must enter some data into this control menu, in order to select different variables:

- Open the tool and select the language
- Select the side of the window frame (top / side / bottom)
- Select the insulation thickness (15cm / 20cm / 25cm)
- Choose window height and width
- Choose the heating system (gas boiler / heat pump)
- Choose a representative climate data OR enter user defined heating degree days

Language:	EN	
Psi-Value:	Top	
Insulation thickness[mm]:	250	
Window height[m]:	1,00	
Window width[m]:	1,60	
Heating system:	Gas boiler	
Climate:	Mannheim	
Heatingdegreedays[kKh/a]:		68

Control menu of the tool

In the fRsi-Value diagram, the user is informed about potential problems with low surface temperatures that may arise from bad installation situations, depending on window position and over-insulation of the frame:



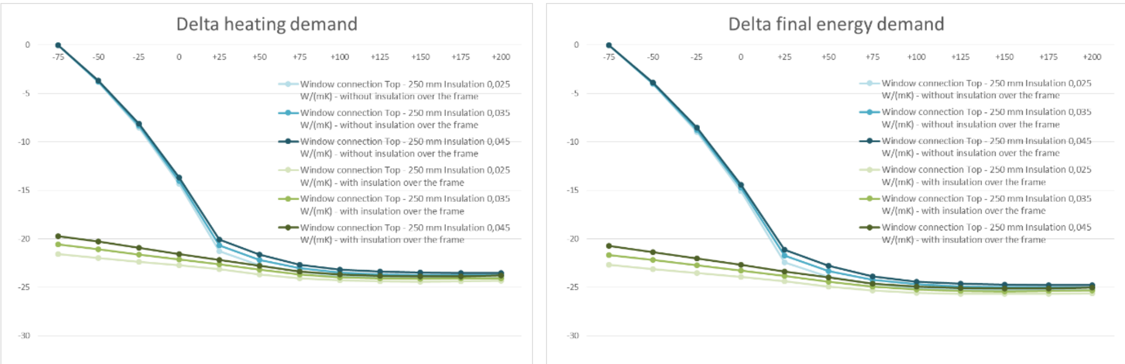
fRsi-Value diagram

IMPACT ON THE HEATING DEMAND:

To demonstrate the impact of the window installation on the whole building, a calculation of the heating demand and final energy demand for the installation thermal bridge was implemented in the tool. For this consideration, window dimensions, heating systems and climates can be varied to explore the impact on the heating demand caused by the installation Ψ-value.

Window installations for the bottom, side and top were evaluated. For the top and side connections also connection details with insulation over the frame were evaluated as with this thermal performance of the window can be improved. For the bottom connection insulation over the frame usually is not possible due to necessary draining of water out of the frame. In some special windows the window sill can be installed directly into the window frame which would make a better insulated installation possible. As this is a rather special construction for now it is not included in the evaluation.

A screenshot of the thermal bridge tool can be seen in the following picture.



Diagrams evaluating the impact of the installation-Psi-Values on heating and final energy

FURTHER EVALUATIONS

To show the impact of the installation thermal bridges further two more values are given by the tool. For a given building type, climate, heating system and window size the resulting delta heating demand and delta end energy demand is given. The heating and end energy demand is based on the difference of the installation Ψ-value. Reference for this is the window position 75 mm from the outside without insulation over the frame as this is a commonly used window installation situation in existing buildings.

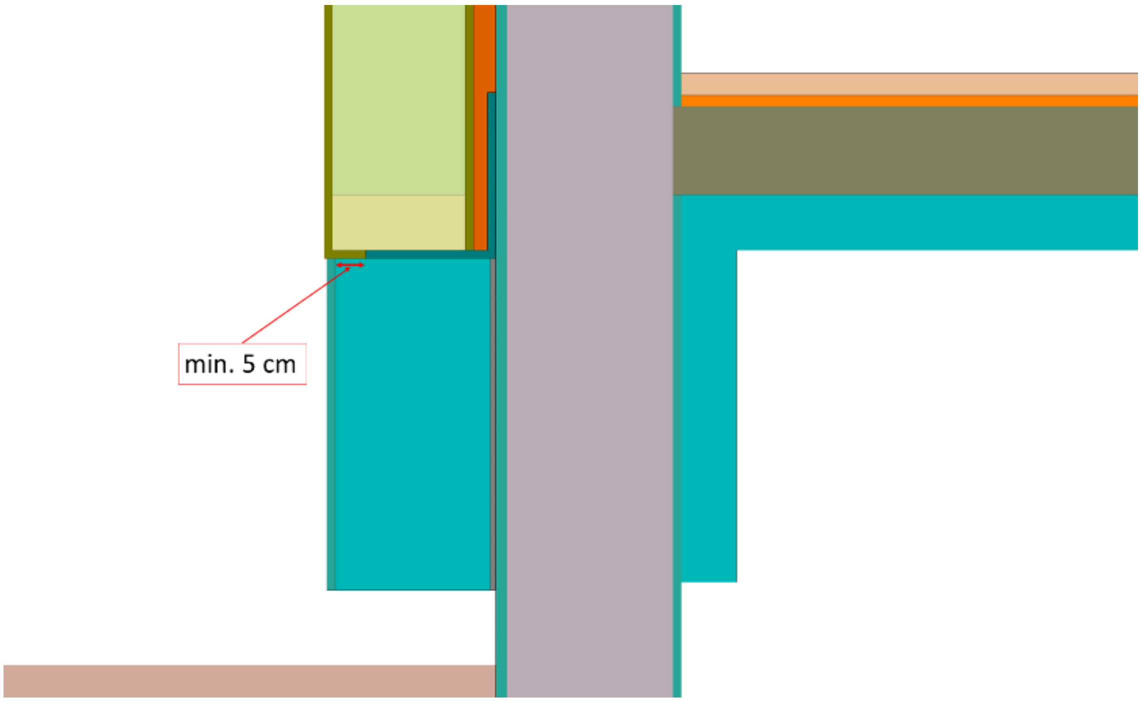
So with these two values it can be evaluated how great the impact is of insulating over the frame or installing the window in a different position in the wall.

4. PERIMETER CONNECTIONS

In renovation projects, thermal bridge effects of the connection between the basement wall and the basement ceiling can be considerable, if no flanking insulation is applied. This checklist helps to understand the effects of various flanking insulation options and offers recommendations on depth and thickness for an optimized perimeter connection, especially for prefabricated wall insulation concepts

CHECKLIST 1: IMPROVED PERIMETER CONNECTIONS

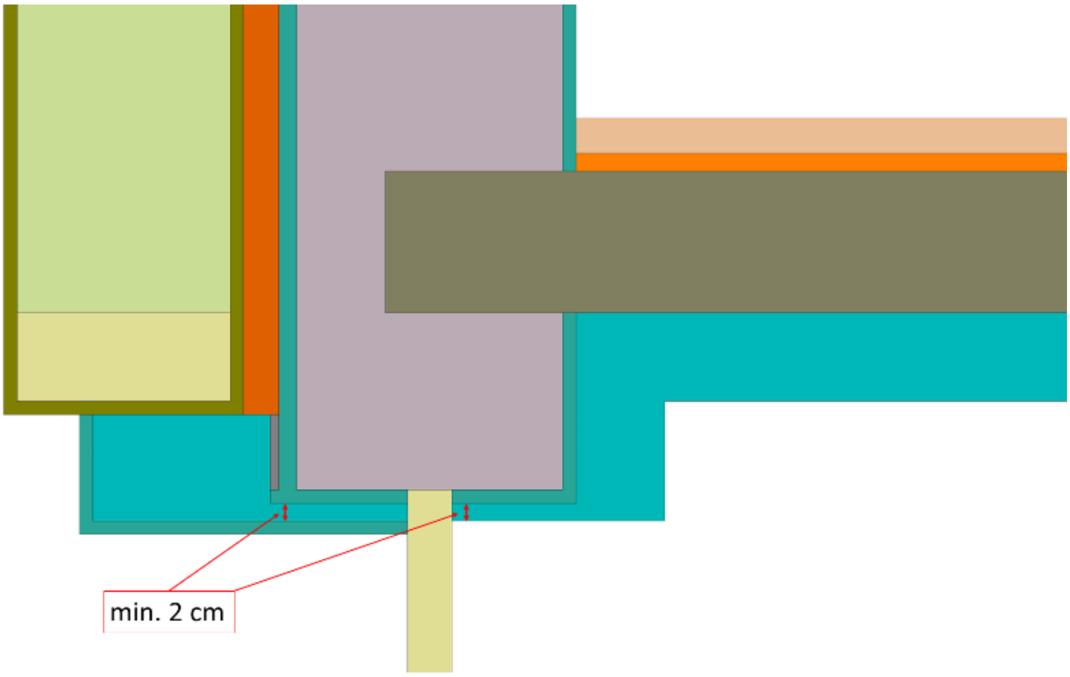
- ☐ Perimeter insulation on the outside of the exterior wall should be continued down to height of the bottom edge of the flanking insulation inside (if applicable). If there is no flanking insulation inside it should be continued down to the bottom edge of the basement ceiling insulation plus an additional 30 cm or more.
- ☐ The thickness of this insulation should be around 20 cm as a minimum.
- ☐ If there are steel brackets at the bottom of the exterior wall assembly, for example for serial renovations, outside perimeter insulation should have a thickness so that the steel brackets are covered with a minimum of 5 cm of insulation (see below):



Optimized perimeter connection for a prefabricated wall renovation approach

CHECKLIST 2: PERIMETER CONNECTIONS IN CASE OF BASEMENT WINDOWS

- ☐ Basement windows should be closed with insulation, if acceptable for the owner. For ventilation of the basement a ventilation system has to be implemented.
- ☐ If the windows cannot be closed, it is recommended to use a minimum of 2 cm insulation to insulate the upper reveal of the basement window as shown below, as this can reduce the thermal bridge effect in this area by almost 50%
- ☐ On the inside and the outside of the basement wall, flanking insulation should be installed, in sufficient thickness

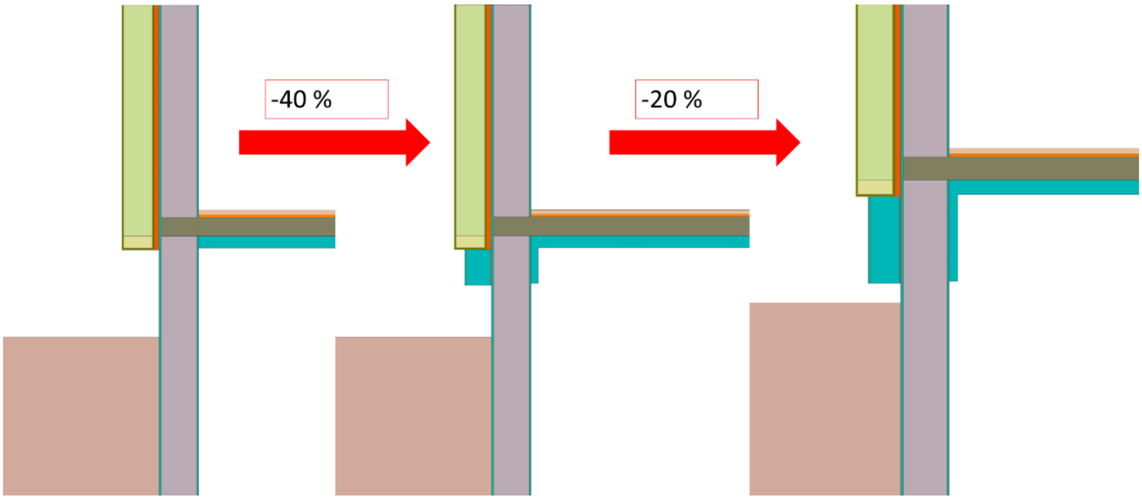


Optimized perimeter connection with basement window

- ☐ On the inside of the basement walls flanking insulation should be placed. The thickness should be the thickness of the basement ceiling insulation or half of that.
- ☐ This flanking insulation should be carried down from the bottom edge of the basement ceiling insulation at a minimum of 20 cm.

INFLUENCE OF THE DEPTH OF THE FLANKING INSULATION

With a flanking insulation depth of 30 cm outside and inside insulation with a thickness of 60 % of the ceiling insulation thickness, compared to no flanking insulation an improvement of 40 % can be achieved.



Influence of the flanking insulation depth

With a flanking insulation depth of 60 cm outside and inside, the improvement for the specific connection detail considered showed another 20%, so 60 % improvement in total in comparison to the situation with no flanking insulation at all (outside nor inside).

5. GROUND TUBES

HEAT DISTRIBUTION VIA UNDERGROUND PIPES – DISTRICT HEATING IN THE NEIGHBORHOOD

The power plants that will be operated with renewable energy sources in the future, as well as heating systems in residential areas that may work with combined heat and power (CHP), will be supplied with surplus energy from the summer half-year into the winter half-year. These summer surpluses of electrical energy must therefore be stored temporarily, for example by converting PV and wind power into liquid or gaseous energy sources using electrolysis etc. ('power-to-gas'). These can then be used in the winter months in the same way as the fossil fuels natural gas and crude oil. The waste heat generated during combustion in CHP plants or fuel cells can generally already be used very well today to heat buildings and provide domestic hot water. The energy content can therefore be used almost completely: electrical energy from the generator for light, power and communication and the waste heat for heating. This will become all the more important in the future because the available budget for renewable energy sources is likely to be more limited and primary energy will therefore be significantly more expensive than it is today, especially in winter.

The at least partial supply of individual neighborhoods via district or local heating networks is therefore an important component of the so called heat production transformation and is therefore an important option for heating and domestic hot water preparation.

Local heating networks are also interesting for the use of heat pumps (HPs) because the heat from larger central HP systems can be distributed to surrounding buildings via a local heating network. In this context, however, a warning should be issued about the heat distribution losses that then occur in the local heating networks: the prerequisite for the use and distribution of heat via heat-conducting pipes laid in the ground is that the heat distribution networks are optimized the best possible. This means that all heat distribution losses must be consistently balanced and minimized as far as possible.

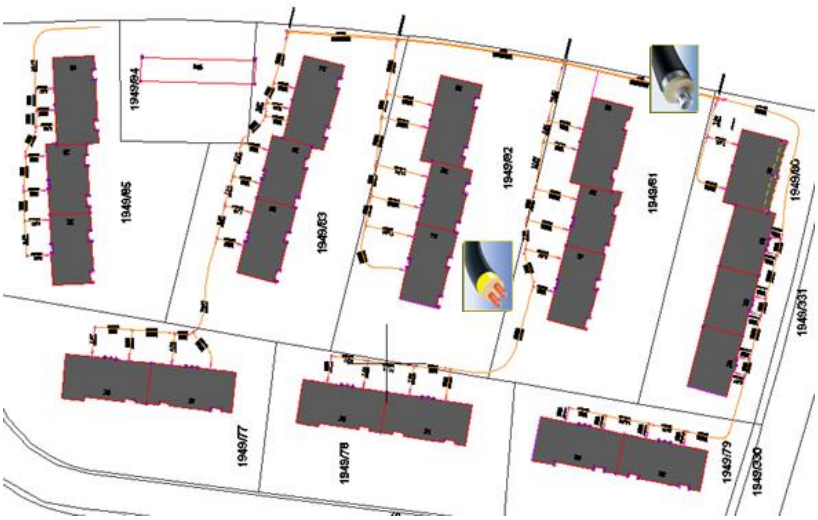
CONSIDERABLE HEAT LOSSES

The heat losses occurring by the distribution of waste heat from combined heat and power plants (CHP) in so-called local and district heating networks are considerable compared to the final energy made available to the user at the house connections. It is therefore instructive to look at the amount of energy lost per year compared to the amount of final energy supplied for different building types.

For passive houses and buildings renovated to the EnerPHit standard in particular, the 'energy density' achievable in the grid is relatively low because the final energy requirement for space heating and domestic hot water is only around 50 kWh/m²a and possibly even less, i.e. only around 6 000 kWh/a of final energy is delivered per residential unit (120 m²). For typical old buildings with a consumption of around 240 kWh/m²a or 29 000 kWh/a, the turnover is significantly higher [AKKP 46 FW]. These figures already include the heat distribution losses within the building.

In [AKKP 46 FW], various scenarios for the configuration of district heating and local heating distribution networks were drawn up and compared. Several different qualities of thermal insulation of the heat distribution pipes were compared with each other and the length of the distribution pipes in a network was varied. The results show that with a moderate improvement in the quality of the pipe insulation and an optimization (shortening) of the network length, acceptable heat distribution losses can already be achieved with today's pipe technology. So passive houses and districts renovated to the EnerPHit standard can be supplied with heat economically. The 'specific' network length in meters/residential unit (m/unit) is an important factor here. The first goal of network optimization must therefore be to keep the specific network length low and thus the network connection density high; values below 6 m/unit should be aimed for [AKKP 46 FW].

A corresponding spreadsheet is provided as an Excel tool for this purpose, which makes the heat distribution losses and their effect on the regenerative supply visible. In the tool all the geometry of the grid i.e. length of underground tubes and quality of thermal insulation can be defined. The characteristic values determined in this way can also be used in the PHPP to ultimately estimate the primary energy input for the heat supply.



Tube length route 850 m

Branch lines 270 m

Risers 365 m

(with extension 607 m)

Tflow 55...65 °C

For variants see Figure 2

Example of a local heating network for a district with 8 buildings, 125 units, and 8 400 m² floor space, with two extra floors extension 208 WE, 14 000 m²

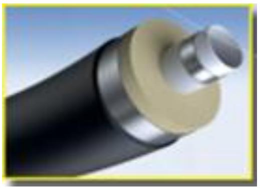
The higher the feed-flow temperatures in the distribution networks, the more relevant are the occurring distribution losses. This is illustrated in Figure 1 using an exemplary local heating network. The buildings and the distribution pipes are shown in the site plan. Each building entrance has a branch pipe from the route and a riser pipe, the lengths of which add up to a figure total of around 12 meters per residential unit. The more residential units are connected, e.g. if the buildings are also extended during renovation, the smaller this figure can become. A re-densification in the course of refurbishment therefore also has a positive effect in this context. Figure 2 also lists the absolute totals for the individual variants in tabular form. This means that the length of the heat distribution network is at the limit of what appears to be compact and reasonable (10 m per residential unit) [AKKP 46 FW]).

The heat losses are quite high at around 17 kWh/(m²a) or 13 kWh/(m²a) after the building has been extended and amount to around two thirds of the expected heating energy demand of the renovated apartments. If the feed-flow temperature is reduced from 65 °C to 55 °C, around 2 kWh/(m²a) can be saved. However, 55 °C seems questionable to provide domestic hot water with an assured temperature in heat transfer stations in every apartment.

This makes it clear that the use of centralized heat pump systems and the distribution of heat at a high temperature level greatly degrades the good energy efficiency of a heat pump. Such losses must always be taken into account in the primary energy balance. [AKKP 61 WP]

The same problem naturally also applies to heat distribution from a CHP plant: the valuable useful heat is made available at a very high temperature level and it must therefore be ensured that heat distribution losses are minimized as far as possible.

Losses Ground tubes		**Variants (results)**									
including raisers		standard		compact grid		ectended levels		better insulation		cold district heating	
		1	2	3	4	5	6	7	8	9	10
Tubes in Route	[kWh/m²a]	11.08	9.33	11.08	9.33	6.65	5.60	6.10	5.13	4.28	2.57
Branch lines	[kWh/m²a]	2.59	2.18	1.29	1.09	0.78	0.65	0.65	0.55	0.70	0.42
Branch lines	[kWh/m²a]	3.49	2.94	3.49	2.94	3.49	2.94	2.94	2.48	1.90	1.90
connection to HP	[kWh/m²a]	2.12	1.89	2.12	1.89	1.27	1.13	1.05	0.95	1.42	0.85
Sum	**[kWh/m²a]**	**19.29**	**16.34**	**17.99**	**15.25**	**12.19**	**10.33**	**10.75**	**9.11**	**8.30**	**5.74**
TFA	[m²]	8400	8400	8400	8400	14000	14000	14000	14000	8400	14000
total length of grid	[m]	1472	1472	1337	1337	1580	1580	1580	1580	1337	1580
No of dwelling units	–	125	125	125	125	208	208	208	208	125	208
length per dwelling unit	**[m]**	**12**	**12**	**11**	**11**	**8**	**8**	**8**	**8**	**11**	**8**
		0	0	0	0	0	0	0	0	0	0
		0	0	0	0	0	0	0	0	0	0
here assumptions for the several variants can be defined											
T_feed_line	**[°C]**	**65**	55	**65**	55	**65**	55	**65**	55	15	15
T_back_line	[°C]	**50**	45	**50**	45	**50**	45	**50**	45	15	15
Delta T in grid	[K]	47.5	40	47.5	40	47.5	40	47.5	40	5	5
length of branch lines	[m]	6	6	3	3	3	3	3	3	3	3
levels in buildings	–	3	3	3	3	5	5	5	5	3	5
psi DUO 50	[W/mK]	0.194	0.194	0.194	0.194	0.194	0.194	0.163	0.163	1.000	1.000
psi DUO 63	[W/mK]	0.232	0.232	0.232	0.232	0.232	0.232	0.192	0.192	1.000	1.000
psi DUO 75	[W/mK]	0.266	0.266	0.266	0.266	0.266	0.266	0.266	0.266	1.000	1.000
psi UNO 90	[W/mK]	0.193	0.193	0.193	0.193	0.193	0.193	0.165	0.165	1.000	1.000
psi UNO 110	[W/mK]	0.220	0.220	0.220	0.220	0.220	0.220	0.118	0.118	1.000	1.000
psi UNO 125	[W/mK]	0.280	0.280	0.280	0.280	0.280	0.280	0.230	0.230	1.000	1.000
psi tubes in technical rooms	[W/mK]	0.200	0.200	0.200	0.200	0.200	0.200	0.150	0.150	1.000	1.000
Efficiency of grid with respect to useful delivered heat											
useful delivered heat winter	[kWh/m²a]	35	35	35	35	35	35	35	35	35	35
Efficiency grid winter		**65%**	**68%**	**66%**	**70%**	**74%**	**77%**	**77%**	**80%**	**81%**	**86%**
useful delivered heat summe	[kWh/m²a]	15	15	15	15	15	15	15	15	15	15
Efficiency grid summer		**43%**	**47%**	**45%**	**49%**	**55%**	**59%**	**58%**	**62%**	**64%**	**72%**
useful delivered heat yearly	[kWh/m²a]	50	50	50	50	50	50	50	50	50	50
Efficiency grid full year average		**72%**	**75%**	**74%**	**77%**	**80%**	**83%**	**82%**	**85%**	**86%**	**90%**



ΨRoute = 0.25 W/mK

ΨBranches = 0.19 W/mK

above: results for heat losses in the local heating network in tabular form from the tool 'district-heat-losses'
left: Characteristic values for underground pipes /

Ψraisers = 0.2 W/mK

Using the Excel tool 'district_heating_losses' and the input parameters mentioned above, the characteristic values of the network configuration can be calculated as shown in [AKKP 61 WP] The efficiency of the local district heating network then results from the ratio of useful heat (space heating energy demand and DHW heat demand) to the total heat demand: (useful heat plus network distribution losses).

In the PHPP, the network losses can only be calculated as a lump sum with a Ψ-value of the distribution routes. The 'district_heating_losses' tool allows a more detailed consideration of the district or local heating network, as e.g. storage losses in the network and other influencing factors are taken into account

As can be seen from the results in the table in Figure 2, the proportion of heat distribution losses is very high compared to the useful heat for the long networks (12 m/unit) and thus the winter efficiency of the networks is quite low (only 65 %) if the losses are calculated honestly, see variant 1. If the summer conditions are considered, when only the useful heat for DHW heating is delivered in the network, then it becomes even worse because the distribution losses are at the same height in summer.

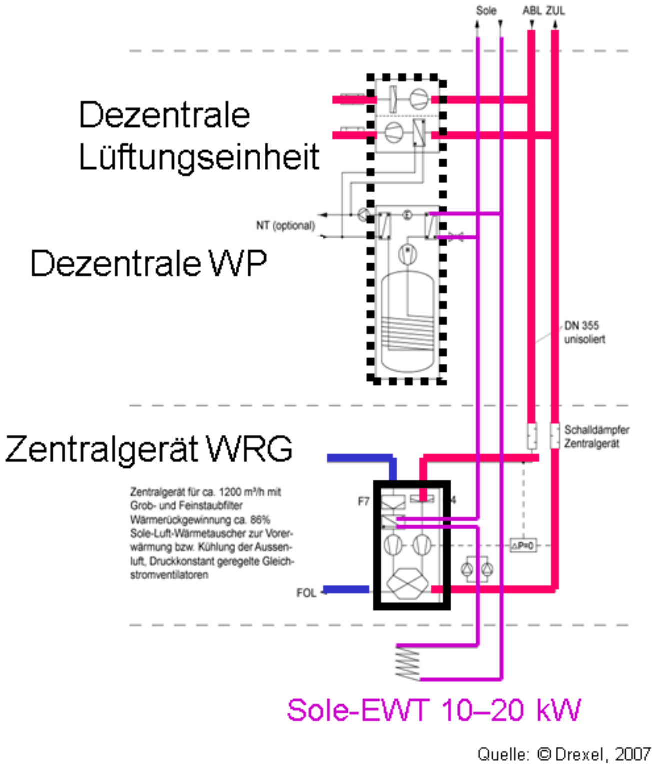
An improvement is achieved by shortening the network (variant 3), improving the thermal insulation of the underground pipes (variant 7) and, if applicable, increasing the density of apartments (variant 5) and reducing the feed flow temperatures (variants 2, 4, 6, 8). With all these measures combined, the efficiency in the example increases to around 80 % (variant 8).

COLD LOCAL DISTRICT HEATING IN UNDERGROUND PIPES

In variants 9 and 10, the feed flow temperatures were reduced to 15 °C. As expected, this immediately drastically reduces the heat losses in the network despite standard thermal insulation. [AKKP 61 WP]. This is the situation for so-called 'cold local district heating': a heat source with very low feed flow temperatures is used for distribution via the underground pipes. In this case, the higher temperatures for the useful heat for heating and hot water in the apartments are then provided by a heat pump.

The heat pump can either be installed decentrally in each residential unit or centrally in each building. This has two advantages:

- Firstly, the primary circuit of the heat pump is operated at a relatively high temperature. This can be ground temperature, i.e. a circuit fed from ground probes, for example. Or it can be waste heat from industrial processes, waste incineration or waste water, which may only be available at temperatures below 30°C. This primary temperature can then be used to operate decentralized residential and building-by-building heat pumps with very high SPFs because they have a good primary heat source available all year round.
- Secondly, this concept reduces the heat distribution losses in the network to practically zero. These 'cold' heat distribution pipes only need to be slightly insulated where they run through the building in order to prevent condensation on the pipes. It would therefore be possible to completely dispense with the thermal insulation of the underground pipes. Even with Ψ = 1 W/mK, the network efficiency is well above 80%.



In this way, compact heat pumps have also been implemented as systems with centralized systems, i.e. each apartment has a ventilation unit with heat recovery combined with a heat pump for supply air heating and a small DHW cylinder. The heat pump is supplied via a brine circuit. [Drexel 2007] [Dimplex]

However, the investment costs will shift with this concept: instead of a central heat pump or CHP system in the entire local district heating network, a heat pump must now be installed for each building or for each residential unit. How the investment costs will compare to the reduced heat losses is beyond the scope of this report. However, an overall economic analysis could be carried out with [districtPH].

Separated heat pump and ventilation concepts

LITERATURE

[AKKP 61 WP] B. Kaufmann, Wärmepumpen für die Altbausanierung, in Arbeitskreis Kostengünstige Passivhäuser, Protokollband 61, Serielle energetische Sanierung nach Passivhaus Prinzipien, Darmstadt, 2024

[AKKP 46 FW] B. Kaufmann, Bewertung leitungsgebundener Energieträger: Wärmeverteilverluste von Fern-/ Nahwärmenetzen Szenarien für die optimierte Fernwärmenutzung aus KWK. In: Arbeitskreis Kostengünstige Passivhäuser, Protokollband 46, Nachhaltige Energieversorgung mit Passivhäusern, Darmstadt 2012

[Drexel 2007] C. Drexel, Tagungsband zur Internationalen Passivhaustagung 2007 (Bregenz), Energie Institut Vorarlberg (EIV) / Passivhaus Institut, Darmstadt 2007.

[Dimplex] https://www.dimplex.co.uk/professional/heat-pumps/ambient-temperature-network?

[districtPH] districtPH is used to create energy balances for neighborhoods, from smaller groups of buildings up to whole districts. A specific strength of the tool is the ability to investigate the effects that different scenarios of development and retrofitting have for the building stock. The analysis takes into account grids for electricity and heat, renewable energies, electromobility and public consumers. districtPH was developed within the EU-funded Sinfonia project. http://www.sinfonia-smartcities.eu/en/

6. VENTILATION DUCTS WITHIN THE INSULATION LAYER

If old buildings are equipped with ventilation systems with heat recovery as part of a refurbishment, it often offers advantages if the supply and extract air ducts can be installed outside the home for the most part. Among other things, less work is required inside occupied flats in this case. One option is to lay the ducts on the outside of the existing external wall and then cover them with thermal insulation. With prefabricated insulation elements, it makes sense to install the ventilation ducts in the elements at the factory.

The heat recovery unit can be located either outside the thermal envelope, e.g. in an unconditioned attic, or inside the building / the flats.

This type of installation results in additional transmission heat losses. It must also be taken into account that the air flowing in the ducts changes its temperature, which affects the ventilation losses. Based on a detailed analysis (see below) it was found that the following points must be considered.

Façade integrated ventilation concept @ NHT

SIMPLE OR DETAILED APPROACH

The additional heat losses must be considered in the energy balance. A simple and conservative way is to carry out a simple thermal bridge analysis, assuming a stable indoor temperature inside the ventilation ducts. The thermal bridge coefficients received from such an analysis can then, together with the length of the ducts, be entered into an energy balance calculation like the Passive House Planning Package PHPP.

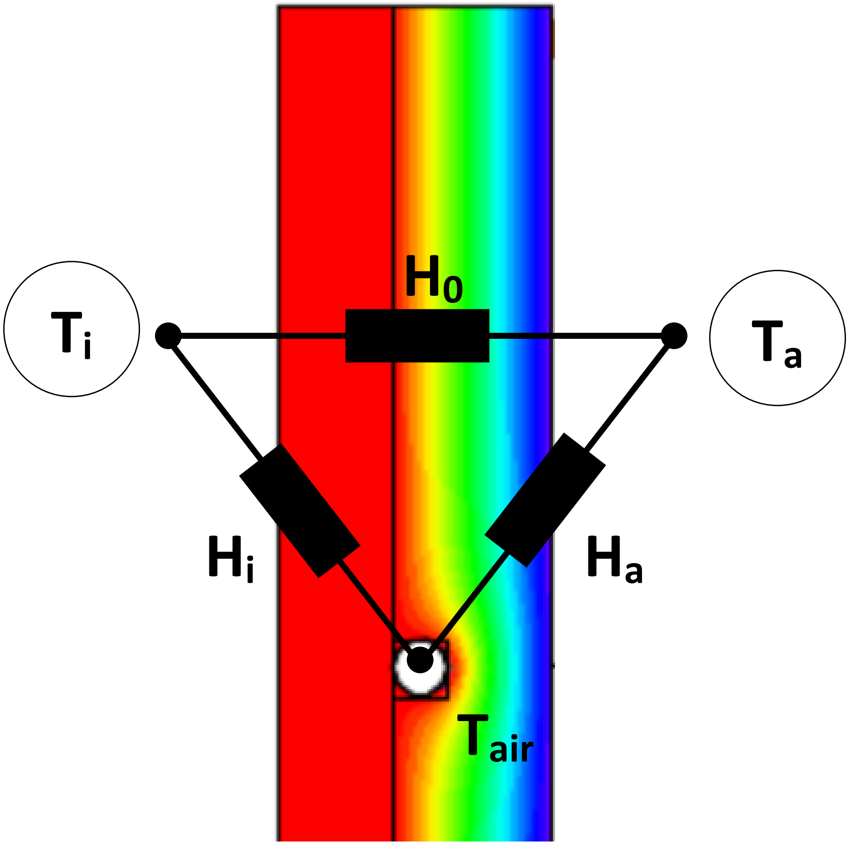
For a more detailed analysis use the outPHit tool for ducts in the insulation layer. It calculates the net additional heat losses and the resulting supply air temperature.

The schematic below shows a section through a ventilation duct which is installed in the thermal insulation on the masonry. Three temperatures are involved in the resulting heat flows:

- the internal temperature Ti,
- the external temperature Ta
- the temperature in the duct Tair.

As shown in the illustration, this situation can be modelled using a delta circuit of conductance values H in W/(mK) between the temperatures mentioned above. Due to the linearity of the heat conduction equation, it is enough to determine the conductance values once using a 2D heat flow calculation for any temperature. In Figure 1 for example, T_i=T_{air}, heat flow over the internal surface is then $H_0(T_i-T_a)$, heat flow over the surface of the ventilation duct is $H_a(T_{air}-T_a)$. For other temperature combinations, the heat flows can then be calculated using the same conductance values (superposition principle).

In the following calculations, it makes sense to use the difference to the regular heat flow instead of H0, i.e. ΔH_0=H_0-Ud(T_i-T_a), where d is the length of the internal or external surface in the 2D model. ΔH_0 together with Hi and Ha then yields the additional heat flow due to the duct in the insulation level. In the analysed examples, H0 was always negative (typically approximately -0.04 W/(mK)), but the ventilation duct still leads to a slightly increased heat loss overall (typically approx. 0.01 W/(mK)) if the calculation is carried out via H_i and H_a.



Ventilation duct in the insulation level of a masonry wall with thermal insulation. The internal room temperature Ti was used here the air temperature Tair in the ventilation duct.

On this basis, a situation such as shown in the figure above**Fehler! Verweisquelle konnte nicht gefunden werden.** can now be analysed in more detail. Different heat flows arise: the warm extract air with temperature $T_{EXT}=T_i$ in the thermal insulation generates increased heat loss via the external surface, but on the other hand it reduces the heat flow from the room into the wall. On its way to the ventilation unit, it gradually cools down so that air with the temperature T_{EXT}' arrives at the connecting piece of the ventilation unit, colder than if the duct were routed inside the building. This shifts the temperature conditions in the ventilation unit itself and the supply air T_{SUP}' is correspondingly colder. Depending on the heat recovery efficiency of the ventilation unit and the position of the duct, the supply air becomes warmer or colder on its way through the wall until it enters the room at temperature T_{SUP}.

In order to understand the influence of this situation on the transmission and ventilation losses of the building, it is helpful to precisely analyse the heat flows. On this basis, simplifications can then be made for practical application.

DETERMINING ADDITIONAL HEAT LOSSES

First of all, it should be assumed that T_{air} has become stationary, as is the case e.g. with still air in the duct, but also at the end of a very long duct. The following will then apply:

$$T_{air} = \frac{H_a T_a + H_i T_i}{H_a + H_i}$$

This temperature will subsequently be referred to as the equilibrium temperature T_{eq}.

The (two-dimensional) overall heat loss per metre of wall or duct length through the internal surface of the wall will then be

$$q_{eq} = H_0(T_i - T_a) + H_i\left(T_i - T_{eq}\right)$$

With reference to the external surface, the same value results in the form

$$q_{eq} = H_0(T_i - T_a) + H_a\left(T_{eq} - T_a\right)$$

The temperature of the air flowing inside the duct becomes similar to the equilibrium temperature exponentially. For instance, the following applies for the extract air duct

$$T_{air}(x) = T_{eq} + \left(T_{EXT} - T_{eq}\right)e^{-\frac{H_a+H_i}{\dot{m}c_p}x}$$

in which $\dot{m}c_p$ is the thermal capacity current in the ventilation duct.

At the connecting piece of the ventilation unit, after passing through the duct length l, the extract air still has the temperature

$$T_{EXT}' = T_{eq} + \left(T_{EXT} - T_{eq}\right)e^{-\frac{H_a+H_i}{\dot{m}c_p}l}$$

Also, at the connecting piece of the ventilation unit, the following supply air temperature is thus calculated by

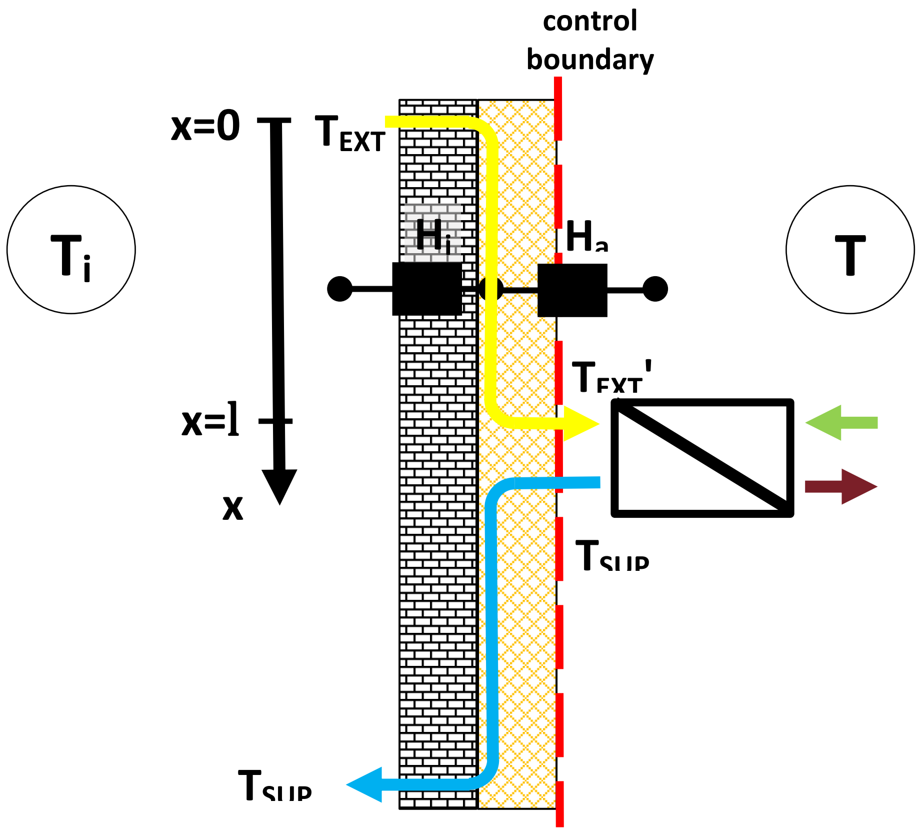
$$T_{SUP}' = T_a + \eta_{HR}(T_{EXT}' - T_a)$$

where η_{HR} is the heat recovery efficiency of the ventilation unit on the supply air side.

The supply air temperature on the inside can be determined in a way similar to that for the extract air temperature.

With the help of these interrelationships, it is now possible to determine the additional heat loss of the building caused by the ventilation ducts routed in the insulation. For calculating this correctly, it is essential to clearly specify the position of the balance boundary. In many respects, it proves to be particularly easy to specify this on the outer surface of the wall, in line with the conventions in the PHPP.

With the help of some interrelationships, it is possible to determine the additional heat loss of the building caused by the ventilation ducts routed in the insulation. For calculating this correctly, it is essential to clearly specify the position of the balance boundary. In many respects, it proves to be particularly easy to specify this on the outer surface of the wall, in line with the conventions in the PHPP.



Ventilation ducts installed in the thermal insulation transport the supply air and extract air between the ventilation unit with heat recovery and the inside of the building. The unit is depicted here as being outside of the thermal envelope, the calculation procedure for units inside the thermal envelope is the same.

In the area of the extract air duct, the transmission heat loss through the external surface is

$$Q_T = H_0 l(T_i - T_a) + \int_0^l H_a(T_{air}(x) - T_a)\,dx$$

$$= H_0 l(T_i - T_a) + H_a \int_0^l T_{eq} + \left(T_{EXT} - T_{eq}\right)e^{-\frac{H_a+H_i}{\dot{m}c_p}x} - T_a\,dx$$

$$= H_0 l(T_i - T_a) + H_a l\left(T_{eq} + \left(T_{EXT} - T_{eq}\right)\frac{\dot{m}c_p}{(H_a + H_i)l}\left(1 - e^{-\frac{H_a+H_i}{\dot{m}c_p}l}\right) - T_a\right)$$

The losses in the area of the supply air duct can be determined in a similar manner.

The ventilation losses result from the temperatures of the supply air and extract air flows through the building envelope

$$Q_V = \dot{m}c_p({T_{EXT}}' - {T_{SUP}}')$$

The calculation procedure described here was implemented in a spreadsheet calculation and applied to some examples.

CHECKLIST TUBES WITHIN THE INSULATION LAYER

- ☐ The insulation should be at least 200 mm thick.
- ☐ The ducts should be covered with at least 50% of the total insulation thickness.
- ☐ Round or flat ducts can be used.
- ☐ The duct lengths should be kept as short as possible.
- ☐ If the existing wall is already insulating significantly, heat losses increase and supply air temperatures may become so low that the incoming air needs to be preheated.
- ☐ Duct connection must be airtight.
- ☐ Avoid structure-borne sound transmission from the ventilation unit.
- ☐ Avoid air infiltration into the resulting cavities.
- ☐ Ensure that fire protection has been taken into account when ducting is routed across storey ceilings.
- ☐ When installing the insulation, make sure that the ducts are not pressed in.
- ☐ Take suitable precautions to ensure that ducts are not drilled into, e.g. for plugs or ETICS components.
- ☐ Store the ducts on site protected from the weather and free from contamination.
- ☐ Seal the penetrations of the new airtight layer by the ventilation ducts.
- ☐ While mounting the ducts, do not impede the function of the new airtight layer.
- ☐ ______________________
- ☐ ______________________
- ☐ ______________________

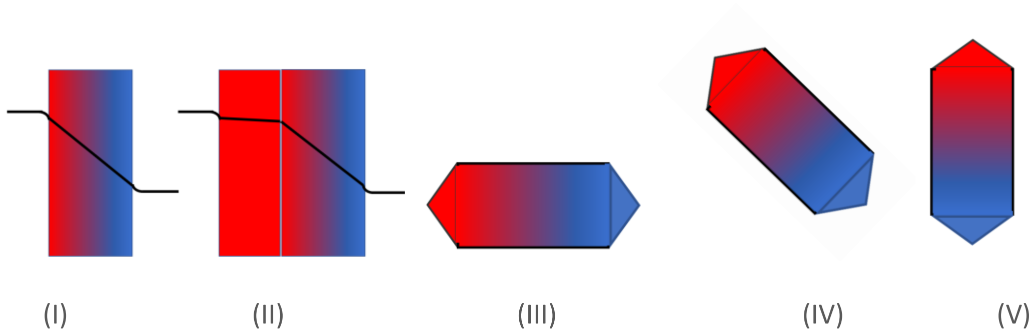
7. FAÇADE INTEGRATION OF DEVICES

If old buildings are equipped with ventilation systems with heat recovery, heat pumps or other devices (such as hot water tanks) as part of a refurbishment, it often offers advantages if this devices are not placed inside the dwelling, but integrated in the façade. This way the device takes less space inside the dwelling and less work is required inside occupied flats in this case. Moreover, the maintenance of the device has to be considered. One option is from inside, but many housing associations are reluctant to choose this option when building rental apartments because appointments must then be made to enter the apartment for maintenance work. The other version is the maintenance from outside. However, a lift is required for this from the first floor onwards, if the unit is not accessible from a balcony or pergola.

With regard to prefabrication, complete integration into the facade modules would be advantageous, but the device depth is then limited by the thickness of the facade. If the device requires a greater installation depth, either radiator niches or window openings can be used. When integrating windows, it may be possible to work with existing opening widths. The use of radiator niches, however, requires chiseling work.

In case of heat recovery ventilation units, the façade integration is the best way to realize short ductwork and low heat losses. A direct connection to the ducts in the façade is possible, a special checklist and tool was elaborated in **D4.6 Deep Renovation Guidelines**.

In some cases, the installation results in additional transmission heat losses, which can be taken into account as χ-values (unit [W/K]) in the energy balance. The façade integration tool will help to estimate these losses.



The temperature gradient in masonry (I) or an insulated solid wall (II) is linear in sections with the larger gradient in the area of lower conductivity. This should be kept in mind when integrating a countercurrent heat exchanger in an insulated wall. To avoid heat losses, the heat exchanger should be installed according to (III) or (IV) if possible. Vertical installation (V) calls for additional insulation to minimize the losses.

MINIMUM SURFACE TEMPERATURES TO PREVENT CONDENSATION AND MOLD

The limit for mold formation is a **relative humidity of 70%** on the surface (activity of water, a_w value). Above this threshold, some types can develop. But with an aw value **of 80%,** almost all types of mold can develop. The value of 80% is therefore considered the limit that should not be exceeded. At a relative humidity of 100%, condensation forms, the nutrient medium becomes noticeably moist, and mold formation is considered unavoidable.

The limit value is determined using the temperature factor f_{Rsi}. **This represents the** difference between the temperature on the inner surface θ_{si} of a component and the outside air temperature θ_e, related to the temperature difference between inside air θ_i and outside air θ_e. The surface temperature is determined using a defined heat transfer resistance R_{si} (R_{si} = 0.25 (m² K)/ W).

$$f_{Rsi} = (\theta_{si} - \theta_e) / (\theta_i - \theta_e)$$

with θ_{si} [°C] surface temperature inside
θ_e [°C] air temperature outside
θ_i [°C] air temperature inside

An **f_{Rsi} value of less than 0.7** indicates that the temperature is below standard conditions, the relative humidity on the surface in question is greater than 80% and mold can therefore form. For this reason, the f_{Rsi} value must be equal to or greater than 0.7.

However, it should be remembered that these are normative minimum requirements. Depending on the climatic conditions, these are not even on the safe side if extremely low outside temperatures or high indoor air temperatures cannot be ruled out in practice.

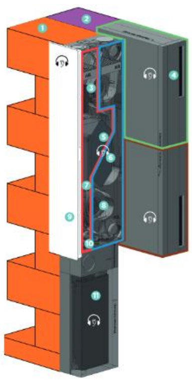
SOUND RADIATION INWARDS AND TO THE OUTSIDE

The limit values according to the PHI certificate apply to the sound emitted by the device to the inside: 30 dB(A) must not be exceeded in the technical room or utility room, and 25 dB(A) in living rooms. The tool can be used to check these limit values depending on the adjacent room.

The sound emitted by the device to the outside must also be limited. This applies to both ventilation devices and heat pumps. The aim is not to disturb neighbours or yourself with noise. Not only does the dB(A)-weighted sound play a role, but the limit values for low-frequency sound must also be observed. The so-called " tone quality " of the noise, if present, must also be taken into account, because particularly high levels of individual frequency bands are perceived as disturbing by the human ear. For ventilation units, external and exhaust air silencers are recommended, especially in apartment buildings or when there are neighbors in the immediate vicinity. Some manufacturers offer particularly flat products that have been specially developed for facade installation.

MICRO HEAT PUMPS

Similar to ventilation units, thermal insulation, sound insulation and moisture protection must also be taken into account with small heat pumps depending on the installation position. Compared to ventilation units, small heat pumps are often not as flat, which often leads to weakening of the insulation thickness of the external walls, but otherwise the problem is similar or the same as with ventilation units. The sound insulation problem is made even more difficult by the compressor noise , and in addition to airborne sound insulation, it is also important to avoid structure-borne sound being transmitted to the external wall or facade module.

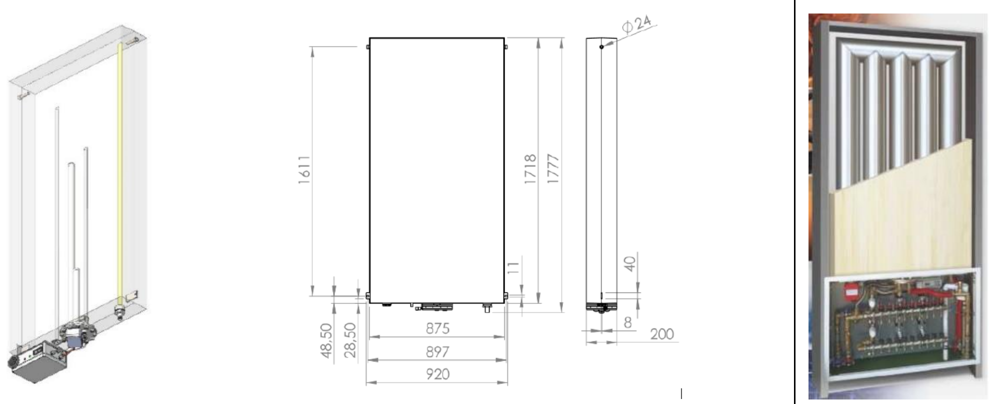


(1) Brickwork
(2) Full thermal insulation
(3) Outside air fan
(4) Silencer element for outside or exhaust air
(5) Heat exchanger
(6) Outside/exhaust air side
(7) Supply/exhaust air side
(8) Exhaust air fan
(9) Sound-damped supply/exhaust air element
(10)Supply air switchover
(11)Supply air silencer

Example of flat silencers (outside/exhaust air) for wall installation, (Source Airvolution KL100)

STORAGE

The integration of heat storage units in the facade is still relatively rare, as there are hardly any products available on the market. The Pink company sells a product that consists of parallel vertical stainless steel pipes that are welded to a horizontal connecting pipe at the top and bottom (partial wall storage unit). With a thickness of 200 mm, this flat storage unit can be installed in the wall or insulation layer. As with the ventilation units, both flush-mounted and wall integration is possible; a universal frame is available as an accessory.

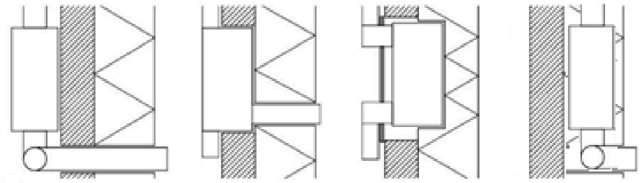


Flat storage from Pink (Enerboxx premium WDS140)

The advantage of space-saving installation through wall integration is offset by the higher heat loss due to the unfavorable A/V ratio. If the storage tank is to be installed in wall modules during prefabrication, it is important to ensure that the remaining insulation has a particularly low thermal conductivity, otherwise the transmission heat losses will be too significant due to the high temperature difference and low insulation thickness.

CHECKLIST FOR WALL AND FAÇADE INTEGRATION

In general, three different ways of integration of devices are possible. The device installation can be done “surface-mounted” (a), “flush-mounted” (b), “integrated into the wall” (c) and “façade integrated” (d) as shown in the following principle sketch.



(a) (b) (c) (d)

Surface-mounted (a):

- ☐ Avoid airborne and structure-borne (sound decoupling) noise transmission from the device to the installation room, as there is no wall in between the device and room.
- ☐ The duct lengths should be kept as short as possible. Supply and extract air ducts are usually laid inside the dwelling.
- ☐ Cold ducts (ambient and exhaust air) should be insulated with vapor tight insulation.
- ☐ The duct bushing must be carefully connected to the airtight level using pipe collars.

Flush-mounted (b):

- ☐ Avoid tructure-borne noise transmission from the device to the installation room by sound decoupling. A sound insulation board in between the device and the room avoids airborne sound transmission.
- ☐ The breakthrough must be checked in advance for any impairment of the statics.
- ☐ Fire protection must be observed.
- ☐ The airtightness of the building envelope must not be weakened by the installation of devices. This also applies to the installation of maintenance openings

Integrated into the wall (c):

- ☐ The same instructions apply to this type of installation as for (b).
- ☐ Depending on the installation depth, the insulation strength of the outer wall is weakened. The χ-values can be calculated with the integration tool.
- ☐ Metal casings should be avoided for thermal bridge reasons.
- ☐ Minimum surface temperatures must be maintained to avoid condensation and mold.

Façade integrated (d):

- ☐ This type of installation is only suitable for particularly flat devices
- ☐ Particular care must be taken to ensure the quality of the remaining insulation thickness in order to be able to comply with the limit values for heat losses and surface temperatures. High efficiency insulation boards might help to reach the goals.
- ☐ Depending on the installation depth, the insulation strength of the outer wall is weakened. The χ-values can be calculated with the integration tool.
- ☐ Metal casings should be avoided for thermal bridge reasons.

8. AIRTIGHTNESS IN DEEP RETROFITS

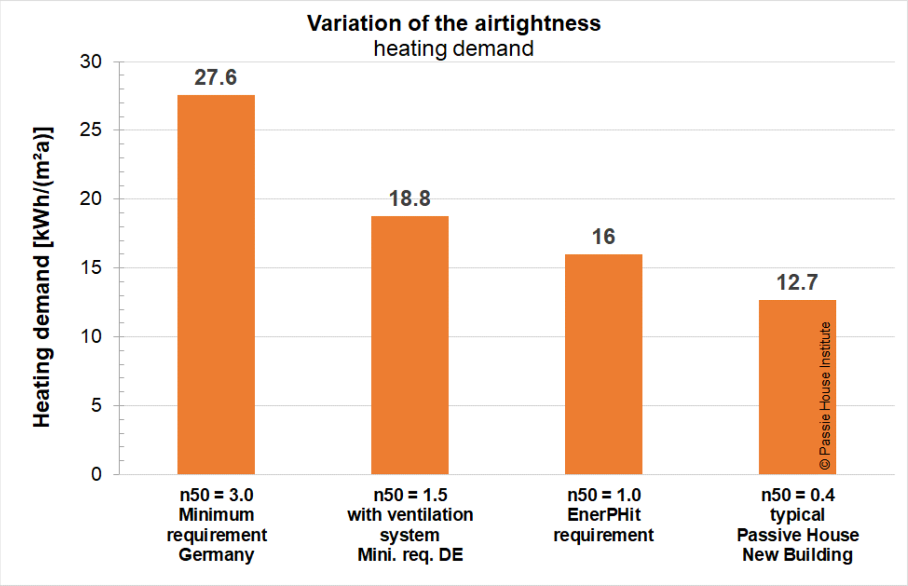
An airtight building envelope is one of the cornerstones of energy efficient buildings. It is necessary to implement an adequate level of airtightness in every building for the following reasons in particular:

Technical/energy relevant reasons	**Comfort related reasons**
Avoidance of structural damage	Avoidance of cold air pockets and draughts
Avoidance of energy losses	Less temperature fluctuations
Prerequisite for proper functioning of a ventilation system	Avoidance of odour transmission
	Preventing the entry of radon gas from the ground

For Passive House buildings, n_{50} values ≤ 0.6 h^{-1} are required; for deep retrofits with Passive House components (EnerPHit), the n_{50} value should not exceed 1.0 h^{-1}. The installation of a serially produced thermally insulating building envelope usually includes the creation of an airtight layer and is therefore assessed according to the requirements for new builds.

AIRTIGHTNESS HAS A CONSIDERABLE INFLUENCE ON DEEP RETROFITS

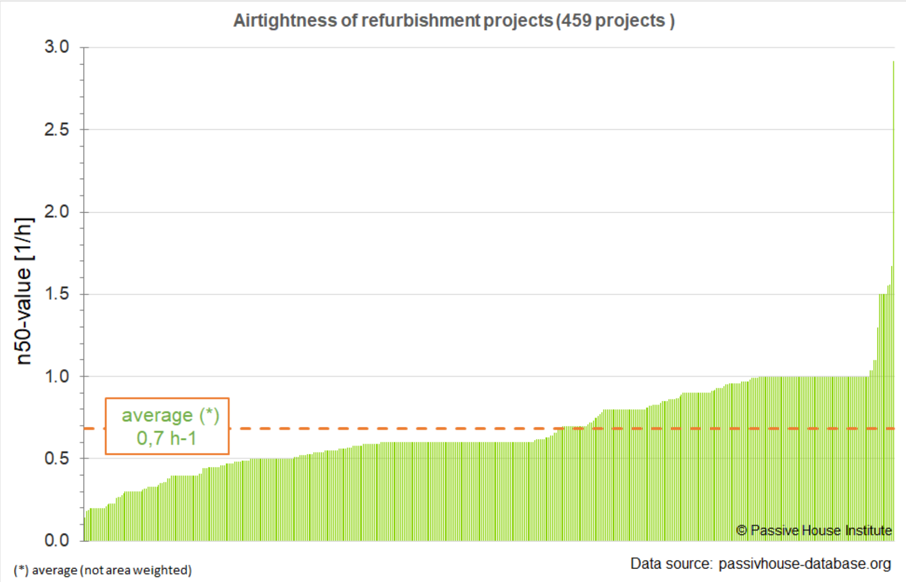
The energy demand of an exemplary Passive House building demonstrates the huge effect airtightness has: the energy demand of the building is **doubled** if the building is only implemented with n_{50} = 3.0 h^{-1} instead of n_{50} = 0.4 h^{-1}, which is the usual value for Passive House buildings, even though all other components of the building remain the same. From the still good airtightness value of n_{50} = 1.0 h^{-1} for a building retrofit (EnerPHit), the heating demand increases by almost 12 kWh/(m²a) if the building is inadequately executed with n_{50} = 3.0 h^{-1}.



Heating demand depending on the airtightness of a building

EXPERIENCES WITH REAL EXAMPLES

If we look at deep retrofit projects in the Passive House project database (www.passivehouse-database.org) which were executed using Passive House components, we see excellent results with an average n_{50} value of 0.7 h^{-1} (simple average value of 459 projects). The EnerPHit requirement of $n_{50} \leq 1.0\ h^{-1}$ for airtightness of a building after a deep retrofit is therefore generally easy to achieve. Only 12 of the included retrofit projects have a measured value that is higher than the EnerPHit requirement of $n_{50} \leq 1.0\ h^{-1}$.



Average airtightness ofn50 = 0,7 1/h for 459 deep retrofits (EnerPHit retrofits)

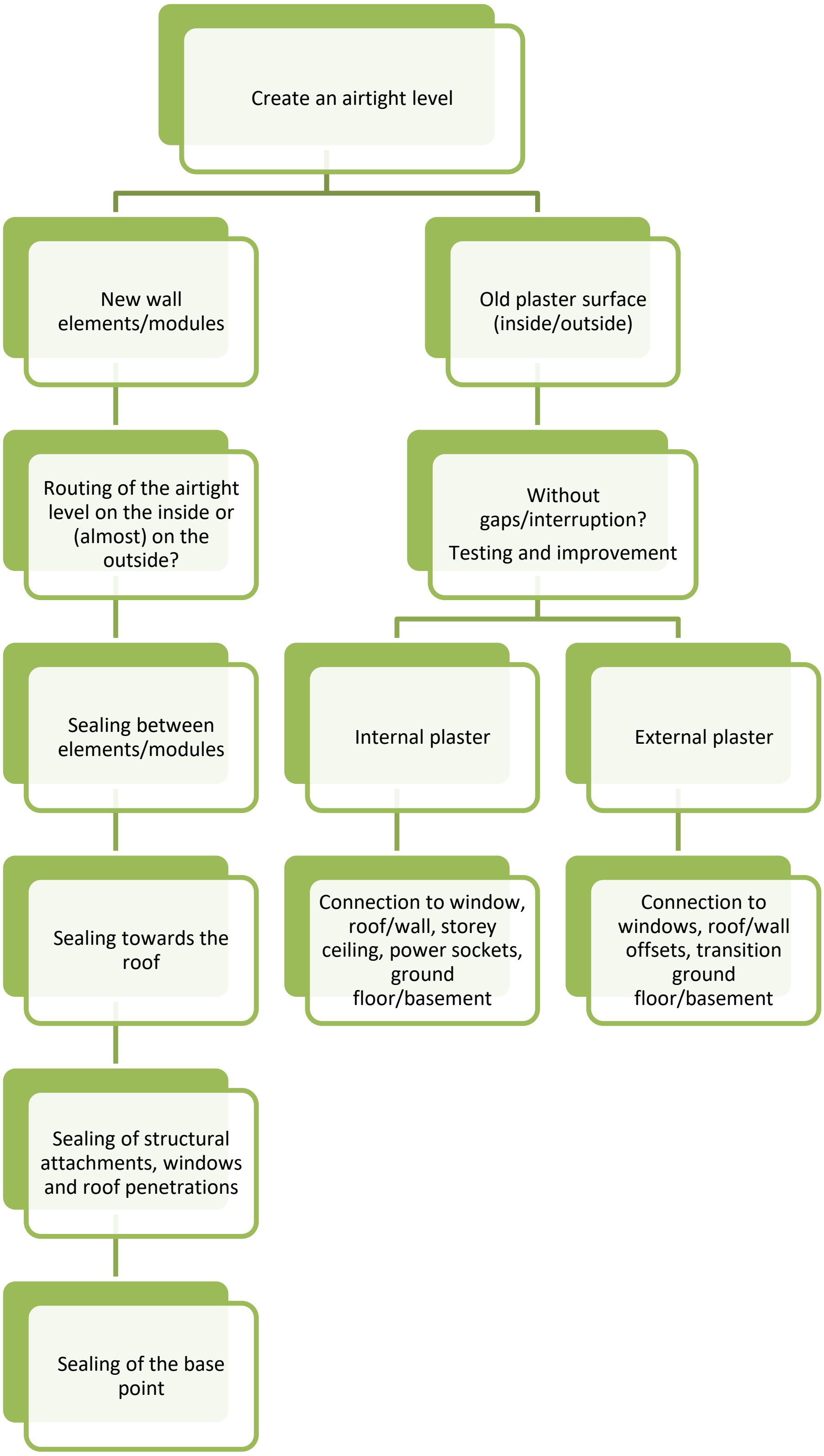
An important **basic rule** applies for airtightness that must generally be observed: there must always be one single airtight layer. Two partly airtight layers do not lead to the required result and are generally more complicated and expensive. For example, a conventional 'vestibule door' behind the non-airtight front door will not lead to an adequate level of airtightness of the building. Imagine a leaky bucket that is placed in another leaky bucket: water continues to leak out (water corresponding to air). It is therefore not advisable for example, to consider the internal plaster as an airtight layer if weak points exist here (e.g. inaccessible wood beam ceilings without plaster on the masonry in this area).

In general, the following methods are available for consistent airtightness during renovation:

- improving the internal plaster,
- improving the external plaster (before installing the exterior insulation or the insulated façade modules)
- integration of the airtight layer in new pre-wall elements. In the process, consistent improvement of the internal plaster (surface, installations, windows, storey ceilings) in an inhabited building probably won't be possible.

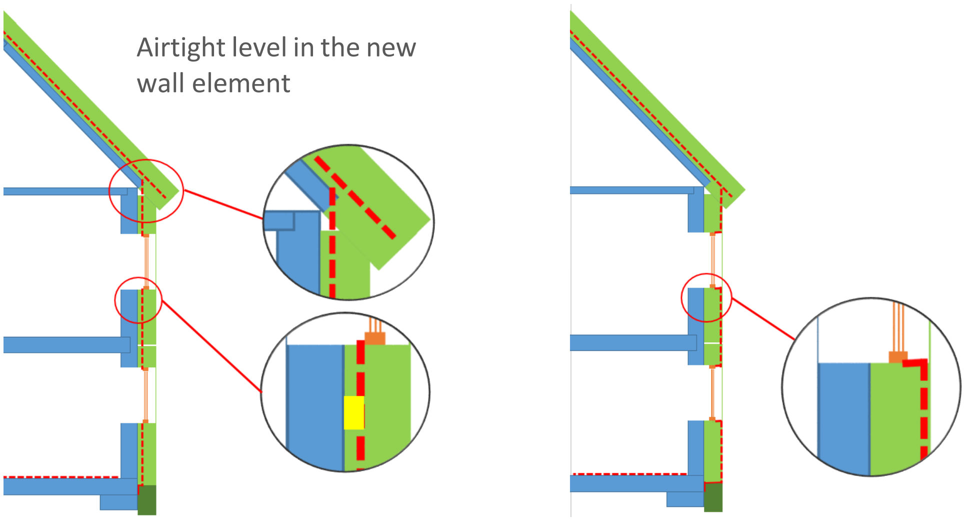
The following matrix shows the possible ways of ensuring airtightness of the building for the renovation process.

DECISION MATRIX FOR THE AIRTIGHTNES POSITION



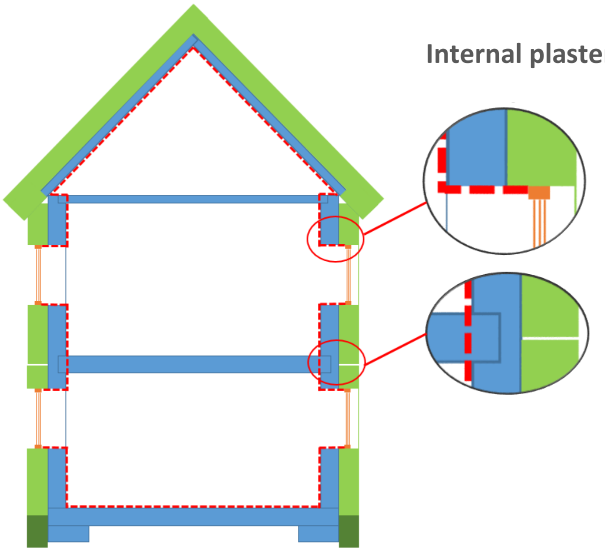
Decision matrix for different positions of the airtight layer

CHECKLIST 1:
AIRTIGHTNESS IN THE NEW WALL ELEMENT



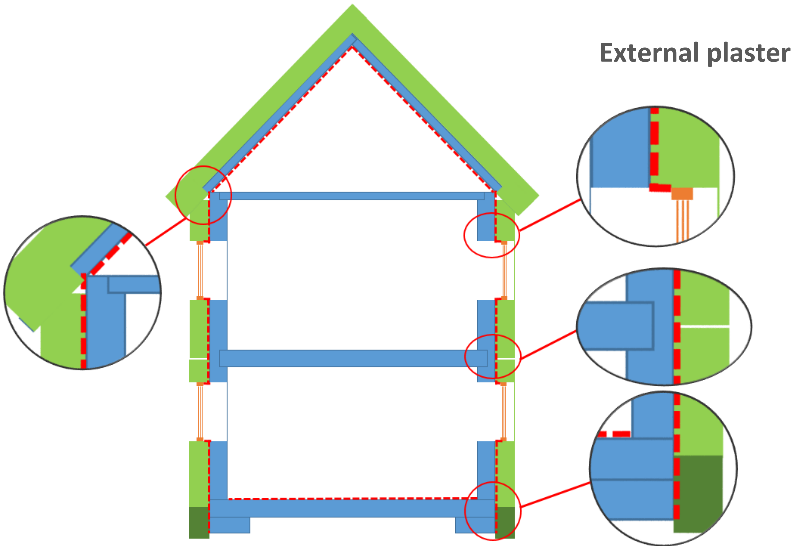
- ☐ Decision: should the airtight level be positioned in the new wall element or almost on the outside (in that case: diffusion-open)?
- ☐ Plan sealing between the elements
- ☐ Sealing at the intersecting points of the elements?
- ☐ Clarification of airtightness in the area of the structural attachment
- ☐ On the top floor: solution for the connection towards the roof or top floor ceiling
- ☐ Solution for the base point of the facade; uninterrupted connection to (unheated) basement
- ☐ Specify airtight level in the roof assembly
- ☐ Is integration of the window in the new facade in the factory possible?
- ☐ Sealing of cable leadthroughs
- ☐ Airtight solution for sealing of pipe penetrations (e.g. ventilation ducts), if necessary already fitted with pipe collars/sleeves during manufacture.
- ☐ ______________________
- ☐ ______________________
- ☐ ______________________

CHECKLIST 2:
AIRTIGHTNESS OF OLD PLASTER LAYER (INTERNAL PLASTER)



- ☐ Check quality of internal plaster (cracks, uninterrupted, …). Is improvement necessary?
- ☐ Clarification: does plaster exist in the floor build-up, in suspended ceilings? Sealing?
- ☐ Creation of the connection of the plaster layers between the storeys (relevant especially in the case of wood beam ceilings).
- ☐ Improvement of electrical installations: are power sockets, switches, cable leadthroughs airtight?
- ☐ Sealing of pipe penetrations (e.g. ventilation ducts)
- ☐ Airtight integration of the new windows all around perimeter (in insulation layer)
- ☐ Is entire reveal area sealed, also underneath the window sill
- ☐ Decide routing of the airtight layer in the roof or on the top floor ceiling
- ☐ Upper floor: connection of the internal plaster to the airtight layer in the roof
- ☐ Specify the airtight layer on the ground floor as demarcation towards the unheated basement
- ☐ Ground floor: connection of the internal plaster to the airtight layer in the floor/basement?
- ☐ ______________________
- ☐ ______________________
- ☐ ______________________

CHECKLIST 3:
AIRTIGHTNESS OF OLD PLASTER LAYER (EXTERNAL PLASTER)



- ☐ Check quality of external plaster (cracks, uninterrupted, …). Is improvement necessary?
- ☐ Does it make sense to test airtightness of the external plaster especially in the area of the storey ceiling?
- ☐ Airtight integration of the new windows all around perimeter (in insulation layer)
- ☐ Decide routing of the airtight layer in the roof or on the top floor ceiling
- ☐ Upper floor: connection of the external plaster to the airtight layer in the roof
- ☐ Specify installation of the airtight layer on the ground floor above the unheated basement
- ☐ Ground floor: is connection of the external plaster to the airtight layer in the floor/basement possible?
- ☐ Sealing of conduits for electrical installations
- ☐ Sealing of pipe penetrations
- ☐ ______________________
- ☐ ______________________
- ☐ ______________________

9. BUILDING MATERIALS LIST

To facilitate the choice of renovation materials and the search for specific calculation values, this building material list is provided for designers, engineers and consultants on the one side, but also for any other stakeholder who wants to receive an overview over the range of possible options that could be selected when choosing building renovation components

VARIOUS BUILDING MATERIAL SPECIFICATIONS

The material list considers several aspect of building concept or building component evaluation:

- Thermal conductivity – for the U-Value calculations, thermal bridge calculations or energy balance calculation
- Material density – helps to identify a material in case of wide density ranges for one specific material leading to differences in other specifications like thermal conductivity
- Vapour resistance – for hygrothermal simulations or decision for vapour barrier use
- Specific heat capacity – for dynamic simulations
- Fire classification according DIN 4102-1 – for choose materials in case of fire protection requirements of specific building components or areas
- Service life – To understand the life cycle in LCA evaluations or economic assessment
- Manufacturing energy and GWP – for LCA assessment of building assemblies

FORMAT AND POSSIBILITIES

The building material list is in Excel format with entries for more than 70 typical building materials to choose from. In order to easier find specific property ranges, like a desired range of thermal conductivity or long service life spans, the list can easily be filtered. Furthermore, in the Excel format, the list can be sorted according to material name or properties.

Building Materials List — outPHit v1.0 (08-2024)

Building material	Representative thermal conductivity (rated value)	Density range	Representative density	µ-value (high)	µ-value (low)	Specific heat capacity c_p	Fire classification according to	Service life*	Manufacturing energy**	Manufacturing GWP	Reference unit
	W/(mK)	kg/m³	kg/m³			J/(kg·K)	DIN 4102-1	years	kWh/ (reference unit)	kg CO_{2eq}/ (reference unit)	
EPS	0,035	15-30	20	100	20	1450	B1	40	286	60	m3
XPS	0,038	25-50	50	200	80	1450	B1	40	446	94	m3

Screenshot of the header of the material list

SCREENSHOTS OF THE BUILDING MATERIAL LIST

Building material	Thermal conductivity (rated value)	Representative density	Specific heat capacity c_p	Fire classification according to	Service life*	Manufacturing energy**	Manufacturing GWP
-	W/(mK)	kg/m³	J/(kg·K)	DIN 4102-1	a	kWh/ (reference unit)	kg CO_{2eq}/ (reference unit)
EPS	0,035	20	1450	B1	40	286	60
XPS	0,038	50	1450	B1	40	446	94
Blown-in mineral wool	0,036	50	1030	A1	40	294	61
Mineral wool (pitched roof insulation)	0,035	30	1030	A1	40	193	45
Mineral wool (floor insulation)	0,035	85	1030	A1	40	581	130
Mineral wool (flat roof insulation)	0,040	145	1030	A1	40	688	206
Mineral wool (façade insulation)	0,035	46,25	1030	A1	40	277	69
Wood fiber insulation board	0,047	160	2100	B2	40	746	3
Wood fiber insulation	0,042	140	2100	B2	40	230	1
Cellulose	0,040	60	1600	B2	40	35	-72
PF (rigid phenolic resin foam)	0,022	40	1400	B1	40	458	87
PIR (polyisocyanurate foam)	0,027	30	1400	B1-B2	40	492	99
PUR (rigid polyurethane foam)	0,027	30	1400	B2	40	850	153
Straw (blown-in insulation)	0,057	105	2000	B2	40	20	-127
Straw (straw bales)	0,049	100	2000	B2	40	20	-127
Expanded cork	0,060	110	1800	B2	40	280	1
Expanded perlite	0,060	100	900	A1	40	216	57
Hemp	0,045	40	2300	B2	40	345	14
Foam glass panels	0,054	115	1000	A1	80	1099	164
Foam glass gravel	0,115	138,5	1000	A1	80	152	39
Calcium silicate	0,070	225	1000	A1	40	2112	565
Vacuum insulation panels 2.5 cm	0,007	181	N/A	A1-B2	50	293	41
Bitumen membrane/sheeting	0,230	1100	1000	B2	30	10678	446
High density concrete	2,000	2400	1000	A1	80	349	271
Reinforced concrete (1% steel)	2,300	2300	1000	A1	80	560	248
Air	0,025	1,23	1008	N/A	-	0	0
effective]	-	1,23	1008	N/A	-	0	0
glass)	1,000	2500	750	A1	40	23019	4740
Aluminum alloys	160,000	2800	880	A1	40	148509	29496
Steel	50,000	7800	450	A1	80	28876	4831
Steel [thermally not effective]	-	7800	450	A1	40	28876	4831
Stainless steel, austenitic	17,000	7900	500	A1	60	125436	28621
Zinc	110,000	7200	380	A1	40	108993	22269
PVC	0,170	1390	900	B1	30	16718	3119
Polyamide (nylon)	0,250	1150	1600	B1	40	56333	11926
Polyamide 6.6 + 25 % glass fibers	0,300	1450	1600	B1	40	50762	11645
EPDM roof membrane	0,250	1150	1000	B2	30	53	8
Polyethylene foam	0,050	70	2300	B2	40	1065	204
Gypsum plaster board	0,250	900	1000	A2	40	9	1
Gypsum plaster	0,570	1300	1000	A2	40	601	112
Lime, sand plaster	0,800	1600	1000	A1	40	1064	398
Cement, sand plaster	1,000	1800	1000	A1	40	1024	348

Building material	Thermal conductivity (rated value)	Representative density	Specific heat capacity c_p	Fire classification according to	Service life*	Manufacturing energy**	Manufacturing GWP
-	W/(mK)	kg/m³	J/(kg·K)	DIN 4102-1	a	Wh/(reference unit)	CO_{2eq}/ (reference ur
Slate	2,200	2700	1000	A1	40	6780	1385
Artificial stone	1,300	1750	1000	A1	40	7091	1307
Clay roof tiles [thermally not effective	-	2000	800	A1	40	64	12
Concrete roof tiles [thermally not effe	-	2100	1000	A1	40	17	9
Timber (planed, if applicable)	0,130	500	1600	B2	80	909	-253
Timber (planed, if applicable) [therma	-	500	1600	B2	40	909	-253
Plywood	0,130	500	1600	B2	80	1856	-198
Cement bonded particle board	0,350	1200	1500	A2-B1	80	6399	1721
OSB board	0,130	650	1700	B2	80	3005	-43
Fiberboard, incl. MDF	0,180	800	1700	B2	80	2766	-18
Synthetic resin plaster (exterior plast	0,700	1700	850	A2	40	7105	1160
Clay plaster	0,910	1800	1000	A1	40	620	196
Sand-lime brick	1,000	1800	1000	A1	80	521	227
Recycled concrete wall with steel rei	2,300	2300	1000	A1	80	562	264
Recycled concrete slab with steel rei	2,500	2400	1000	A1	80	708	288
Recycled concrete floor slab with ste	2,300	2300	1000	A1	80	453	246
Lightweight vertically perforated brick	0,325	575	N/A	A1	80	388	113
Solid bricks	0,810	1800	900	A1	80	2478	523
Brick (filled with insulating material)	0,070	605	N/A	A1	80	509	146
Natural stone slab	3,000	2600	1000	A1	40	5311	1032
Reinforced concrete floor slab	2,300	2300	1000	A1	80	450	231
Reinforced concrete wall	2,300	2300	1000	A1	80	560	248
Reinforced concrete ceiling	2,500	2400	1000	A1	80	706	272
Cement floor screed	1,400	2000	1000	A1	60	875	370
Cement mortar	1,600	2000	1000	A1	40	403	319
Recycled clay roof tiles [thermally nc	-	2000	800	A1	40	10	2
Adhesive mortar	1,000	1000	1000	A1	40	476	101
Underlay PUR on PET fleece [therma	-	673	N/A	B2	40	4	1
PE foil [thermally not effective]	-	950	2000	B1-B2	40	18	4
Laminated wood, cross-laminated tin	0,130	500	N/A	B2	80	1264	-177
OSB, medium density fiberboard (MD	0,130	670	N/A	B2	80	2886	-15
Gravel [thermally not effective]	-	1850	N/A	A1	40	25	5
Dry screed (gypsum fiber board)	0,320	1150	1100	A2	40	2213	351
Mineral bonded wood wool board (ma	0,090	490	2100	B1	40	968	18

* The service life may vary depending on the installation conditions (e.g., a longer service life when installed in a protected environment).

** Process energy only, methodology as per [outPHit report].

This list was developed under the outPHit project and has been carefully compiled. If you find any discrepancies, please contact us.Note: the Passive House Institute, its partners, and funding organizations are not liable for any errors.