Details for Passive Houses: Renovation

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Details for Passive Houses: Renovation

A Catalogue of Ecologically Rated Constructions

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Editor:
IBO – Austrian Institute for Building and Ecology GmbH
1090 Vienna, Alserbachstraße 5

Authors:
DI Thomas Zelger, Mag. Hildegund Figl, DI (FH) Astrid Scharnhorst, MSc, DI Dr. Bernhard Lipp,
Dr. Tobias Waltjen (all IBO)
ao. Univ. Prof. DI Dr. Thomas Bednar, DI Paul Wegerer, DI Johann Schwaller, all TU Vienna (humidity simulations)
Ing. Jürgen Obermayer (building services), DI Michael Steinbrecher (drying out of walls),
Arch DI Martin Wölfl (architectural aspects), DI Arch. Martin Ploss, Energieinstitut Vorarlberg (costs and cost effectiveness)

Coworkers IBO:
Ing. Mag. Maria Fellner, Andreas Galosi, MSc, DI (FH) Felix Heisinger, DI Wolfgang Huber ✝, Mag. Veronika Huemer-Kals,
DI Lisa Kögler, DI Erna Motz, Mario Schmitradner, MSc, DI Tobias Steiner, Dr. Caroline Thurner (all IBO)

Consultants:
Arch. DI Heinz Geza Ambrozy (timber construction details), DI Dr. Karl Torghele (connections, sound insulation),
DI Walter Pokorny (building physics), Clemens Häusler, MSc (building physics), DI Michael Steinbrecher (structural engineering)

Editing: Tobias Waltjen, IBO
Translation from German into English: Rupert Hebblethwaite, Vienna; Brian Dorsey
Layout and cover design: Gerhard Enzenberger, IBO
Production/Project management: Angelika Heller, Birkhäuser Verlag GmbH, Vienna
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Preface

For many years the Federal Ministry of Transport, Innovation and Technology has supported research into and the development of technologies for sustainable building. The funding programmes "City of Tomorrow" and its predecessor "Building of Tomorrow" were equally successful. Their outcomes, like innovative methods and technologies, are well established in building practice.

When it comes to renovation and refurbishment of the urban building stock, it is a challenge to meet the needs of modern energy and environmental engineering as well as the building budget. The programme "City of Tomorrow" addresses these questions to reduce energy demand and to enable the use of renewable energy resources. Passive house components play a crucial role.

The Passive House Catalogue of Building Details for Renovation provides an extensive overview of new methods and technologies for renovation and refurbishment of the building stock, including special energy-efficient solutions for buildings from the 1980s back to the so called "Gründerzeit" in the 19th century.

In this context, this publication can be interpreted as an exhibition of applied research in the field of building technologies.

Jörg Leichtfried
Federal Minister for Transport, Innovation and Technology

1 Introduction

Modernization for the future: refurbishment with passive house components

At the 2015 climate conference in Paris almost all of the world's countries agreed to limit global warming to significantly less than 2 °C compared with the pre-industrial age, in order to limit the drastic environmental impact as much as possible. There is a scientific consensus that, in order to reach this target, each person may only emit 100 more tons of fossil CO_2 and that the global economy must be CO_2-neutral by the middle of the century [Schellnhuber 2015].

One of the major sources of CO_2 emissions is the conditioning of the world's buildings. In temperate and cold climate zones a significant share of total energy consumption is used to heat these buildings. Much of this is represented by such fossil sources as crude oil and natural gas whereas wood, heat from cogeneration plants and electricity for either direct heating or the operation of heat pumps also play a role in certain countries. In addition to this, electricity in most countries is non-renewable and largely produced from fossil sources and uranium.

The refurbishment of buildings to passive house standard as set out in detail in this book leads to heating cost savings of between 75 and 90 %. The large-scale implementation of this approach across the course of the next 35 years is a key requirement for meeting the binding climate protection targets anchored in international law. Conventional refurbishment fails to achieve even half of this potential. The later high quality refurbishment of such "half-refurbished" objects makes no economic sense due to the fact that the cost-savings produced by thermal refurbishment are dependent upon the initial energetic condition. Suboptimally refurbished objects are thus not suitable for high-quality refurbishment until their next refurbishment cycle and hence reinforce this suboptimal situation over many years and decades.

The fact that refurbishment with passive house components creates buildings which, in building physics terms, are reliable and, in economic terms, can be heated at low cost will support the creation of an economy free of imported energy. The most physically tangible benefit of passive houses is the comfort provided by agreeable radiance temperatures. High surface temperatures also permit more flexible furniture layouts due to the fact that wardrobes and sofas can also be located against external walls.

If renovation work is already pending, passive house refurbishment requires only marginally higher investment costs. For example:

- If the external wall already has to be repainted the façade can be simultaneously insulated to a passive house thickness (20 to 30 cm insulation thickness).
- If the roof has to be newly covered it can also be simultaneously insulated to a reasonable thickness (30 to 40 cm insulation thickness).
- If the windows need to be replaced, passive house windows can be placed in the insulating layer. If the frames are still in a good condition the old glazing can be replaced by contemporary triple glazing.
- If the cellars or walls of residential buildings which are in contact with the earth have to be refurbished due to humidity problems a minimum of 20 cm of thermal insulation can be applied to the vertical waterproofing.

Alongside high quality thermal insulation, a passive house also requires needs-based controlled comfort ventilation with high performance heat recovery. This guarantees the necessary rate of air changes and the internal air quality. Ventilation plant only works efficiently if a building envelope is air-tight. Non-airtight building envelopes are not only a comfort problem, but also the main cause of damage to buildings. High quality refurbishment avoids such typical problems of conventional refurbishment as the formation of mold (airtight windows and, hence air humidity levels of well over 40 %, cold bridges) in two ways:

1. The temperatures of internal surfaces are much higher due to the increased thermal protection and conscious reduction of cold bridges
2. Needs-based comfort ventilation generally reduces air humidity in winter to below 40 %.

The additional costs of passive house components arise principally from comfort ventilation and high-quality windows. On the other hand, the increase of insulation thicknesses to passive house levels only involves minimal additional costs given that it is only the cost of the insulating material which rises and this that only represents a small proportion of the total costs in comparison with the material and labor costs which would have arisen anyway (e.g. for scaffolding, the cleaning of old façades, external plaster, adhesives, fixings, etc.). Considering the lifecycle of a building, passive house refurbishment is cost-effective.

When refurbishing to passive house standard it is very important that projects have an **overall concept** and that individual measures are coordinated and have a clear objective. These individual measures can then be implemented in phases. In line with the notion of "deep renovation", each passive house refurbishment measure is designed to realize the entire energy efficiency potential and to leave no potential unused until the next refurbishment cycle.

For example, overall concepts can build upon the following possibilities:

- Lateral extensions, extra stories and the enclosing of balconies can make a building more compact and reduce transmission losses

- Constructional cold bridges (corners of exterior walls, interfaces between cellar ceilings and walls etc.) can be reduced by appropriate insulation measures.
- Airtightness can be ensured by the external plaster if the internal plaster is incomplete or not continued to slab level.
- High levels of airtightness must be achieved at connections, openings (e.g. chimneys) and service duct openings!
- Unused chimneys can be used for the integration of ventilation pipes.
- The enlargement and expansion of window areas can improve daylight levels and increase solar gain.
- Centrally located water heating plant and consequently short distribution distances minimize heat losses.
- Electricity-saving building services, equipment and lighting increase the efficiency potential of the high quality refurbished building envelope.

The high quality refurbishment of a large proportion of existing buildings to passive house standard would allow us the flexibility not to insulate the relatively small number of façades which are historically-protected or hard to refurbish externally for other reasons or, if necessary, to insulate these modestly on the inside – while still enabling us to these heat these buildings over the long-term.

This Passive House Building Element Refurbishment Catalog proposes a series of systematic refurbishment solutions using passive house components and describes and evaluates these across their entire lifecycle in line with technical, building physics and ecological criteria. Such specific issues as non-watertight cellars, ground floors which come into contact with the earth, internal insulation, design issues, investigations of hazardous materials and the ecological quality of refurbishment solutions are specially addressed in separate chapters.

The building certification of refurbishment projects

A sustainable and economic modernization project should at least meet passive house standards. However, in addition to this basic requirement, other quality criteria such as the minimizing of polluting emissions from – and the ecological quality of – the building materials can also make an important contribution to the sustainable quality of refurbishment measures. This section contains a compact overview of this issue and of several certification systems. In addition to this, this overview uses examples of typical building certification systems to show how much and how strongly this "measured" building quality can be influenced by passive house-related refurbishment measures.

An overview of building assessment systems in Austria

While demand for building certification is growing and this has become a well-established aspect of new building projects, the certification of refurbishment objects is much less common. Some certification systems have developed their own criteria catalogs for refurbishment objects (EnerPHit of the PHI Darmstadt, klimaaktiv, BREEAM, DGNB), whereas the strategy of others is to adapt criteria on a case-by-case basis and differentiate between new building and refurbishment projects in individual criteria (LEED®, TQB etc.).

The following evaluation systems for refurbishment and new building are offered in Austria:

- Passive House Certification and EnerPHit, (www.passiv.de, responsible body: Passivhaus Institut Darmstadt, since 2004 / EnerPHit since 2011)
- klimaaktiv Bauen & Sanieren (www.klimaaktiv.at/bauen-sanieren.html, responsible body: BMLFUW – Federal Ministry of Agriculture, Forestry, Environment and Water Management, since 2004)
- TQB – Total Quality Building (www.oegnb.net, responsible body: ÖGNB – Austrian Sustainable Building Council, since 2002, successor to the "Total Quality" system)
- IBO ÖKOPASS (www.ibo.at, responsible body: IBO – Österreichisches Institut für Bauen und Ökologie GmbH, since 2001)
- DGNB Certification System (www.dgnb.de; responsible body: German Sustainable Building Council, in Austria since 2009)
- EU Green Building (www.ibo.at/de/greenbuilding, responsible body: EU Commission, since 2007)
- LEED®–Leadership in Energy and Environmental Design™ (www.usgbc.org, responsible body: USGBC® – U.S. Green Building Council® / GBCI® _Green Building Certification Institute, since 1993)
- BREEAM – Building Research Establishment Environmental Assessment Method (www.breeam.org; responsible body: BRE – Building Research Establishment; since 1990)

The benefits of the building certification of refurbishment measures

What are the benefits of the building certification of refurbishment measures? Is refurbishment not already the most sustainable way of building due to the fact that existing resources are used without being devalued?

On the one hand, new building can rarely match refurbishment in terms of ecological quality. On the other hand, passive house standard is harder to achieve in a refurbishment than in a new building. However, most refurbishment projects leave enough scope for optimizing their sustainability aspects.

Building certification systems offer guidelines for sustainable building which minimize negative environmental effects and maximize comfort while optimizing executional quality in line with the latest technological standards. If the certification team is involved from the preliminary design phase of the design process the best possible results can be obtained at the lowest possible cost.

Building certification systems claim to set the agenda for sustainable building – ecologically, economically and socially. Well-balanced points systems quantify the effects of building measures and provide an incentive not to make savings at the expense of the environment. While "Green Washing" seeks to market projects on the unjustifiable basis of an apparently environmentally friendly and responsible image, recognized certification systems are based on transparent criteria and testing processes. The boundary conditions and minimum requirements for the top awards should be based on the latest level of knowledge.

Further benefits of the certification of sustainable and high-quality refurbished objects are:

- Competitive advantages in sale and letting
- Quality assurance (mold, airtightness etc.)
- Control of the quality of execution (blower door test, measurement of ambient air quality, noise protection measurements etc.)
- Setting of higher building standards (e.g. regarding criteria for energy, ecology and comfort) in the early design phases
- Savings during the building process that are made at the cost of executional and ecological quality (airtightness, warm bridges, efficiency of ventilation plant, choice of materials etc.) no longer remain unnoticed thanks to the certification tool
- Guaranteeing of increased residential and workplace quality (comfort, ambient air etc.)
- Lower operating costs
- Stable and higher real estate value (e.g. as pension provision)

Evaluation of refurbishment measures in the framework of building evaluation systems using the examples of EnerPHit, IBO ÖKOPASS, klimaaktiv, and TQB

High quality energy efficiency refurbishments using passive house components are mostly integrated into building evaluation systems in the form of such individual criteria as heating energy, final energy and primary energy demand; CO_2 emissions during building operation, elimination of warm bridges, airtightness etc. The evaluation of constructional refurbishment measures under the EnerPHit, IBO ÖKOPASS, klimaaktiv and Total Quality Building (TQB) assessment systems are presented below.

EnerPHit Standard and Passive House Certification[1]

As a result of complications caused by the constructional methods of the existing buildings, refurbishment projects are subject to economic and technical parameters which often make it impossible to achieve passive house (new building) standards at justifiable cost. Passivhaus Institut Darmstadt has created an instrument – its EnerPHit form of certification – which is able to comprehensively evaluate the application of passive house components to individual building elements and document improvements in terms of increasing comfort, saving energy and avoiding constructional damage. If more than 25 % of the area of opaque external wall is internally insulated during a refurbishment project then the EnerPHit+i seal is awarded. In the case of particularly ambitious modernization or refurbishment projects with limited constructional constraints, (new construction) passive house standard can also be achieved.

Passive House Seal | EnerPHit Seal | EnerPHit+i Seal

1 Criteria for the Passive House, EnerPHit and PHI Low Energy Building Standard, version 9c, revised 30.06.2016, ed. by Passivhaus Institut Darmstadt

EnerPHit has two alternative verification methods: The building component method with requirements related to building components (the criteria of which are largely identical to those of certified passive house components) or a method with requirements related to entire buildings (energy demand method). Given that the criteria and requirements to be met change in line with building location and climatic zone, EnerPHit certification is possible worldwide.

a) Building component method

The building component method defines maximum heat transfer coefficients (U-values) for opaque building elements and differentiates between internally and externally insulated walls as a function of the number of degree days. As it is not always possible to justify the cost of completely avoiding thermal bridges in refurbishment projects, thermal bridges are to be incorporated in the calculation of the U-value – as long as these are part of the standard construction of the building component. In the case of transparent building component, the required U-values and g-values are also dependent upon the position of the building component (there is a basic differentiation between horizontal, inclined and vertical glazing). In hot and very hot climatic zones the external colors are also decisive for meeting the cooling load requirements: it is strongly recommended to use "cool colors" with a high solar reflection index (SRI). Air conditioning units require a minimum heat recovery efficiency of 75 % in warm-temperate and cool-temperate climatic zones and 80 % in cold and arctic zones or extreme mountainous locations, and this value is to be calculated by taking the entire ventilation system into account (e.g. including the heat loss due to warm ventilation ducts in cold areas and cold ducts in warm areas). The thermal insulation requirements for building components in contact with the ground are naturally determined from the specific heating and cooling degree days of the location.

Exceptions to the EnerPHit U-value rules set out in Table 1 are permitted due to economic considerations or practical constructional reasons (historic buildings, fire protection requirements, etc.). In such cases, however, the U-value may only be exceeded by the absolutely unavoidable amount (and when using this exception clause, the minimum insulation requirements are in any case to be met for reasons of thermal comfort and avoiding constructional damage – see the current version of the EnerPHit certification criteria, www.passiv.de/Zertifizierung/Gebäude).

Climate zone according to PHPP	Opaque envelope against...				Windows (including exterior doors)					Ventilation	
	...ground	...ambient air			Overall			Glazing	Solar load		
	Insulation	Exterior insulation	Interior insulation	Exterior paint	Max. heat transfer coefficient ($U_{D/W,installed}$)			Solar heat gain coefficient (g-value)	Max. specific solar load during cooling period	Min. heat recovery rate	Min. humidity recovery rate
	Max. heat transfer coefficient (U-value)			Cool colours							
	[W/(m²K)]			-	[W/(m²K)]			-	[kWh/m²a]	%	
Arctic	Determined in PHPP from project specific heating and cooling degree days against ground.	0.09	0.25	-	0.45	0.50	0.60	$U_g - g*0.7 \le 0$	100	80%	-
Cold		0.12	0.30	-	0.65	0.70	0.80	$U_g - g*1.0 \le 0$		80%	-
Cool-temperate		0.15	0.35	-	0.85	1.00	1.10	$U_g - g*1.6 \le 0$		75%	-
Warm-temperate		0.30	0.50	-	1.05	1.10	1.20	$U_g - g*2.8 \le -1$		75%	-
Warm		0.50	0.75	-	1.25	1.30	1.40	-		-	-
Hot		0.50	0.75	Yes	1.25	1.30	1.40	-		-	60 % (humid climate)
Very hot		0.25	0.45	Yes	1.05	1.10	1.20	-		-	60 % (humid climate)

Tab. 1: EnerPHit Criteria for the building component method (30.06.2016)

An important role in establishing comfort levels in line with EnerPHit is also played by the avoidance of overheating in summer and increased humidity. The proportion of hours in the year with an ambient air temperature over 25 °C is to be limited to a maximum of 10 % in the case of buildings without active cooling and the proportion of hours in the year with absolute internal air humidity over 12 g/kg to less than 20 % in the case of buildings without active cooling and less than 10 % in the case of buildings with active cooling.

b) Energy demand method

According to the PHPP the specific heating energy demand should not exceed 25 $kWh/m^2_{ERA}a$ for cool-temperate climatic zones (in Central Europe) and 35 kWh/m²a for arctic zones (this case can also be applied to mountainous locations). The values for cooling and dehumidification requirements are subsumed, with the limiting value for the dehumidification contribution being applied on a project-specific basis as a function of climatic data, internal humidity load and the number of air changes and being determined automatically in PHPP (Passivhaus Projektierungs-Paket from version 9.0)[2].

In the case of both methods (Building component method and Energy demand method) there is an obligation to meet the minimum pressure test air change requirements (for a pressure difference of 50 Pa) of 1.0 1/h for refurbishments.

In order to place projects into the EnerPHit Classic, Plus and Premium certification classes, project-specific minimum requirements for both renewable primary energy (PER) demand and – for the Plus and Premium classes – the generation of renewable energy (as a function of the building footprint) have been defined

2 Passive House Planning Package (PHPP): The energy balance and planning tool for efficient buildings and refurbishments, Version 9 (2015), ed. Passivhaus Institut Darmstadt

in situ since 2015. For a transition period, "EnerPhit Classic" standard can also be verified by compliance with the limiting value for non-renewable primary energy whereas the approval of national primary energy conversion factors including the adaptation of the limiting values of the Passivhaus Institut is implemented from PHPP Version 9.6.

Renewable Primary Energy (PER)		Criteria Classic	Plus	Premium	Altern. criteria
PER-Demand	[kWh/(m²a)] ≤	$60 + (Q_H - Q_{H,PH}) \cdot f_{OPER,H} + (Q_C - Q_{C,PH}) \cdot 1/2$	$45 + (Q_H - Q_{H,PH}) + (Q_C - Q_{C,PH}) \cdot 1/2$	$30 + (Q_H - Q_{H,PH}) + (Q_C - Q_{C,PH}) \cdot 1/2$	+/-15 kWh/(m²a) deviation from criteria…
Renewable energy generation (with reference to projected building footprint)	[kWh/(m²a)] ≥	-	60	120	…with compensation of the above deviation – by different amount of generation

Tab. 2: EnerPHit requirements for renewable primary energy PER (demand and generation in situ) in line with the certification classes Classic, Plus, Premium

As 85 % of modernizations in Germany take the form of partial refurbishments, step-by-step EnerPHit certification – which includes the issuing of a preliminary certificate after the carrying out of a first important step and the presentation of a refurbishment timetable and comprehensive refurbishment program – is available from 2016. This first important step should be either a reduction of heating energy demand by a minimum of 20 % or 40 kWh/m²a or a reduction of the renewable or non-renewable primary energy demand by at least 20 % or, in the case of several property owners, at least one residential unit should have been comprehensively thermally refurbished or an extension should have been added.

EnerPHit and passive house certification criteria and the underlying calculation methodology are subject to constant revision and adaptation in line with continuous technological developments. In the case of building certification, "as a priority, the current criteria and technical rules are always valid (and always to be found under www.passiv.de), followed by the calculation methods described in the PHPP Handbook and PHPP Program." The assessment of whether the required documents conform to current certification criteria and the issuing of the certificate are carried out by freely chosen certifiers accredited by the Passivhaus Institut.

IBO ÖKOPASS

The IBO ÖKOPASS was developed as a building passport – especially for residential complexes. It focuses on the subjects of user comfort, healthy living and sustainability and its evaluation categories are 1. Comfort in summer and winter, 2. Internal air quality, 3. Noise protection, 4. Daylight and insolation, 5. Electromagnetic quality, 6. Ecological quality, 7. Overall energy concept and 8. Use of water. The categories can be rated "excellent", "very good", "good" and "satisfactory". The IBO ÖKOPASS has a two-stage evaluation strategy – the evaluation of the design and of the completed object – and includes measurements and site visits. Building physics-optimized refurbishment to passive house quality can score particularly well in terms of the criteria comfort in summer and winter, internal air quality and overall energy concept. If, in addition to this, the refurbishment involves the use of ecologically sustainable building materials, the evaluation in the category ecological quality will also improve.

klimaaktiv Bauen und Sanieren

klimaaktiv evaluates projects using a 1,000 point formula. Depending on building quality three award levels can be reached: klimaaktiv gold (900 to 1,000 points), silver (750 to 899 points) and bronze (in which all mandatory criteria are met).

There are four evaluation categories: Design and execution, energy efficiency, building materials and construction, comfort and internal air quality. A detailed explanation of the criteria can be seen at: http://www.klimaaktiv.at/bauen-sanieren/gebaeudedeklaration/kriterienkatalog.htm.

It should be noted that the total of the maximum achievable number of points in all sub-criteria in a category can be higher than the total of the maximum achievable number of points in the category itself. This means that there are different potential optimization strategies for those seeking to achieve the maximum number of points in a category.

As one aim of klimaaktiv is to support Austria's climate strategy, energy efficiency plays a major role (650 of 1,000 points). This requires an efficient comfort ventilation plant with heat recovery that meets the klimaaktiv comfort criteria, the reduction of the energy demand in general and the choice of an energy supply with renewable energy (relevant for CO_2 emissions and primary energy demand).

Moreover, if ecologically optimized building materials and construction (C) and low-emission products (D2.2) are used, a further 150 points can be achieved. If the construction is also optimized in terms of thermal comfort in summer and life cycle costs were taken into account, a total of 960 points (gold) can be reached by ecological and building physics-related passive house refurbishment measures alone.

Total Quality Building (TQB)

Total Quality Building (TQB) is compatible with – but more comprehensive than – the klimaaktiv building standard. A maximum of 1,000 points can be achieved and there are no specific award levels. The TQB criteria are divided into five main categories: Location and facilities, economy and technical quality, energy and supply, health and comfort and resource efficiency. The individual sub-criteria are adapted for refurbishment projects. The detailed explanations of the criteria are accessible at: https://www.oegnb.net/en/tqb.htm.

Unlike in the case of the klimaaktiv criteria catalog the weighting of the five main categories is equal – with 200 evaluation points. This means that the influence on the overall result of energy efficiency measures alone is lower (~15 % of the total number of points).

The economic aspects of the optimization of building elements across the entire lifecycle of a building flow into the result with at least 65 points.

In addition to this, if the suggestions in this book for optimizing building elements are applied, a further 200 points in "E Resource efficiency" and 112 points in "D Health and comfort" and, hence, a total of 527 points (53 %) can be achieved. All other criteria are to be met by additional measures which do not fall into the category of constructional and ecologically optimized refurbishment measures.

Conclusion

Building certification systems can support the targeting of the Building Element Refurbishment Catalog in that they can serve as guidelines for selecting sustainable refurbishment measures. There is extensive room for optimizing the sustainability aspects of not only new buildings but also refurbishment projects.

At the construction level, the Building Element Refurbishment Catalog is a powerful tool for the implementation of high quality refurbishment which is available to both designers and builders. The cost of building certification should be in proportion to the benefits achieved and can be effectively reduced by the Building Element Refurbishment Catalog – even in cases when constructional details are not precisely used but adapted according to need or where the catalog is only used for selected building elements.

2 Basics

Applied methods

Lifecycle assessment indicators

The following lifecycle assessment indicators were used for the ecological evaluation of the standard cross-sections and functional units:

- Total non-renewable primary energy (PENRT)
- Global warming potential (GWP)
- Acidification potential (AP)
- Aggregated indicator OI3

The data used for calculating the lifecycle assessment indicators in this book are taken from the IBO Catalogue of Reference Values for Building Materials. The current catalogue was compiled at the end of 2007 for the “Passive House Building Element Catalog” study [IBO 2008] and updated in April 2016. The basic data (normative term “generic data”) for such general processes as energy systems, transport systems, basic materials, disposal processes and packaging materials are largely taken from ecoinvent v 2.1. Some basic data for raw materials and upstream products were collected by the IBO during product evaluation work and research projects. The specific basic parameters and methodic specifications for the building ecology reference values are to be found in [IBO 2010]. For the specific values used refer to www.ibo.at/PH_SAN.

Evaluation is made of the manufacturing phase (cradle to gate, modules A1 to A3 in line with EN 15804) and the replacement of building materials upon the expiry of their expected useful life (module B4 in line with EN 15804) during a period of observation of 100 years. In simple terms, the calculation is made as follows: After the end of the expected useful life of a building material the material is produced once again with the number of new production cycles in the entire period of observation being the result of dividing the period of observation by the expected useful life. The cost of removing and building in the renewed materials is ignored.

The data in [ZELGER 2009] is used for the expected useful life. In this work, resilient values for the maximum expected useful life were derived from statistical evaluations, in-depth analyses and primary plausibility considerations.

Total non-renewable primary energy (PENRT)

Total non-renewable primary energy (abbreviation PENRT) describes the total non-renewable energy resources required to produce a product or a service. PENRT is given in MJ and calculated from the lower calorific value of the energy resources deployed. The Total non-renewable primary energy of all non-renewable resources (crude oil, coal etc.) is given in PENRT. It includes both energetically and materially used resources.

Global warming potential (GWP)

The global warming potential GWP describes the contribution of a trace gas to global warming for a time horizon of 100 years compared with carbon dioxide. GWP contains both the contribution of the greenhouse gas emissions to global warming and the quantities of carbon dioxide trapped in biomass.
The greenhouse gas potential is given in kg CO_2 equivalents.

Acidification potential (AP)

Acidification is principally caused by the interaction of nitrogen oxide (NO_x) and sulfur dioxide (SO_2) gases with other constituent parts of the air. One of the clearly associated consequences is the acidification of lakes and rivers and subsequent decimation of fish stocks in terms of both quantity and diversity. The average “European acidification potential” is used for the calculation of acidification potential.
Acidification potential is presented in kg SO_2 equivalents.

OI3 Indicator

The OI3 indicator is a dimensionless ecological indicator for a building or a thermal building envelope TGH, which is formed from the three indicators: Total non-renewable primary energy, global warming potential and acidification potential. Various OI3 indicator sets are defined depending upon the assessment boundaries and the reference value. In this project the ecological indicator OI3 KON (incl. module B4) is used.

Details on the calculation of the OI3 indicator can be accessed at http://www.ibo.at/documents/OI3_Berechnungsleitfaden_V3.pdf.

Waste management indicator (recycling, incineration, dumping)

The waste management indicator was used in line with the method in [Schneider 2010], which is briefly set out below; detailed information can be found in the above-mentioned work.

Determination and grading of the waste management procedure

It is assumed that demolition will be oriented towards recycling. Building elements which can be cleanly separated into homogenous layers are separated into these layers whereas, in the case of layers which cannot be cleanly separated, assumptions are made about the interfaces between neighboring materials. If building elements cannot be separated into individual materials these are disposed of together.

The waste management procedures and processes are classified on the basis of current waste management practice with the help of an evaluation matrix.

The starting point for the evaluation of the characteristics of construction materials is the evaluation matrix developed in ABC-Disposal [Mötzl 2009]. However, a five-step rather than a four-step system is used:

	Recycling	Incineration	Dumping
1	Reuse or recycling into a technically equivalent secondary product or raw material	Higher calorific value (>2000 MJ/m³); natural metal and halogen content in ppm-range, homogenous material	Waste suitable for depositing on inert waste dump
2	Recycling material can be separated into homogenous materials at low cost and be recycled to a high quality	As 1, but not homogenous, maximum proportion of non-organic contaminants 3 M.-%	To be deposited with uncontaminated construction waste
3	Recycling material is contaminated, can be broken up at higher cost and then recycled after processing	As 1 or 2, but medium calorific value (500–2000 MJ/m³) or low metal or halogen content (<3 M.-%)	Materials with low non-mineral content, e.g. mineral construction waste with organic contamination from bitumen or residual thermal insulation
4	Downcycling	Higher nitrogen content, higher proportion of mineral content or increased metal or halogen content (3–10 M.-%)	Materials with low non-mineral content, e.g. mineral construction waste with organic contamination from bitumen or residual thermal insulation
5	No recycling possible	Higher metal or halogen content	Organic-mineral composite, metals as contamination of construction waste

Tab. 1: Evaluation criteria for the qualitative classification of the waste management characteristics of building constructions.

Examples for the classification of various demolition products and the evaluation of a building construction can be found in [Schneider 2010].

The building element layers are classified in line with the evaluation matrix. A new feature of [Schneider 2010] was that "Recycling" (material-based recycling) and "Incineration" (energy-based recycling) are only treated as recycling up to level 3. Levels 4 and 5 are regarded as "Removal", just like all levels of "Dumping".

Consolidation at the level of the building element

After the grading of all the building element layers the next step is their consolidation for each waste management procedure. The measured variable is the volume (m³).

The percentage distribution between the various waste management procedures is calculated.

The average grade for each waste management procedure is also calculated. For each building element layer the grade is multiplied by the quantity. The results for each building element layer are added together and, finally, divided by the total quantity.

Single figure evaluation ("recyclability")

As the table of results described above is very unclear and an interpretation is only possible within and after detailed consideration of the specific construction, the results of the evaluation for the measurement variable "volume" were additionally consolidated in a single figure. In order to do this, the grades for the individual waste management procedures were weighted against each other with the following factors:

Factor	Waste management classification
1	Recycling
1	Incineration with grade <2
2	Incineration with grade >2 and <3
3	Removal

For each waste management procedure the volume produced is multiplied by the grade and the weighting factor. Finally, the results are added together. These results give a quick guide but should be treated with appropriate caution. The weighting factors, which were set here as 1, 2, 3, have a not insignificant influence on the result.

Evaluation methods for the formation of mold and fungus and the decay of wood

Formation of mold

If suitable growing conditions are present, mold will form on the surfaces of or within constructional elements. Air flowing into interior spaces from areas in which mold is growing leads to a massive deterioration of interior air quality. The following table shows the key factors which influence the growth of mold.

Influencing factor	Parameter	Unit	Growth range minimum	maximum	Comments
Temperature	Temperature on the surface of the building element	°C	-8	60	Depends upon the type of mold and phase of development (spore germination or mycelial growth)
Humidity	relative air humidity on the surface of the building element	%	70	100	
Substrata	Nutrient and salt content	–	–	–	Nutrients can also be found in dust deposits
Environment	pH value of the surface	–	2	11	
Time	e.g. hours per day	h/d	1	–	According to temperature and humidity
Atmosphere	Oxygen content	%	0,25		Always present

Tab. 2: Key factors which influence the germination and growth of mold including information about minimum and maximum growth range [Sedlbauer 2003]

In chapter "The Influence of Passive House Refurbishment on the Hygrothermal Indoor Climate of Unheated Cellars without Dampproofing" the risk of the formation of mold in building construction is only analyzed on the basis of time-dependent temperature and humidity conditions. The algorithm of [Thelandersson 2009] is used to determine the number of days with growth conditions.

The decay of wood

When certain temperatures and humidities are present for certain periods of time, wood-destroying mold and fungi can grow which can result in timber losing mass and, subsequently, stability. A mathematical model of this process was carried out in [Viitanen 1996]. Based on this model, a critical pore air humidity for each temperature was given in [Kehl 2013]. This approach permits a simple evaluation of the results of a simulation and was used for the evaluation of the critical conditions at the heads of timber beams at internally insulated external walls.

The ecological "payback" of modernization measures

The term "ecological payback" in the area of building refurbishment was introduced in analogy to the economic concept of "payback" and should be seen in the context of an initial situation that is extremely unfavorable in ecological (and, hence, often economic) terms: badly insulated and leaking buildings which consume large amounts of heat energy and, consequently, non-renewable resources in colder climates. The greatest demand for heat occurs at the height of winter when the availability of renewable resources (sun, water, ambient heat) is limited. The intense use of combustibles or electrical energy is linked to high levels of environmental damage resulting from the emission of pollutants (CO_2, NOx, SO_2, particles etc.). This means that efficiency measures in the heating of buildings are even more urgently needed than, for instance, in cooling. However, the manufacture, maintenance and removal of insulation systems designed to reduce heating loads are also linked to environmental damage and the consumption of resources.

For any chosen environmental parameter, the concept of "ecological payback" identifies modernization measures as being preferable to business as usual (the continuation of the initial situation without the taking of any measures) if the cost of this modernization leads to a reduction in operating costs and if the total of all costs across the entire lifecycle is lower than the total cost had no measures been taken. Together with economic payback considerations, however, this can lead to significantly suboptimal solutions given that only the improvement of the initial situation is taken into account and not the sustainable operable environmental space of the users of the conditioned building [WBGU 2014].

The COP21 Climate Summit in Paris in 2015 set a binding limit under international law for maximum global warming of significantly below 2 °C in comparison with pre-industrial times. This limit demands CO_2 neutrality (0 kg CO_2 equivalent) by 2050 [Schellnhuber 2015]. This can be achieved in buildings via:

- very high levels of thermal protection: at or significantly above passive house standards (30 to 50 cm thermal insulation with 0.040 W/mK)
- insulation systems with low manufacturing, maintenance and disposal costs and high levels of recycling (see the chapter on functional units page 193)
- the retention of biogenic carbons by the construction for as long as possible – ideally in constructional layers with long lives and constructions which are reliable in terms of building physics (see the chapter on functional units page 193)
- The avoidance of the use of fossil hydrocarbons in the construction and heating of buildings

As the fossil carbon content of future heating systems is difficult to estimate, highly thermally insulated insulation systems with low greenhouse gas emission levels should be adopted as a precautionary measure.

Despite the weakness of the concept, "ecological payback" helps to indicate orders of magnitude for the period of time over which manufacturing costs can be recovered. To this end, a simple evaluation of the total ecological and economic costs and benefits of the refurbishment of an external wall is set out below. The combined evaluation of manufacture and operation highlights how a focus on minimum manufacturing costs can result in economically misguided optimization and clarifies ecological preconceptions about the allegedly higher "grey energy" of insulation systems compared with the savings in operational energy.

Methodical assumptions about environmental footprints and costs

The results for ecological payback set out below were calculated using the freely accessible online tool the baubook AWR (Amortisations- und Wirtschaftlichkeitsrechner (http://www.baubook.at/awr/). They are developed from a consideration of the manufacturing costs of an insulation system and of the heating required to compensate for transmission heat loss. They are based on one square meter of building element. This limitation of the functional unit to a square meter of a constructional element is generally allowed, given that it is transmission losses that almost directly determine the changes in the heating demand of a building (see EN ISO 13790).

Calculation of the costs of the construction and maintenance phase

The costs of the manufacture of the insulating system are based on an examination of the phases from the extraction of the raw materials to production (cradle to gate) together with the manufacture of the building materials replaced during the observation period. For more details about the environmental footprint method see Chapter Methods page 10.

Calculation of the costs during the use phase

The final energy loss ΔQ per 1 m² building element per year in kWh is calculated using the following formula:

$$\Delta Q = \frac{1{,}1}{\eta_H} \cdot U_{Bauteil} \cdot HGT \cdot 0{,}024$$

ΔQ: Heating demand per 1 m² building element per year in kWh/m²
1.1: 10 % thermal bridge correction factor
ηH: Annual efficiency level of the heating system (losses from heat loss, distribution, storage, production)
HGT: Heating degree days in Kd based here on 20 °C internal temperature and 12 °C limiting temperature
0,024: Conversion factor to kWh in h/(d*1000)
$U_{Bauteil}$: Heat transfer coefficient in W/m²K

The observation period is set at 30 years. Enviromental impacts are calculated for all ecobalance indicators. No discounting is applied for the period under consideration.

Costs

Costs are presented below on the basis of the annuity method (see ÖNORM M 7140:2013, VDI 2067 September 2012). This method combines one-off payments (investments) and ongoing payments during a certain observation period and presents these as annual value-adjusted payments.

The reference values for interest rates and the costs and price rises of energy sources come from the sources given in the information sheet of the calculator. These can, however, be adapted.

The refurbishment costs are a combination of the fixed costs of refurbishment ("costs which would have been incurred anyway"), the fixed costs of the system and variable costs (costs of thermal insulation per 1 m² and 1 cm of thickness). Residual values are also taken into account.

Calculation options

The baubook AWR is freely accessible at http://www.baubook.at/awr/. Five standard basic constructional approaches to refurbishment are available. Further constructional approaches can be freely added, imported, copied and saved in the professional version.

After the selection of the basic construction, up to four refurbishment variants – e.g. with different insulation materials or energy sources can be compared. Suggested values for, for example, costs can be adjusted individually.

Upon clicking "create a diagram" the annual environmental effects and costs are presented in easily comprehensible diagrams. Freely selectable impact categories include primary energy content (renewable/non-renewable), greenhouse gas and acidification potential and the ecological indicator OI3. The output is the selected value per square meter of construction per year.

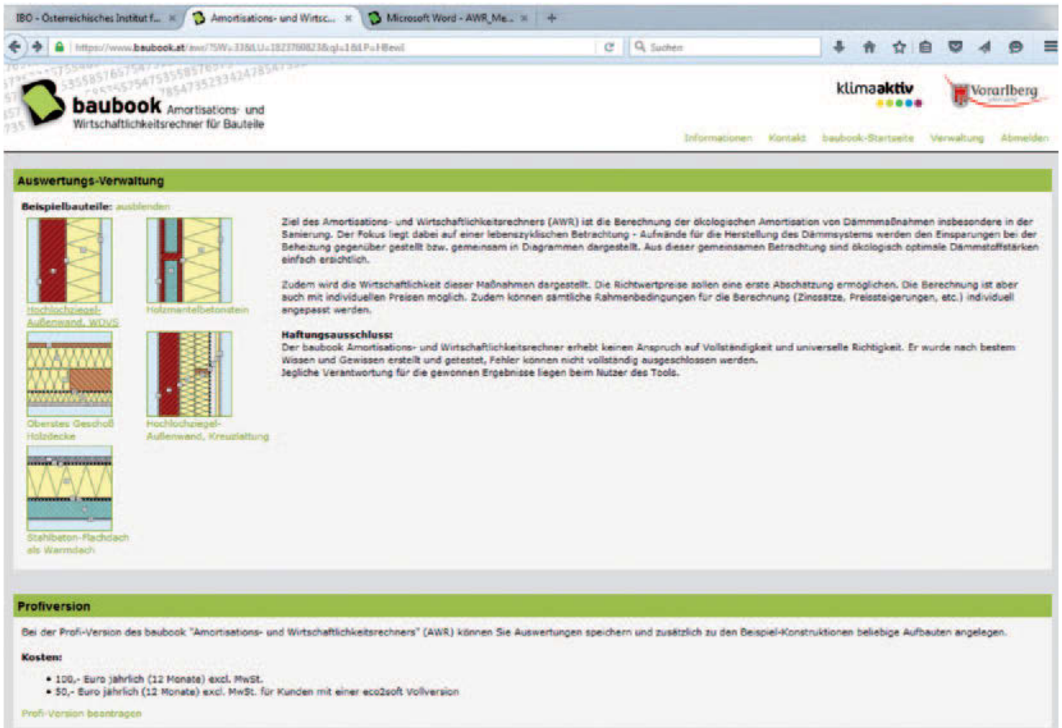

Fig. 1: baubook AWR for the calculation of ecologically and economically optimal insulation thicknesses

Example of application

The total ecological and economic costs and optimal insulation thicknesses based on the example of the refurbishment of an external wall with a composite thermal insulation system and the heating of a building by a range of energy sources is set out below. The period of observation is 30 years.

Fig. 2 shows the total costs (execution + heating) of a building refurbished with a thermal insulation composite system with mineral foam panel and gas-fired heating. The results of the calculation show that, for the parameter "non-renewable primary energy (PENRT)", the ecologically optimal insulation thickness is around 80 cm whereupon the minimum is virtually achieved at 59 cm.

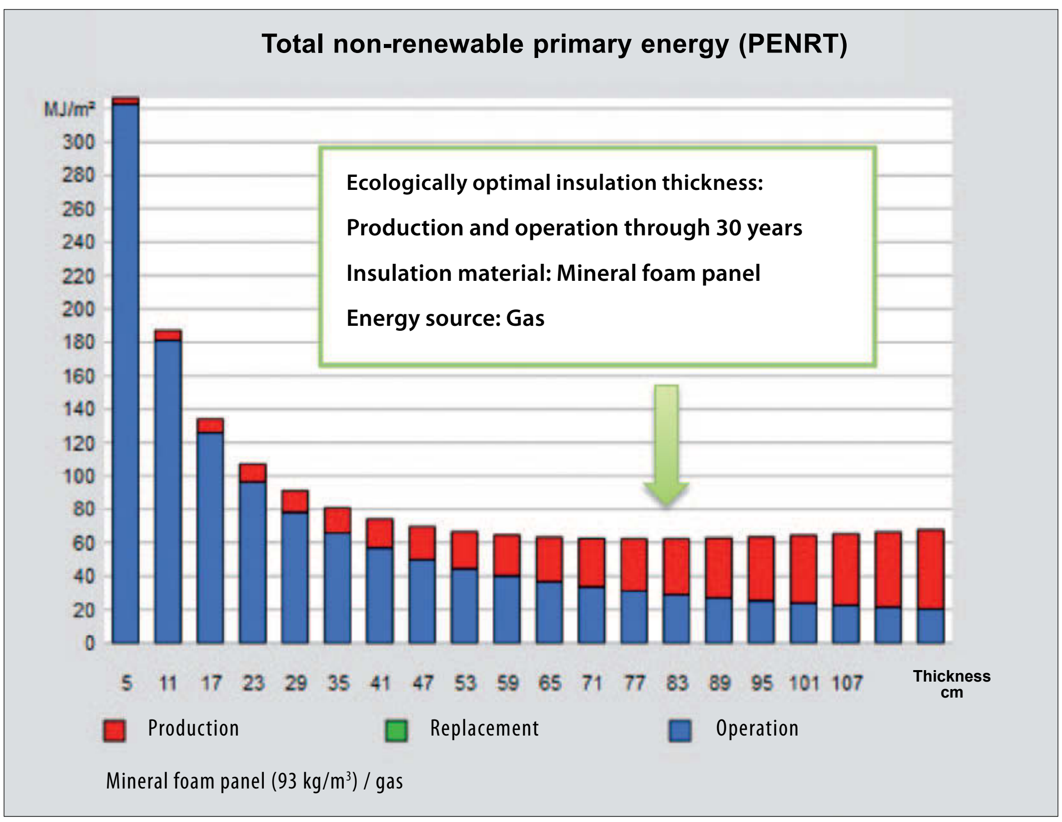

Fig. 2: Presentation of the primary energy required for execution and operation over 30 years as a function of the thickness of a sheet of mineral foam panel

The following figures show the ecologically optimal insulation thicknesses for a range of thermal insulation composite systems where gas is the energy source for the heating. The reference point is considered to be a brick wall with 10 cm of thermal insulation.

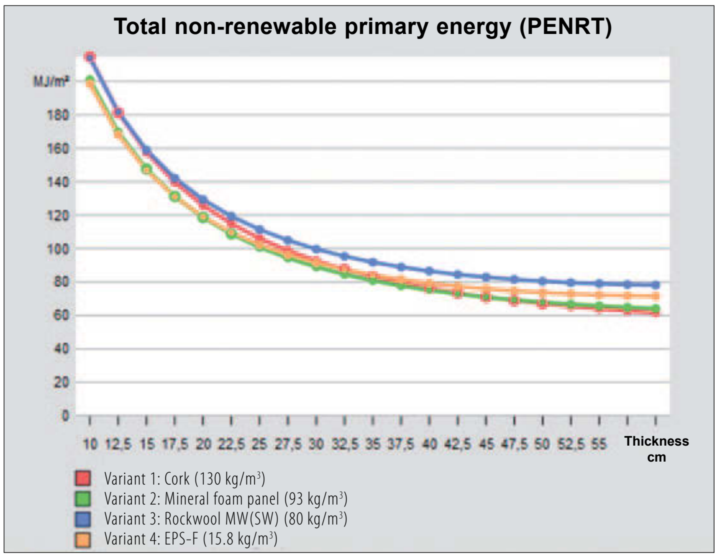

Fig.3: The total non-renewable primary energy (PENRT) for various insulation systems as a function of the thickness of the insulation where the energy source is gas.

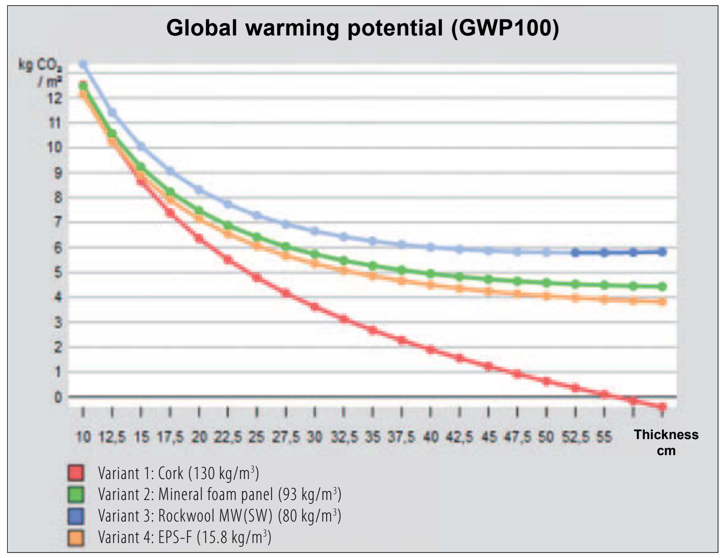

Fig. 4: The global warming potential (GWP100) for various insulation systems as a function of the thickness of the insulation where the energy source is gas.

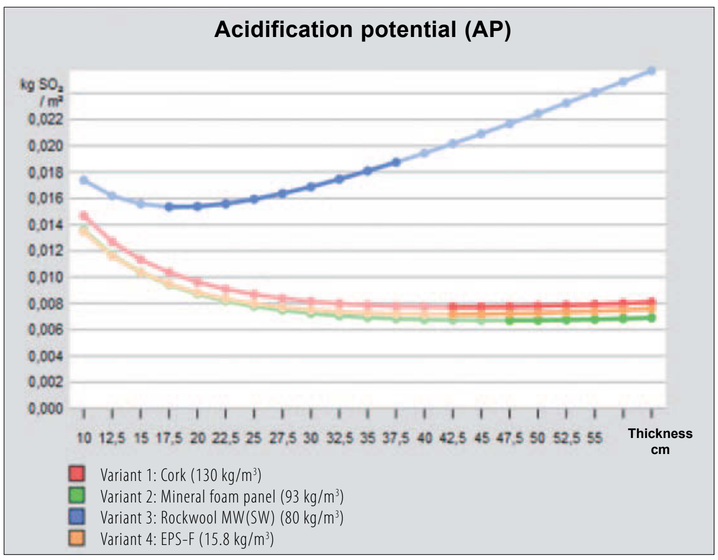

Fig. 5: The acidification potential AP for various insulation systems as a function of the thickness of the insulation where the energy source is gas.

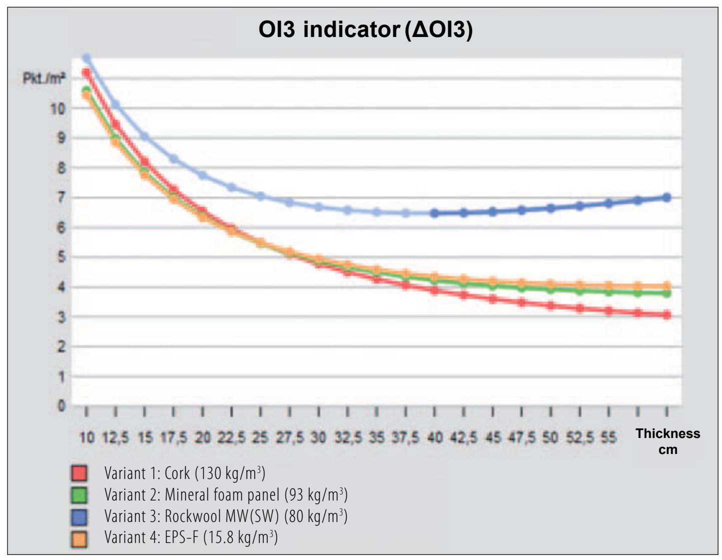

Fig. 6: Aggregated indicator OI3 for various insulation systems as a function of the thickness of the insulation where the energy source is gas.

The ecological optimum for the assessment indicator PENRT is found at thicknesses of over 60 cm for all systems. The differences when the thickness of insulation is 30 cm are between 10 and 20 % (Fig. 3).

The ecological optimum for the assessment indicator GWP 100 is found at thicknesses of over 60 cm for all systems. The differences when the thickness of insulation is 30cm are between 50 and 100 % with a clearly visible advantage for insulation from renewable raw materials (here cork, Fig. 4).

The ecological optimum for the assessment indicator AP is found at a thickness of around 20 cm for mineral wool and around 50 cm for the other systems. The differences when the thickness of insulation is 30 cm are around 20 % for cork, EPS-F and mineral thermal insulation panels. The difference for a mineral wool insulating system is 100 % greater (Fig. 5).

The ecological optimum for the assessment indicator OI3 is found at a thickness of around 40 cm for mineral wool and above 60 cm for the other systems. The differences when the thickness of insulation is 30 cm are around 5 % for cork, EPS-F and mineral thermal insulation panels. The difference for a mineral wool insulating system is around 35 % greater (Fig. 6).

In conclusion, it can be noted that the differences between various insulating systems can be very large depending upon the assessment indicator that is under observation. Regarding the key indicator of global warming, the advantage of insulating systems made from renewable raw materials and which have an ecologically optimized production can be clearly seen.

The following figures show the ecologically optimal thicknesses of insulation for a range of heating energy sources. The reference point is considered to be a brick wall with 10 cm of thermal insulation.

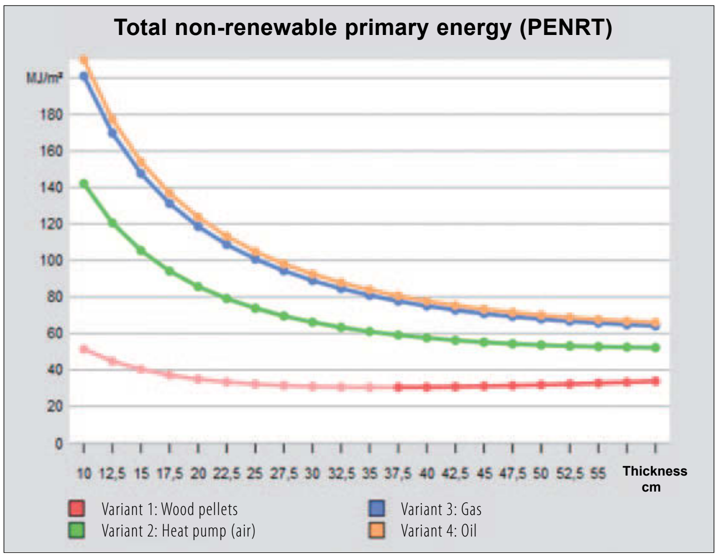

Fig.7: The total non-renewable primary energy (PENRT) over 30 years for a mineral thermal insulation composite system considering various heating energy sources as a function of the thickness of the insulation

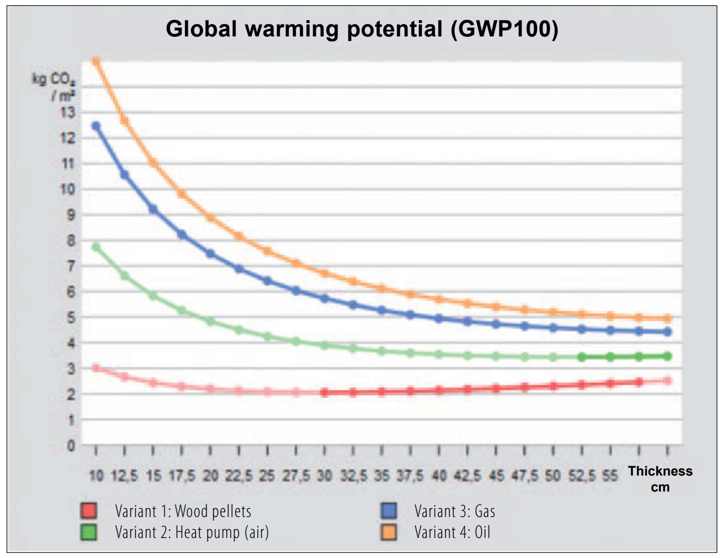

Fig. 8: The total global warming potential GWP100 over 30 years for a mineral thermal insulation composite system considering various heating energy sources as a function of the thickness of the insulation

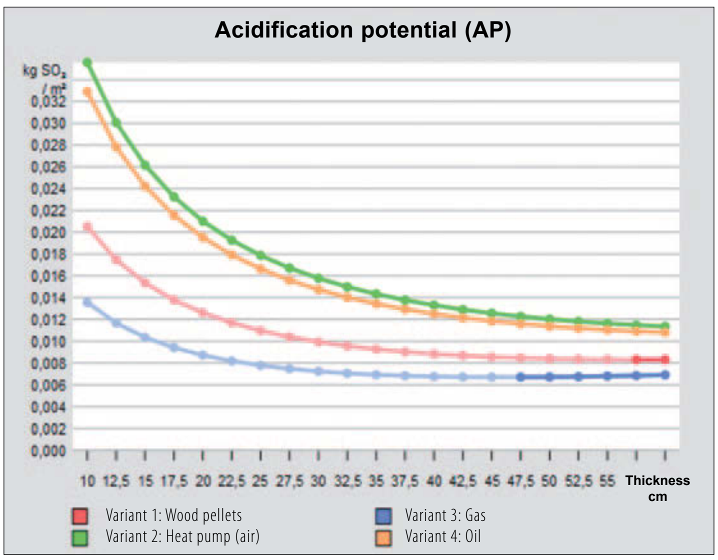

Fig. 9: The total acidification potential AP over 30 years for a mineral thermal insulation composite system considering various heating energy sources as a function of the thickness of the insulation

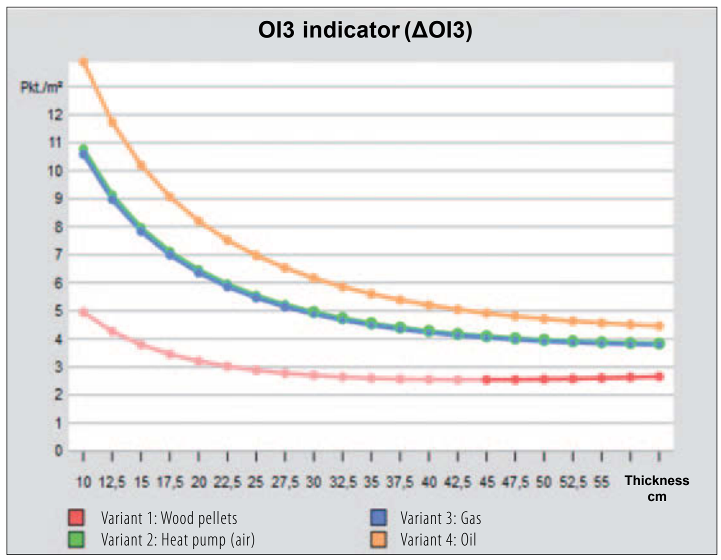

Fig. 10: The aggregated indicator OI3 over 30 years for a mineral thermal insulation composite system considering various heating energy sources as a function of the thickness of the insulation

The ecological optimum for the assessment indicator PENRT is found at a thickness of over 60 cm for all energy sources except pellets. The differences when the thickness of insulation is 30 cm are between 200 and 300 % (Fig. 7).

The ecological optimum for the assessment indicator GWP100 is found at a thickness of around 30 cm for pellets and over 50cm for all other energy sources. The differences when the thickness of insulation is 30 cm are between 100 and 250 % (Fig. 8).

The ecological optimum for the assessment indicator AP is found at a thickness of 50 cm for gas as an energy source and more than 60 cm for the other systems. The differences when the thickness of insulation is 30 cm are between 50 and 230 % (Fig. 9).

The ecological optimum for the aggregated indicator OI3 is found at a thickness of 45 cm for pellets as an energy source and more than 60 cm for the other energy sources. The differences when the thickness of insulation is 30cm are between 100 and 200 % (Fig. 10).

If one assumes that the cost-optimized insulation thickness is selected and that minimal execution costs and operating costs across thirty years are used in the calculation, insulation thicknesses above the minimum should always be chosen due to uncertainty about the development of energy costs. This area, in which such costs are a maximum of 20 % above the calculated optimum, is highlighted in the cost graph (Fig. 11).

The calculation in Fig. 12 below shows the above-described effect on this optimal area in the event of energy price increases of 2 %, 5.5 % and 10 %.

Under typical current economic optimization strategies the red arrow would represent the "optimal" result. Every additional centimeter of insulation hardly improves the overall result. However, if one moves past the

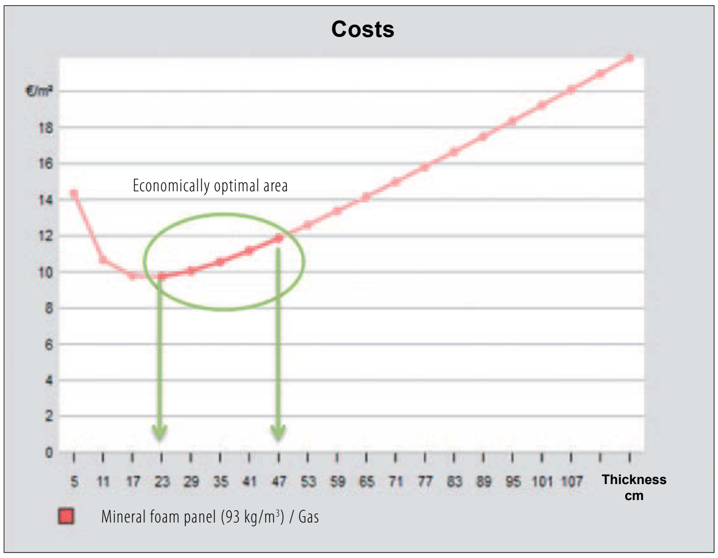

Fig. 11: Optimal cost area. The optimum is emphasised (from the minimum to 20%)

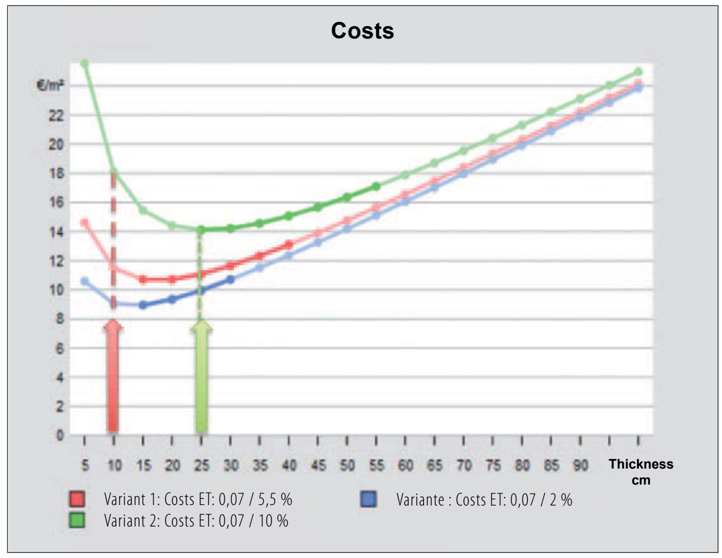

Fig. 12: Changes in the optimal costs across 30 years as a function of different levels of energy price increase. The optimum is emphasised (from the minimum to 20%). ET=Energy source

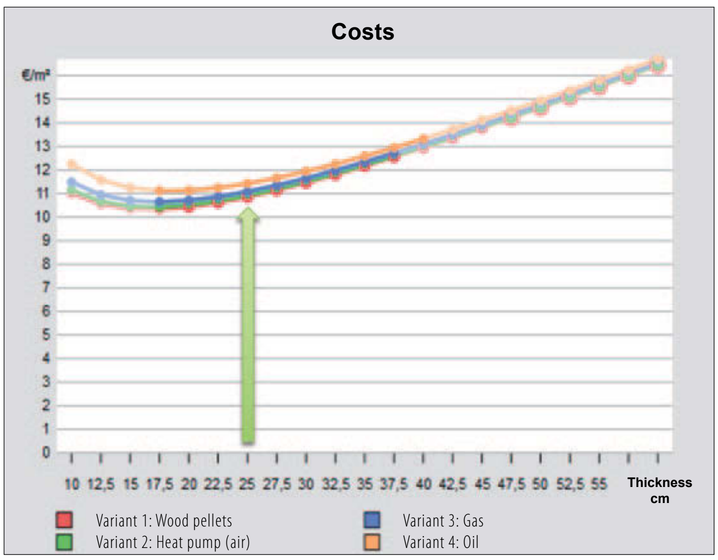

Fig. 13: Changes in the optimal costs across 30 years as a function of different energy sources

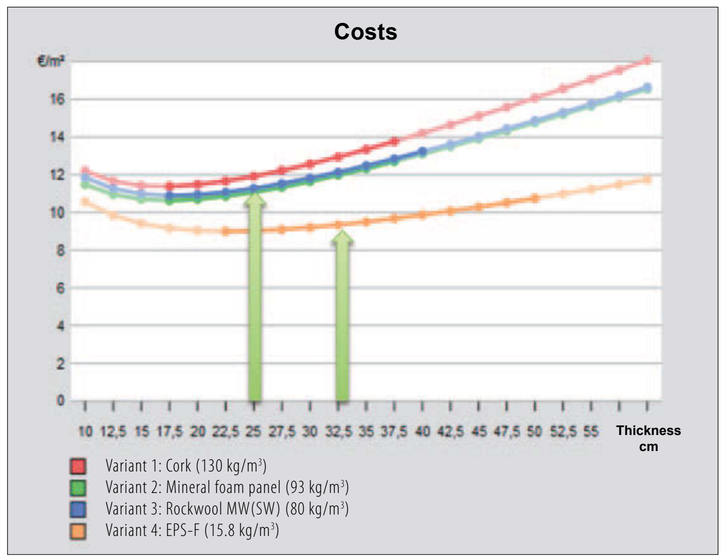

Fig. 14: The economically optimal insulation thicknesses of different thermal insulation systems over a period of 30 years

optimal area towards increased thicknesses of insulation, one is much better safeguarded against higher energy price rises (green arrow) at little extra cost. While overall costs double in the case of higher energy price rises (10 %) when the insulation thickness is low, these costs only increase by 40 % when optimization takes the form of increased insulation thicknesses. On the other hand, the increased costs of this optimization strategy are less than 10 % – even in the event of very low energy price rises.

Taking into account the previously explained optimization strategy one can identify economically robust insulation thicknesses of around 25 cm for a mineral thermal insulation panel system, regardless of the energy source (Fig. 13, green arrow).

Given that different insulation systems not only generate different "ecological costs" but also result in very different economic investment costs, the economically optimal insulation thickness also varies significantly.

Fig. 14 shows that the economically optimal insulation thicknesses for such costlier insulating materials as cork, mineral wool or mineral foam sheets is around 25 cm whereas the optimal insulation thickness for the currently cheapest façade insulation material (EPS-F) is around 32 cm.

It should be pointed out that only one passive house refurbishment measure (thermal insulation) was considered here. Synergy effects with other passive house refurbishment measures (controlled heat recovery, cost-efficient heating systems) were not taken into consideration.

Tools such as the baubook AWR can be used to, for example, compare different variants of insulation materials under real cost conditions. The calculations presented (combined with the explained decision-making strategies) show that refurbishment constructions suitable for passive houses are not only best in ecological terms but are also on the safe side in economic terms.

The costs and cost effectiveness of refurbishment to passive house level

The cost effectiveness of energy-efficient buildings

Cost and cost effectiveness are often used – without differentiation – as arguments against the realization of highly efficient buildings, and the additional costs of energy efficiency measures have been cited in many discussions of recent years as one of the main drivers of construction costs.

The invalidity of this argument is confirmed by current studies from the field of new building.

In [Ploss 2013] it could be shown that optimum costs over 30 years are produced by buildings whose primary energy demand (PED) is significantly below the maximum value of 160 kWh/m^2_{GFA} set out in the National Plan for the end of 2020. This study focused on buildings which primarily reduce PED by reducing heat loss and using small-scale solar plant to produce warm water (passive house concept).

[Ploss 2014] also investigated buildings which achieve low PED values by using large-scale thermal solar plant. The most important results of the study are the facts that both of the energy concepts which were investigated permit the reduction of primary energy demand to levels significantly below 60 $kWh/m^2_{GFA}a$ and that the cost-optimized variant – a passive house building envelope and 6 m^2 of solar collector – has a PED of 76 $kWh/m^2_{GFA}a$. This cost optimum is very flat which means that numerous variants can be operated at PED values between 55 and 90 $kWh/m^2_{GFA}a$ for the same total annual cost as the reference variant designed with a PED of 130 $kWh/m^2_{GFA}a$ in line with the minimum requirements of OIB Guideline 6. This optimum cost represents a PED value which is around half of the value of 160 $kWh/m^2_{GFA}a$ that is set out in the Austrian National Plan as a minimum requirement for 2020 [OIB 2012].

Detailed studies of the costs and cost effectiveness of highly energy-efficient building refurbishment remain rare and yet several realized buildings show that extensive savings can also be cost-effectively achieved in this area. The following examples compare the refurbishment of multistory residential buildings to passive house level with their refurbishment in line with the minimum legal requirements.

Aspects of addressing the cost-effectiveness of refurbishment

Even if detailed studies of the cost-effectiveness of energy-efficient refurbishment are rare it can be shown that highly efficient building refurbishment can be cost-effectively executed. However, in addressing the cost-effectiveness of refurbishment the following aspects must be considered:

- The cost-effectiveness of energy-efficient refurbishment is dependent upon the initial condition of the existing building. For example, assuming that costs remain unchanged the application of the same 20 cm thick insulation to an external wall leads to lower savings in a building whose walls have an initial U-value of 0.6 W/m^2K than in a building where this initial U-value is 1.2 W/m^2K. In other words, the cost-benefit relationship – the cost-effectiveness of the identical measures – varies with the variable quality of the non-refurbished wall.
- The choice of the right point in time is decisive in determining the cost-effectiveness of energy-efficiency measures in existing buildings. Energy refurbishment should be coupled with other necessary refurbishment measures (plaster improvement, roof repairs, window replacement…). In this case the entire refurbishment costs do not have to be charged to the energy-efficiency measures – merely the additional costs arising from the higher-quality execution in energy terms: if a window has to be replaced anyway, only the cost difference between the better quality execution (e.g. of passive house windows) and the standard execution (e.g. of standard double-glazed windows) – has to be charged as an energy-efficiency measure. Hence, the costs of measures which would have been required anyway are to be subtracted from the cost of the refurbishment. This economically logical coupling of energy-efficiency measures with measures which would have been required anyway creates a refurbishment-cycle which is dependent upon the technical life-expectancy of the main elements of the building structure (external wall, roof, windows) and the building services (heat generating equipment). Energy refurbishment projects that are carried out before these many components have reached the end of their technical life are generally sub-optimal in both operational and economic terms.
- Cost-effectiveness observations only yield useful results when appropriate calculating methods are used: Investments in building efficiency are always measures which are effective over the long-term. Appropriate calculating methods are those which reveal the cost-effectiveness of the chosen measures across a period which is similar to that of the technical life-expectancy of the main components and the duration of a credit. Typical periods for such observations are between 25 and 50 years. Appropriate methods include the net present value method or the annuity method, both of which consider residual value and replacement investments during the period of observation. Methods such as the calculation of the payback period are unsuitable because these lead to suboptimal results for the entire period of observation.

Example: the refurbishment of a multi-family dwelling to passive house level in comparison with a refurbishment in line with minimum legal standards

The following investigation examines the cost-effectiveness of the refurbishment of a typical multi-family dwelling (with around three stories and 10 to 15 residential units) from the 1950s or 1960s because such buildings are common and provide the most complete cost information. As detailed and useable cost information about high quality energy refurbishment is only available for few Austrian projects, the following investigation will use cost information from German projects. The calculations assume that the refurbishment occurs at a moment at which comprehensive refurbishment would have been required anyway.

Comparison is made between the following execution variants:

- Reference refurbishment without energy measures (standard pre-refurbishment needs)
- Refurbishment to NEH standard
- Refurbishment to EnerPHit standard
- Refurbishment to passive house standard

The non-energy measures (floor plan changes, new balconies and electrical and sanitary installations …) were assumed to be identical in all four variants.

Table 3 collates technical information about the most important building elements and components.

Building element/component	Unit	NEH	EnerPHit	PH
Slab above 2nd story	W/m²K	0.15	0.13	0.11
External wall	W/m²K	0.32	0.15	0.10
Cellar ceiling	W/m²K	0.40	0.22	0.17
Windows		double glazing	triple glazing	triple glazing. passive house frame
Ventilation		exhaust	heat recovery	optimized heat recovery
Heat demand$_{PHPP}$	kWh/m²$_{ERA}$a	approx. 55	approx. 25	approx. 15
Heat supply		district heating. radiators		

Tab. 3: Parameters of the investigated building variants

It was assumed that the number of air changes of the exhaust air plant and comfort ventilation were identical in order to compare building variants with the same air quality.

Heating demand from the refurbishment variant without energy measures is around 160 kWh/m²$_{ERA}$a, and warm water demand was commonly assumed to be around 20 kWh/m²$_{ERA}$a.

The gross refurbishment costs of the reference refurbishment without energy measures were assumed to be around 820 EUR/m²$_{UFA}$ which signifies a relatively high level of intervention.

The gross additional costs of the energy-improved variants in comparison with the variant without energy-saving measures are:

- 246 EUR/m²$_{UFA}$ for the NEH variant
- 326 EUR/m²$_{UFA}$ for the EnerPHit variant
- 394 EUR/m²$_{UFA}$ for the passive house variant

The costs named here are towards the upper end of the spectrum for the additional costs for refurbishment in Germany mentioned above with the values for the NEH and PH variants corresponding with those of the Ludwigshafen-Hoheloogstraße research project [Kaufmann 2010].

On the basis of the energy parameters and costs set out above the cost-effectiveness for the three improved energy standards was calculated in comparison with the variant without energy-saving measures. In addition to energy costs the calculation also considered the maintenance costs of radiators and ventilation systems whereas other maintenance costs – of, for example, the district heating transfer station – were assumed to be constant and were not considered.

The calculations were performed without considering any subsidies and taking the following assumptions and boundary conditions into account:

	Explanation	Value	Unit
Observation period	residual value considered	30	year
Cost of capital	real	1.5	%
Equity yield rate	real	0.8	%
current basic price district heating	gross	0.10	EUR/kWh
current basic price electricity	gross	0.16	EUR/kWh
average price increase district heating	real	2.5	%
average price increase electricity	real	2.0	%
Life expectancy building services		30	year
Life expectancy insulation		50	year
Life expectancy windows		40	year

Tab. 4: Assumptions and boundary conditions for the calculation of cost-effectiveness

The described assumptions and boundary conditions lead to the results presented in fig 15.

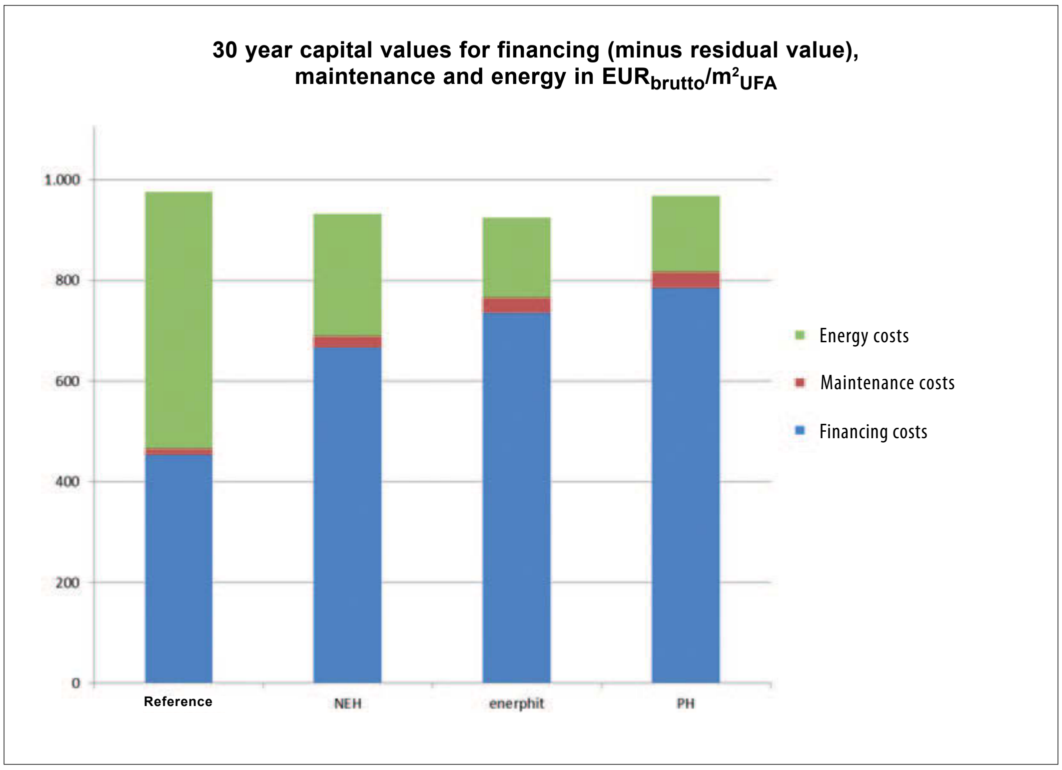

Fig. 15: Assumptions and boundary conditions for the calculation of cost-effectiveness

As shown, the total capital value of the financing, maintenance and energy is between 925 and 975 EUR/m^2_{UFA}. It can be seen that the energy level only has a minor influence on the total capital value. The three energy-improved variants have lower total capital values than the reference variant, which means that they are cost-effective – even without subsidy. The lowest total capital value is given by the EnerPHit variant with a Heat DemandPHPP of around 25 kWh/m^2_{ERA}a. It should be noted that the ecological pollution resulting from heating is significantly lower in the passive house variants than in the case of NEH refurbishment.

Correlation of calculation-demand

A pre-requirement for the cost-effectiveness of energy-efficient new buildings and refurbishment is that the low energy demand calculated in advance can also be achieved in reality.

As the measured values of realized high-value building refurbishment projects show, a very high level of correlation between the calculation of needs and actual consumption can be achieved if evaluated calculation programs such as PHPP are used and realistic boundary conditions selected.

Fig. 16 shows the measured consumption of heating energy of highly-efficient building refurbishments in terms of the similarly measured average ambient air temperature.

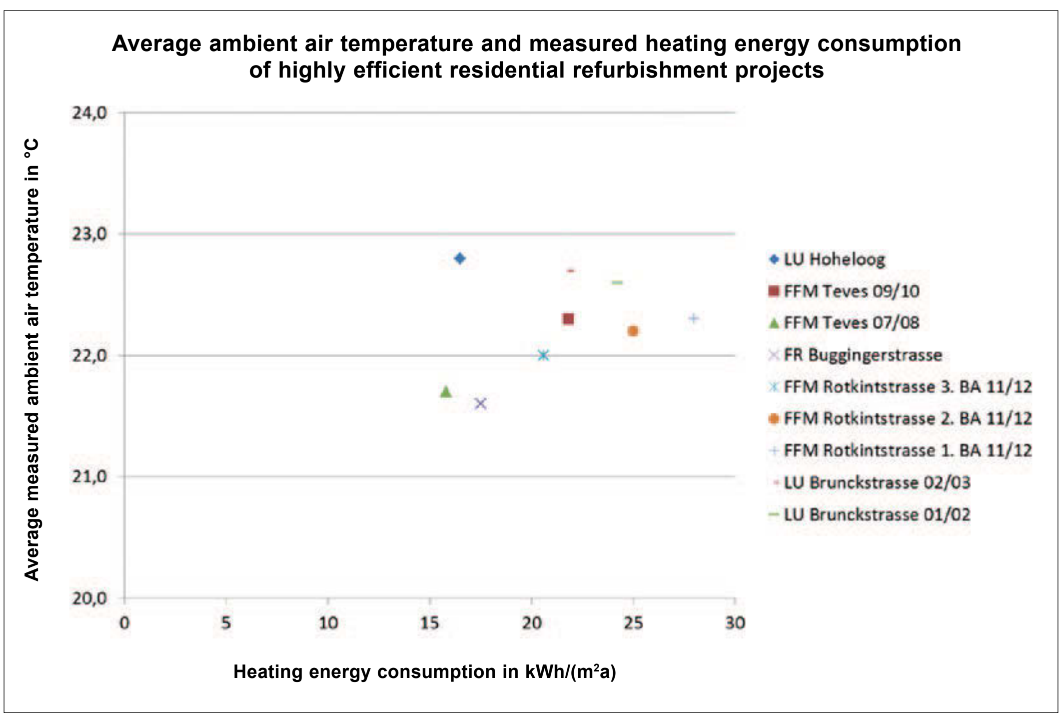

Fig. 16: Average ambient air temperature and measured heating energy consumption for innovative refurbishment projects [Großklos 2013], with the addition of the projects FR Buggingerstraße [Kagerer 2013] and LU-Brunckviertel [Weyand 2005]

As the figure shows, the measured heating energy consumption of the seven projects presented lies between just above 15 and 28 $kWh/m^2_{ERA}a$ and, hence, in the expected range for newly built and EnerPHit-refurbished passive houses, although the average ambient air temperatures measured in the heating period lie between 21.5 and almost 23 °C.

Airtightness

It is desirable for buildings to be airtight because drafts resulting from a lack of airtightness are inadequate – and also not permitted – as a form of ventilation. On the contrary, if gaps result in air leaking out of a building in winter there is a danger of structural damage occurring because humidity in the warm internal air can condense during its journey to the outside and lead to substantial humidity penetrating the construction. Air flowing from outside to inside because of driving rain and wind pressure can also result in water entering the construction from the outside.

Airtightness is best controlled by two pressure tests before and after completion of the refurbishment work.

The following can be considered airtight:

- external masonry walls with continuous plasterwork
- window panes
- concrete slabs

Joints and connections must be carefully masked in the case of:

- Surfaces made up of composite wooden boarding

The red pencil method helps find gaps in the airtight envelope: it must be possible to draw an unbroken line around the entire volume with a broad pencil (Wolfgang Feist in [Zelger 2009]). In older buildings this is not always possible. The beam heads of timber beam ceilings can often break through the airtight envelope as a result of which these beam heads are threatened by condensation. The search for the solution to this problem is ongoing.

While the airtight envelope in new buildings is best created to the inside of the construction, in the case of refurbishment projects with additional external insulation this airtight envelope can be provided by the old external plaster layer – if all cracks are filled – together with the protective new layer of insulation. Effort should be made to ensure the optimum level of connection to both existing plaster layers – by using, for example, a smooth plaster layer to create an airtight connection between existing external plaster and internal plaster and between these plaster layers and windows. The result is that both layers are effective.

The problem of humidity in existing buildings and in their refurbishment

During the design phase before the start of the thermal refurbishment of an existing building – particularly a building from the late 19th century or a building with brick walls at basement and ground floor level – it must be ascertained whether the basement and ground floor masonry is already humid. Signs of this can include a muggy odor in the basement, flaking plasterwork on the base of the building and discolored plaster due to salt efflorescence. If such humidity is already present, a retroactive sealing should be applied and measures introduced to reduce the level of humidity in the masonry.

In general the humidity of the masonry and of the surrounding internal and external air will find an equilibrium after the completion of a building. After the humidity generated by the construction process has diffused – and as long as it is penetrated by no more additional water or humidity – the masonry will arrive at an equilibrium moisture content corresponding with the internal and external climate.

In (basement) masonry which is humid due to rising damp or surface water entering laterally, the humidity level of the masonry is higher than the equilibrium moisture content. The water will rise within the wall in line with the capillary climbing height of the building material and then evaporate from the external plaster surface. The evaporation horizon is recognizable on brick masonry due to the typical signs of damage to the plaster (flaking, discoloration, etc.). The crystallization of the salts dissolved in the water adjacent to the evaporation horizon leads to an increase in volume. The pressure induced by this crystallization is so great that, over a period of years, even hard lime cement plaster will be fragmented and destroyed by these salts.

Rebuilding and façade refurbishment work alters the year-long equilibrium between evaporation and rising humidity until a new equilibrium is established. If, in cases of rising damp, no drying-out measures are carried out and evaporation at the base of the building is impeded or completely prevented by such vapor retarding layers as cement plaster, sealing or vapor impermeable thermal insulation, either a new, higher evaporation horizon will be established or humidity will accumulate in the wall material or evaporate within the building. The released salt will then damage the internal plaster.

Even when drying-out measures are carried out these only impede the capillary movement of future water and the "dried out" masonry will remain humid. Hence, either the dried-out masonry must be allowed time to dry (which, in the case of basement masonry with a thickness of 90 cm, can be two to three years) or technical aids (such as heating rods) with the appropriate energy supply should be used to accelerate this process. For example: 1 m^3 of masonry with fully saturated capillary pores can, depending on the gross density of the bricks, contain 200 to approx. 300 liters of water!

In the case of natural stone masonry the capillary climbing height is, depending on the type of stone, generally lower than that of brick masonry. In the case of masonry containing a mix of brick and stone the brick is often more humid and more damaged than the stone.

A basic decision to be taken during a thermal refurbishment project is whether or not to insulate the basement. If the basement is not insulated and the ground floor somewhat raised above the surrounding ground level (e.g. a free-standing detached house with natural stone base) it is possible to use accompanying measures (refurbishment of downpipes, rainwater and drainage pipes, lowering of the surrounding ground level, guiding of surface water away from the building) as a means of lowering the evaporation horizon far enough to ensure that damage due to rising damp is avoided. This should be checked in each case in line with object-specific factors – if necessary through a simulation calculation. If the basement is thermally insulated and, hence, becomes part of the thermal building envelope, measures to dehumidify the masonry are usually unavoidable and drying-out measures should to be tested in line, amongst other things, with the planned use of the basement.

In general, although humidity damage is recognizable due to the appearance of an evaporation horizon on the façade, not every case of humidity damage is caused by rising damp (see more about this below). In many cases it makes sense to include neighboring buildings in such an examination. Do these also show signs of damage? Have these also been dried out? Is the neighboring basement also humid?

The drying out of masonry

The drying-out of humid masonry requires, on the one hand, the careful analysis of causes and, on the other hand, the detailed design of the measures required. The only successful measures are those which address the object-specific conditions and are checked after the execution of the drying-out work to see if they have been successful. Unlike other countries, Austria has norms (ÖNORM) for the drying-out of humid masonry which address the areas of design and execution.

The use of methods for drying-out masonry only makes sense when this moisture is definitely due to rising damp. Other causes of humid masonry can be as follows:

- Laterally penetrating (surface) water: e.g. leaking downpipes, rain and drainage pipes, external concrete slabs which slope towards the external basement wall, etc.
- Condensation: especially in spring and summer when humid external air can condense on the surface of cold (basement) walls – e.g. after a thunderstorm.
- hygroscopic salts: salts can absorb and release water: typical signs of damage are humid stains on plaster walls

Building diagnosis

Building diagnosis is required in order to establish the cause of damage and as a basis for the selection of the appropriate measures to be taken as part of a refurbishment project. ÖNORM B 3355-1 defines this building diagnosis procedure. In general, a building diagnosis should include the following points: a recording of the existing situation, the taking of samples and the establishment of specific values for the building materials.

Recording of the existing building and its surroundings:

- Obtaining of the last approved plans from the statutory authorities and/or drawing up of as-built plans and investigation of the history of the building
- Investigation of the groundwater level and of the stratigraphic composition of the ground.
- Investigation of the wall and slab construction, wall and slab materials and foundation type
- Investigation and analysis of the ground and the groundwater, e.g. through test excavations and the chemical salt analysis of the groundwater in the laboratory
- Recording of the surroundings of the building: terrain, vegetation etc.
- Identification of damage to the building, e.g.: cracks, water damage
- Investigation of former uses of the building, e.g.: for the manufacture of chemicals or the keeping of animals – and determination of future use

In the case of historically protected buildings further (art-historical) investigations and reports could also be required. This is to be decided with the responsible authorities on a case-by-case basis.

Samples taken must be representative in terms of humidity and salt content, the building material used, the condition of the building and the pattern of damage.