Federal Ministry
of the Interior, Building
and Community

Federal Institute for
Research on Building,
Urban Affairs and
Spatial Development
within the Federal Office for
Building and Regional Planning

What makes an Efficiency House Plus?

Principles and examples of energy-generating buildings

Fraunhofer IBP
FORSCHUNGSINITIATIVE Zukunft BAU
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Inhalt

Foreword

Buildings are the mirrors of our society. Developing affordable, climate-compatible housing today requires ideas for the construction and housing of tomorrow. We need practically orientated, economic solutions for climate-compatible, affordable and resource-saving buildings.

The Efficiency House Plus generates more power than it requires for its operation: the building's technical systems not only cover their own power requirements, but also supply additional energy, for instance for e-mobility. The age of building with positive energy balances has already begun, bringing with it a wide range of attractive, climate-compatible buildings.

Buildings are currently the largest energy consumers in our economy and make up a little over a third of our overall energy demand. It is an area we want to address to achieve a turnaround to a building stock that is virtually climate-neutral by the middle of this century. This federal government aims to develop new approaches to the use of natural resources and reduce the production of greenhouse gases in the field of buildings.

The Efficiency House Plus initiative was launched in 2011 with a federal prototype building. Today, almost 40 co-funded Efficiency House Plus housing development projects have proven their practical applicability. The experience and solutions derived from those pilot projects provide help in the further development and market introduction of this building standard in the field of housing. In a next step, the practical applicability of this innovative generation of buildings will be tested in the construction of educational buildings.

With its Efficiency House Plus initiative, the Federal Ministry of the Interior, Building and Community is giving new impulses to research and development in the field of energy-efficient building. At the same time, the principles of economy, technological freedom, simplification and the voluntary aspect of measures continue to apply. Furthermore, the Efficiency House Plus building standard allows a high level of design freedom.

This brochure provides information on the results achieved so far. It is aimed at motivating and inspiring its readers. It also provides support to projects in practice. Over 44 projects, numerous innovative developments and important tips on energy-efficient building provide encouragement to join us in making our environment liveable and climate-compatible.

Horst Seehofer
Federal Minister of the Interior, Building and Community

Introduction

Development of energy-saving buildings

There is a long tradition of energy-saving buildings in Germany. Research into climate-neutral buildings of the future that can be inhabited without having any impact on the climate has been ongoing for over 30 years. The low-energy building has been a minimum statutory requirement for new edifices for over 15 years. Intensive research and development has allowed buildings to advance to a point where they no longer just consume energy, but also generate it. As defined by the Federal Government, the Efficiency House Plus is able to produce more energy over the course of a year than the building and its users consume.

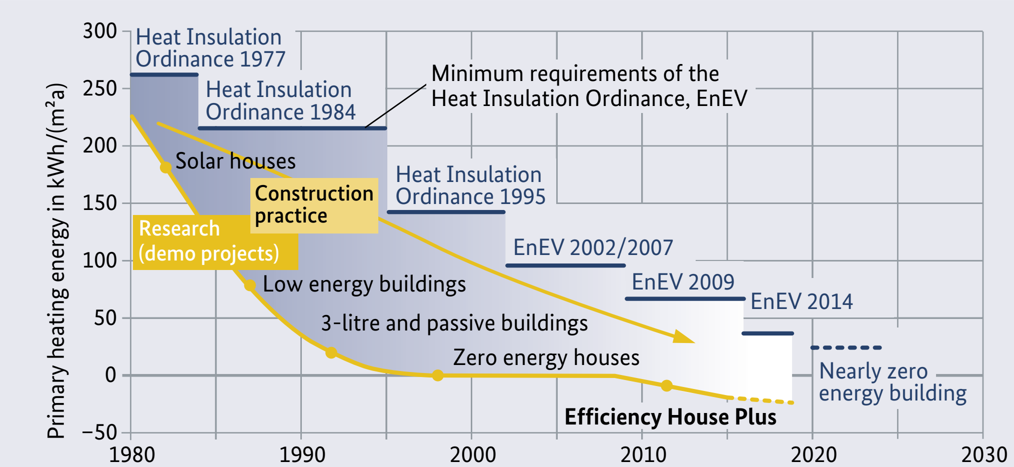
In 2007, the Technische Universität (TU) Darmstadt developed a surplus-energy house as part of its "Future Building" research initiative, with which it won the renowned "Solar Decathlon" competition in Washington DC (USA). Based on the building designed by the TU Darmstadt, the Federal Ministry of Building erected its own presentation and exhibition pavilion that went on a unique tour of Germany between 2009 and 2011, presenting the concept to six metropolitan regions.

! Tip

Compared to new buildings erected in accordance with the statutory minimum standard (EnEV), the environment benefits from new Efficiency House Plus developments by an average of 50 kg/m²a of carbon dioxide (CO_2)-equivalents per square metre of heated net floor area.

The Efficiency House Plus is not restricted to any particular technology, but can be achieved in a diverse range of ways by intelligently combining energy-efficient construction technologies and renewable energy generation systems. It is therefore an approach that is open to different technologies. The Efficiency House Plus is an ideal module with which to fulfil Germany's climate protection targets, which require a virtually climate-neutral building stock by 2050. Unlike standard buildings, each completed Efficiency House Plus reduces both fossil fuel consumption and greenhouse gas emissions in Germany. The buildings also lower our country's climate balance.

Figure 1: Primary energy demand of a single-family home



Development of a single-family home's primary energy demand in recent decades.
The lower curve presents exemplary research initiatives, while the upper documents the statutory minimum requirements. Innovative building practice moves between those two levels.

The legal framework

In Germany the provisions of the European Union Directive on the Energy Performance of Buildings are implemented by the Energy Saving Ordinance (EnEV). These provisions also contribute to attaining the EU energy objectives of the German Federal Government, achieving in particular an almost climate-neutral building stock by 2050.

It specifies maximum values for annual primary energy demand and transmission heat loss for for new residential buildings. Calculation of annual primary energy demand is based on DIN V 18599. Alternatively DIN V 4108-6, in conjunction with DIN V 4701-10, can be used for the calculation.

Furthermore, new buildings must also comply with the requirements of the Act on the Promotion of Renewable Energies in the Heat Sector (EEWärmeG). This requires owners of new buildings to meet some of their heat demand from renewable energy sources or carry out appropriate compensatory measures.

Due to their high energy standards, Efficiency House Plus buildings meet both these requirements. Nevertheless, they also have to provide evidence of their energy performance in accordance with the Energy Saving Ordinance (EnEV) and Act on the Promotion of Renewable Energies in the Heat Sector (EEWärmeG). The planned Building Energy Law (GEG) is aimed at merging the Energy Saving Act (EnEG), the Energy Saving Ordinance (EnEV) and the Act on the Promotion of Renewable Energies in the Heat Sector (EEWärmeG).

Figure 2: Requirements in accordance with EnEV and EEWärmeG

EnEV requirements

The maximum permitted annual primary energy demand of a new residential building is 25 percent less than the value of a reference building with the same geometry, alignment and use as the building to be erected, which conforms to a defined construction method for the building envelope and technical systems.

Definition of annual primary energy demand

The energy required to cover the annual energy demand for space and DHW heating Q_h, Q_{tw} (demand and technical systems' demand), taking into account the energy volumes created through prior process chains outside the boundaries of the "system of the building" in generating, transforming and distributing the relevant consumed fuels.

Implementation of EU building regulations in Germany

→ **EU regulation**
Energy Performance of Buildings Directive (EPBD)

↓

→ **EnEG**
Economy regulation

↓

→ **EnEV amendment**
Material regulations for requirements, methods, energy performance certificates, inspections

↓

- → **Technical directives, standards** (e.g. simplified data recording, energy consumption figures)
- → **DIN V 18599** "Energy efficiency of buildings"
- → **DIN V 4108-6**
- → **DIN 4701-10 Supplement 2**
- → **DIN V 4108** …

EEWärmeG requirements

100 % fulfilment of EEWärmeG through		Minimum proportion
Renewable energies	Solar radiation	**15 %**
	Solid biomass	**50 %**
	Liquid biomass	**50 %**
	Gaseous biomass in cogeneration units	**30 %**
	Geothermal and environmental heat	**50 %**
Compensation measures	Systems for using waste heat	**50 %**
	Cogeneration systems	**50 %**
	Energy-saving measures	**~15 %**
	Local or district heating heating with above proportions of renewable energy or compensation measures	

Definition: Efficiency House Plus

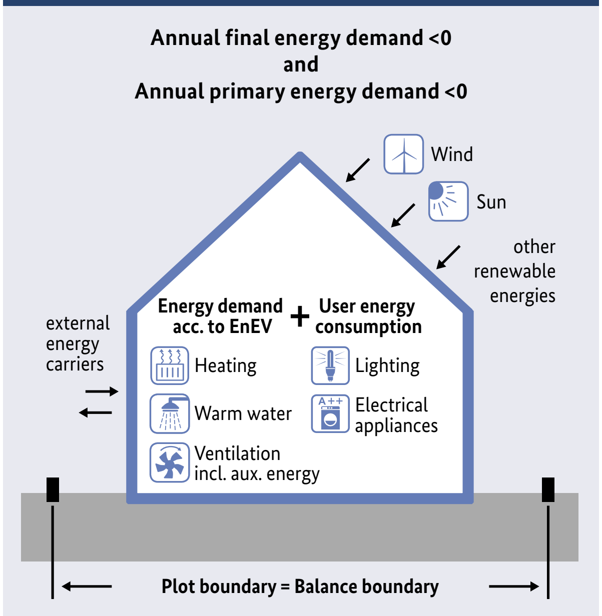
Definition: Efficiency House Plus

The Efficiency House Plus standard is deemed to have been achieved if a building has both a negative annual primary energy demand (∑Qp < 0 kilowatt hours per square metre per year) and a negative annual final energy demand (∑Qe < 0 kilowatt hours per square metre per year). All other requirements of the Energy Saving Ordinance (EnEV), such as those relating to measures to improve heat insulation in the summer, must also be complied with.

Evaluation method: Extended Energy Saving Ordinance certificate in accordance with DIN V 18599

The currently applicable Energy Saving Ordinance (EnEV) requires that certification shall be provided as set out in DIN V 18599. The network's total electricity infeed shall be assessed analogously to the displacement electricity mix. This must be based on the average location in Germany as defined in the Energy Saving Ordinance. However, in addition to the requirements under this certification procedure, the final and primary energy demand values for user energy consumption must be included in the calculations. An overall annual final energy demand of 20 kilowatt hours per square metre of heated net floor area is used for residential buildings. For educational buildings, depending on the energy efficiency of the appliances used, 10 or 15 kilowatt hours per square metre of heated net floor area per year is assumed.

Figure 3: Efficiency House Plus energy balance



Balance boundary: Plot boundary

The boundaries used in the performance assessment (also to include renewable energy facilities) are the boundaries of the plot on which the house is to be built. In addition to the area for EnEV assessment (with a direct spatial connection to the building), the sum of all the energy generated from renewable sources within the site boundaries (on-site generation) can be taken into account. The plot boundary is the boundary of the property as entered in the land registry. If there are several buildings on a plot, the amount of renewable energy generated on site will be allocated proportionally to the individual buildings, based on the usable floor area of those buildings.

Recommendation: Use appliances with the highest energy-efficiency label

The building should only use appliances with the highest energy-efficiency label and be equipped with smart meters.

Additional information required on the certificate: The self-used proportion of renewable energy generated on site

The ratio of self-used renewable energy generated on site to energy generated within the balance boundary must be documented in addition to the annual primary energy demand and the annual final energy demand. The calculation must be made in accordance with EnEV assessment based on monthly balances.

Calculation tool and energy performance certificate

The standardised calculations for an Efficiency House Plus can be carried out using a free online tool (*www.effizienzhaus-plus-rechner.de*). The tool also allows the generation of an additional information sheet specially developed for the Efficiency House Plus, both for housing and non-residential buildings, which can present the savings-effect of the generation of these buildings that goes beyond EnEV. See pages 8 and 9 for example applications.

Figure 4: Additional information sheet for the Efficiency House Plus standard energy performance certificate for housing

ENERGIEAUSWEIS für Wohngebäude

zusätzliche Informationen gemäß §17, Absatz 4 der Energieeinsparverordnung (EnEV)

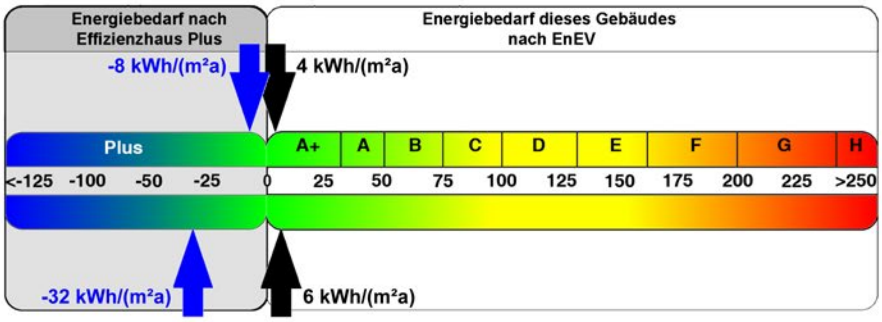
Berechneter Energiebedarf des Gebäudes

Registriernummer [1] 123

(oder: "Registriernummer wurde beantragt am ...")

2

Energiebedarf nach Effizienzhaus Plus und EnEV



Für Energiebedarfsberechnungen verwendetes Verfahren:

Nach Effizienzhaus Plus Bewertung (BMUB)

Energiebedarf nach Effizienzhaus Plus Bewertung

Endenergie:	-8	kWh/(m²·a)
Primärenergie:	-32	kWh/(m²·a)

Anforderungen gemäß EnEV [2]

Primärenergiebedarf

Ist-Wert 6 kWh/(m²·a) Anforderungswert 45 kWh/(m²·a)

Energetische Qualität der Gebäudehülle H_T'

Ist-Wert 0,23 W/(m²·K) Anforderungswert 0,40 W/(m²·K)

Sommerlicher Wärmeschutz (bei Neubau) □ eingehalten

Endenergiebedarf nach Effizienzhaus Plus

Energieträger	Jährlicher Endenergiebedarf in kWh/(m²a) für: Gebäudetechnik nach DIN V 18599	Nutzerstrom [3]	Netzbezug	Netzeinspeisung	Bedarf nach Effizienzhaus Plus	Eigennutzungsgrad [%]
Strom	3,8	6,0	9,9	-17,7	-7,8	
Summe	3,8	6,0	9,9	-17,7	-7,8	53,2

Endenergiebedarf nach Effizienzhaus Plus	**-7,8**	**kWh/(m²·a)**
Primärenergiebedarf nach Effizienzhaus Plus	**-31,8**	**kWh/(m²·a)**

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Erläuterungen zum Berechnungsverfahren

Definition:

Das Effizienzhaus-Plus Niveau ist erreicht, wenn sowohl ein negativer Jahres-Primärenergiebedarf ($\Sigma Qp < 0$ kWh/(m²a)) als auch ein negativer Jahres-Endenergiebedarf ($\Sigma Qe < 0$ kWh/(m²a)) vorliegen. Alle sonstigen Bedingungen der aktuell gültigen Energieeinsparverordnung (EnEV) wie z.B. die Anforderungen an den sommerlichen Wärmeschutz sind einzuhalten.

Bewertungsmethode:

Die Nachweise sind in Anlehnung an die aktuell gültige Energieeinsparverordnung (EnEV) nach der DIN V 18599 zu führen. Allerdings müssen in Ergänzung zur Nachweisprozedur der EnEV die End- und Primärenergiebedarfswerte für die Wohnungsbeleuchtung und für die Haushaltsgeräte und –prozesse in der Berechnung mitberücksichtigt werden. Für Wohngebäude ist dabei ein pauschaler Endenergiewert von 20 kWh/m²a (davon Kochen: 3 kWh/m²a) anzunehmen.
Als Bilanzgrenze (auch im Sinne der Einbeziehung der Anlagen zur Nutzung erneuerbarer Energien) ist das Grundstück, auf dem das Haus errichtet wird, anzusetzen. In Erweiterung zum Bilanzraum der EnEV (unmittelbarer räumlicher Zu-sammenhang mit dem Gebäude) ist die Summe der auf dem Grundstück des zu bewertenden Gebäudes generierten Energie aus erneuerbaren Energiequellen anrechenbar (»on-site Generation«).

[1] siehe Fußnote 2 auf Seite 1 des Energieausweises
[2] nur bei Neubau sowie bei Modernisierung im Fall des §16 Absatz 1 Satz 3 EnEV
[3] Nutzerstrom (Elektrische Geräte und – prozesse)

Additional information sheet for the Efficiency House Plus in accordance with § 17 EnEV (tool-generated)

Figure 5: Additional information sheet for the Efficiency House Plus standard energy performance certificate for non-residential buildings

ENERGIEAUSWEIS für Nichtwohngebäude

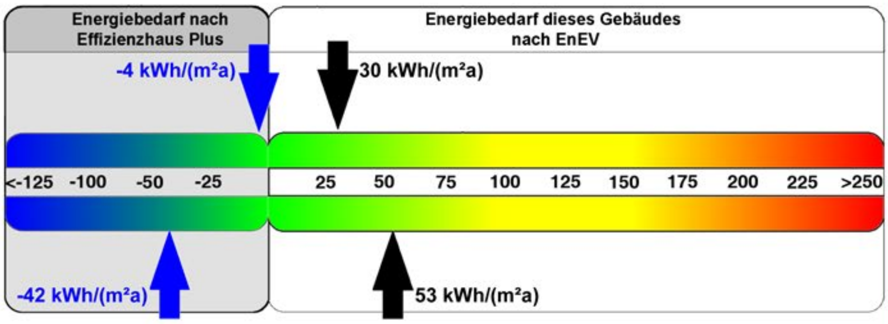
zusätzliche Informationen gemäß §17, Absatz 4 der Energieeinsparverordnung (EnEV)

Berechneter Energiebedarf des Gebäudes

Registriernummer [1] Reg123
(oder: "Registriernummer wurde beantragt am ...")

2

Energiebedarf nach Effizienzhaus Plus und EnEV



Für Energiebedarfsberechnungen verwendetes Verfahren:
Nach Effizienzhaus Plus Bewertung (BMUB) 10 kWh/(m²·a)

Energiebedarf nach Effizienzhaus Plus Bewertung

Endenergie:	-4	kWh/(m²·a)
Primärenergie:	-42	kWh/(m²·a)

Anforderungen gemäß EnEV [2]

Primärenergiebedarf

Ist-Wert	53	kWh/(m²·a)	Anforderungswert	93	kWh/(m²·a)
Mittlere Wärmedurchgangskoeffizienten				☒	eingehalten
Sommerlicher Wärmeschutz (bei Neubau)				☒	eingehalten

Endenergiebedarf nach Effizienzhaus Plus

Energieträger	Jährlicher Endenergiebedarf in kWh/(m²a) für: Gebäudetechnik nach DIN V 18599	Nutzerstrom [3]	Netzbezug	Netzeinspeizung	Bedarf nach Effizienzhaus Plus	Eigennutzungs-grad [%]
Strom	5,4	3,3	8,7	-23,3	-14,6	
Nah-/Fernwärme a	10,4		10,4		10,4	
Summe	15,8	3,3	19,1	-23,3	-4,2	46,7

Endenergiebedarf nach Effizienzhaus Plus	**-4,2**	**kWh/(m²·a)**
Primärenergiebedarf nach Effizienzhaus Plus	**-42,3**	**kWh/(m²·a)**

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Erläuterungen zum Berechnungsverfahren

Definition:
Das Effizienzhaus Plus - Niveau nach der Bekanntmachung des Bundesministeriums für Umwelt, Naturschutz, Bau und Reaktorsicherheit über die Vergabe von Zuwendungen für Modellprojekte für Bildungsbauten ist erreicht, wenn sowohl ein negativer Jahres-Primärenergiebedarf ($\Sigma Qp < 0$ kWh/(m²a)) als auch ein negativer Jahres-Endenergiebedarf ($\Sigma Qe < 0$ kWh/(m²a)) vorliegen. Alle sonstigen Bedingungen der zum Zeitpunkt der Beantragung gültigen Energieeinsparverordnung (EnEV) wie z.B. die Anforderungen an den sommerlichen Wärmeschutz, sind einzuhalten.

Bewertungsmethode:
Die Nachweise sind in Anlehnung an die Energieeinsparverordnung (EnEV) nach der DIN V 18599, Ausgabe 2011 zu führen. Allerdings müssen in Ergänzung zur Nachweisprozedur der EnEV die End- und Primärenergiebedarfswerte für den Nutzerstrom (Elektrische Geräte und – prozesse) in der Berechnung mitberücksichtigt werden.
Als Bilanzgrenze (auch im Sinne der Einbeziehung der Anlagen zur Nutzung erneuerbarer Energien) ist das Grundstück, auf dem das Haus errichtet wird, anzusetzen. In Erweiterung zum Bilanzraum der EnEV (unmittelbarer räumlicher Zusammenhang mit dem Gebäude) ist die Summe der auf dem Grundstück des zu bewertenden Gebäudes generierten Energie aus erneuerbaren Energiequellen anrechenbar (»on-site Generation«).

[1] siehe Fußnote 2 auf Seite 1 des Energieausweises
[2] nur bei Neubau sowie bei Modernisierung im Fall des §16 Absatz 1 Satz 3 EnEV
[3] Nutzerstrom (Elektrische Geräte und – prozesse)

Additional information sheet for the Efficiency House Plus in accordance with § 17 EnEV (tool-generated)

The components: Energy efficiency and renewable energy sources

Compared to traditional building practice, the Efficiency House Plus is based on three key principles:

- Maximising the building's energy efficiency
- Reducing the energy demand of household processes as much as possible
- Self-using renewable energy to cover own requirements

Energy efficiency is improved by building design (compact building form, ideal orientation), thermal insulation (highly efficient windows and thermal insulation systems for the building envelope), optimised workmanship (no thermal bridges and airtight structures and structural connections), as well as energy-conscious behaviour on the part of the occupants (supported, for example, by energy-use displays and smart metering). At the same time, occupant comfort is usually increased by the measures to reduce energy demand, since the resulting warm surfaces improve thermal comfort in the rooms.

Energy efficiency can be further increased by low system temperatures (resulting in lower heat losses) in the heating system, short pipe runs for heating, hot water, and ventilation systems (which in turn mean lower heat losses and lower energy consumption for pumps and fans), by heat recovery systems in the ventilation and waste water systems, hydraulic adjustments in all systems (which means lower energy consumption for pumps and fans), demand-controlled heating and ventilation systems (avoiding the oversupply of fresh air and heating energy to rooms), household appliances that have the highest energy efficiency rating (A+++) and efficient room lighting (LEDs or low-energy bulbs combined with presence detectors).

Renewable energy can be actively and passively used in the building. Passive solar gains through the windows can be used at no cost at all to reduce the need for heating energy, while also lowering the demand for artificial light. Renewable energies can also be actively harnessed using solar thermal collectors, biogenic fuels, geothermal energy and ambient heat. The "Plus" in these buildings refers to power-generating systems such as photovoltaics or wind turbines. The surplus produced can be temporarily stored in the building and, if there is still a surplus, fed into the grid of the energy supplier.

Figure 6: The energy pillars of an Efficiency House Plus

Efficiency House Plus

Energy-efficient building

- Compact building
- Ideal orientation
- Thermal zoning
- Thermal insulation
- Good triple-glazed windows or vacuum glazing, good frames (U_W-value, g-value)
- Avoiding thermal bridges
- Airtightness
- Low system temperature
- Short pipe runs
- Hydraulic balancing
- Efficient operating systems
- Demand-controlled systems
- Efficient appliances
- Efficient lighting
- Heat recovery

Using renewable energy sources

- Solar gains through windows
- Using daylight
- Solar collectors
- Biogenic fuels
- Geothermal energy or ambient heat
- Heat recovery
- Photovoltaics
- Wind turbines

Key parameters

Building design

The decisive factors of energy and land-saving, ecological and economical building are determined early on in the design stage. In terms of building design, the following three aspects deserve special attention:

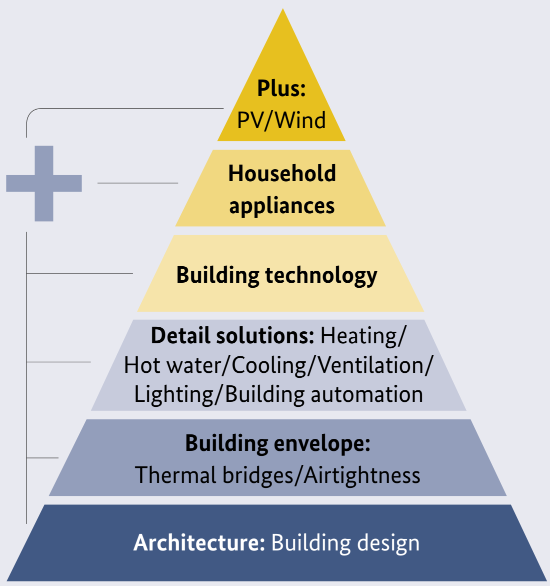
Compactness

Given a comparable standard of insulation, detached houses have a significantly higher need for heating energy per square metre of living area than semi-detached and terraced houses or apartment blocks. This is due to the higher surface area to volume (S/V) ratio. This ratio indicates the size of the envelope of the heated part of a building through which heat exchange occurs in proportion to the volume it encloses. Roof shapes should be kept simple to permit compactness. Dormer and bay windows should be avoided where possible since they increase the surface area and usually have poorer thermal insulation.

Figure 7: The Efficiency House Plus design pyramid

Energy-influencing design factors

- → Compactness
- → Orientation
- → Building zoning
- → Thermal insulation
- → Ventilation concept
- → Heating concept



Orientation

To optimise solar energy gains through windows, as many surfaces as possible should face south. South-facing roofs with an incline of about 30° enable ideal efficiency all year round for solar water heating collectors or photovoltaics. Even north-facing roofs can be used for photovoltaic systems if they have a very shallow pitch.

Building zones

Rooms that are not heated as much, such as parents' bedrooms or the kitchen, should be north-facing. Rooms with direct sunshine can have lower temperature requirements than in shaded rooms. The layout should be organised to minimise the surface area of partition walls between the heated and unheated zones. Internal heat losses within a building can have a significant impact on the overall heat loss of the entire building. Open-plan designs over several storeys may pose a problem in terms of energy consumption.

Central technical building systems

The building's floor plan should arrange the boiler room/utility room at its centre wherever possible so that heat losses from the heat generator and storage tank can be directly used in the heated zone and to ensure that piping between solar collectors and the storage tank, as well as for any exhaust gases, is as short as possible. The service shafts should also be in a central position in the building's heated area to keep distribution piping short and heat losses low.

! Tip

More compact buildings have two benefits: a reduction in surface area to a volume (S/V) ratio of 0.1 metres^{-1} usually lowers annual heat-energy demand by up to 10 kilowatt hours per square metre, as well as lowering construction costs by 50 to 80 Euros per square metre. The use of bay and dormer windows in particular should be reconsidered.

Building envelope

The quality of a building's thermal insulation is the main factor determining its heating energy demand. Between 50 and 75 percent of heat loss from an average building is the result of transmission heat losses through the building envelope. Thus, insulating external building components has significant energy-saving potential and has proven to be the most reliable way of reducing heating energy demand. An Efficiency House Plus cannot be built without high-quality thermal insulation.

Exterior walls

Over the decades, many different ways of building exterior walls have developed and proved their merit. In the last 50 years, exterior walls have improved their thermal insulation quality by a factor of 10. Both innovative monolithic exterior walls and multi-layer building components can be used in an Efficiency House Plus.

Windows

Generally, windows have the lowest insulation value of all exterior building components. However, windows can also achieve significant solar gains, so that with appropriate positioning and orientation, passive solar gains from windows can completely compensate for heat losses. When planning transparent building elements, both the insulation value (U) and passive solar gains should be taken into account. These are described as the energy transmittance value (g). The U-value should be as low and the g-value as high as possible.
Modern triple-glazed windows usually have U-values of 0.9 Watt per square metre per Kelvin (W/m²·K) or less, and g-values of 0.5 or more.

Basement ceilings/floor slabs

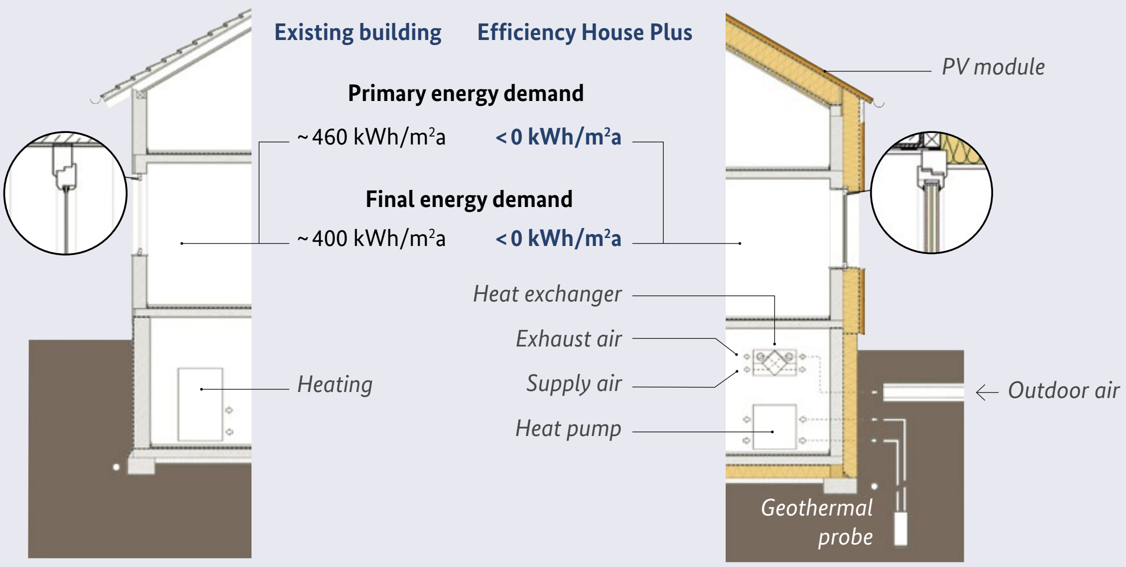
The average annual temperature difference between the space above a floor slab and the ground beneath it is only about half as much as the temperature difference when building components have contact with outdoor air. This makes heat insulation measures in these areas of a building less effective.

Tip

Investments in the building envelope have a long-term impact. It is therefore important that they are of a particularly high quality.

Figure 8: Comparison between an old building and the Efficiency House Plus

Example structure and heating supply, including energy demand, of a 50-year-old building compared to an Efficiency House Plus.



Specifics

Prevent thermal bridging

Additional energy losses from thermal bridges can be calculated as heat loss per unit length of thermal bridge [Ψ]. The influence of thermal bridges on heating energy demand is easy to calculate once this linear thermal bridge loss coefficient has been determined. Additional heat losses through thermal bridges are between 0 percent in a best-case design and 25 percent in minimum-case scenarios. For a detached house with 150 square metres of heated floor area, this produces an additional annual demand for heating energy of up to 1,500 kilowatt hours per square metre, depending on the standard of the building. A stringent inspection of the workmanship is therefore crucial, since well-designed connection components that have been poorly implemented can often cause energy-related weak points.

Make the building airtight

In addition to the air exchange rate that can normally be ensured by opening windows or using mechanical ventilation systems, additional uncontrolled infiltration air exchange occurs at building joints and points where the building's envelope is not airtight etc. They are normally between 0.1 h^{-1} in the case of very airtight buildings and over 0.3 h^{-1} in buildings that are less airtight. In terms of potential, this tolerance is comparable with the influence of thermal bridges (about 10 kilowatt hours per square metre per year). To achieve an airtight building envelope, an airtightness plan must be prepared at the design stage. The airtight envelope must enclose all surfaces of the volume to be heated and, in the case of multi-storey apartment buildings, should if possible enclose each separate living unit to rule out leakage through stair wells, service shafts etc. Particular care should be taken with converted loft spaces that have purlin and trussed rafter roofs since their structures include many points where the building shell is perforated. During construction measures, care must be taken to ensure that after the airtight layer has been completed, no leaks are caused by subsequent work. Any leaks can be located using blower-door tests.

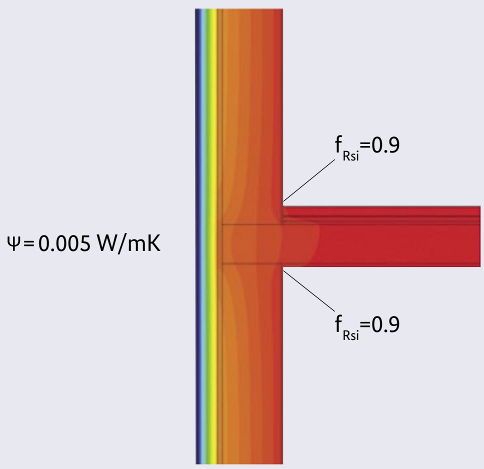
! **Tip**

Airtightness and minimising thermal bridges have a comparable annual energy saving potential of more than 10 kilowatt hours per square metre.

Figure 9: Calculation of the influence of thermal bridges on the temperature and heat flows

Building joint	Linear thermal bridge loss coefficient Ψ [W/mK]	
Exterior wall corner	-0.30	-0.07
Window joint recess	0.06	0.12
Window joint sill	0.13	0.20
Window joint lintel	0.06	0.25
Floor bearings	0.00	0.15
Basement bearings	-0.14	0.20
Roof connection eave	-0.20	0.11
Roof connection verge	-0.03	0.10

Range of linear thermal bridge loss coefficients in building connections: considerable savings potential exists between heat-loss-minimised and standard (maximised) versions. These must be exploited while planning Efficiency House Plus buildings.



For example, floor bearings using well-planned connection details can almost completely prevent thermal bridges.

Technical building systems

A range of different technologies, including building systems, can be used to achieve an Efficiency House Plus. The most important aspect is that the systems used (to provide space heating and cooling, hot water, fresh air and light as required) consume as little energy as possible for the task.

Heating

Heat losses during heat generation can easily be as great as the space heating demand it is meant to cover. It is therefore important to design the heating system very carefully to keep the energy demand as low as possible. Temperatures in the distribution system should be as low as possible (less than 35 degrees Celsius). A common way of using ambient heat for heating purposes involves heat pumps to utilise the thermal energy in the ground, ground water or ambient air. Solar thermal systems are sometimes used as supplementary heating, in conjunction with seasonal storage systems, to cover basic heating demand. Another way of incorporating renewable energy is to use biogenic fuels (biomass, bio-oil or biogas). Here particular attention should be paid to minimising the energy needed to operate the system.

Hot water

The energy demand for hot water in well-insulated buildings is roughly the same as the space heating demand. Circulation pipes can easily more than double the energy demand for hot water. It is therefore advisable to site the water heater/tank close to the taps to avoid the need for circulation pipes or to fit a timer to the circulation system. Today's solar water heating is well developed and works reliably. It can save up to two thirds of the energy demand for hot water.

Cooling

A good (climate-compatible) design – in conjunction with suitable exterior shading devices – eliminates the need for mechanical cooling systems in residential buildings in Germany. Appropriate passive measures (for example night ventilation, thermal component activation or the use of phase-change materials in attic spaces) can make summer temperatures in buildings even more comfortable.

! Tip

Ensure that a hydraulic balance has been carried out on your heating system (savings potential of more than 10 percent possible).

Figure 10: Using ambient heat with heat pumps and geothermal probes

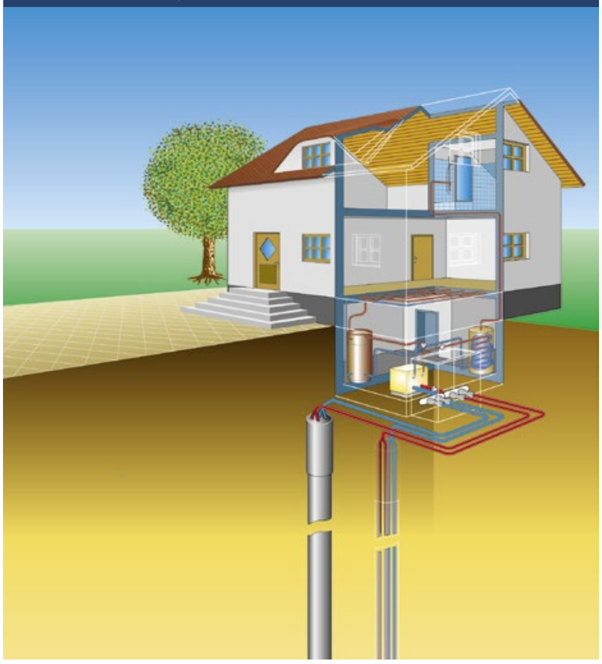
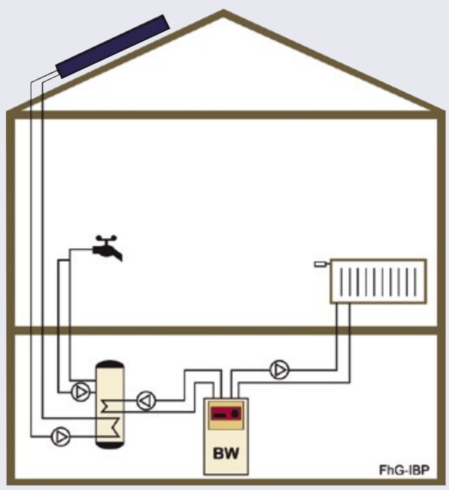


Figure 11: Schematic presentation of a heating system with a solar hot water supply



Ventilation

Controlled residential ventilation systems with heat recovery units can significantly reduce ventilation heat losses. Heat recovery rates of over 80 percent are not uncommon for today's modern systems. However, rising recovery rates usually increase electricity consumption for fans. Mechanical ventilation systems must therefore be designed very precisely, otherwise the energy consumption of the fans can exceed any energy gains, for example if piping is very complicated and has an unsuitable cross-section.

Lighting

Compact fluorescent lamps with integrated ballasts and LED lamps are more efficient than incandescent or halogen lamps. Whereas incandescent lamps convert only 5 percent of the electricity used into light and over 95 percent into heat, the light yield from compact fluorescent lamps and LED lamps is four to five times higher than incandescent lamps.

Residential LED lighting

Bright interior surfaces also result in better ambient lighting and thus in lower energy demand than dark surfaces. The design of interior surfaces can have a relatively strong influence on the energy consumption of lighting, as can the choice of lighting type. Task-related lighting solutions (in kitchens or studies, for example) can also be particularly effective. This involves using powerful light only for a specific part of the room (for example, a reading lamp) and keeping the lighting level lower in the rest of the space. It is also advisable to consider using lighting management systems (for example, presence detection) in hallways, basements and for outdoor lighting.

Building automation/Smart metering

Smart meters can provide users with better information and a clearer overview of costs, which in turn raises their awareness of their household electricity consumption. They should be standard fittings in an Efficiency House Plus. Building automation systems are also beginning to establish themselves on the market. They connect household appliances in an in-house (wireless) network to a central control unit and can also be used for smart heating control. However, the focus here is on convenience rather than energy saving. It is imperative to check the power rating and energy demand of building automation systems and their add-on components. A power rating of more than 50 Watts should be avoided since its energy use will cancel out any savings!

! Tip

Check the power rating of your ventilation system. It should be lower than 50 Watt per housing unit. Each additional Watt of performance requires around 10 kilowatt hours of electrical power a year.

Household appliances

The average amount of electricity used by Germany's approx. 41 million households for household processes and lighting (not counting space and water heating) is currently 2,615 kilowatt hours per year (30 kilowatt hours per square metre per year), and the trend is falling slightly.[1] Of this total, around 36 percent is accounted for by household processes (cooking, drying laundry and ironing), approximately 10 percent by lighting and the remaining 54 percent by household appliances and communication devices. About 13 percent of households' electricity consumption is accounted for by stand-by losses, especially from household appliances and communication devices.

Household appliances

In addition to good performance characteristics, low energy and water consumption are important criteria when choosing an electrical appliance. Since 1996, the energy label (energy efficiency label, EU label) has provided precise information on those aspects. Such information for consumers is a statutory requirement and is regulated in Germany by the Ordinance on Energy Consumption Labelling. Tumble dryers have the highest level of consumption, but also the greatest savings potential, followed by refrigerators and freezers.

Labelling is mandatory for the following household appliances:

- → Refrigerators/freezers
- → Washing machines
- → Washer-dryers
- → Dishwashers
- → Electric ovens

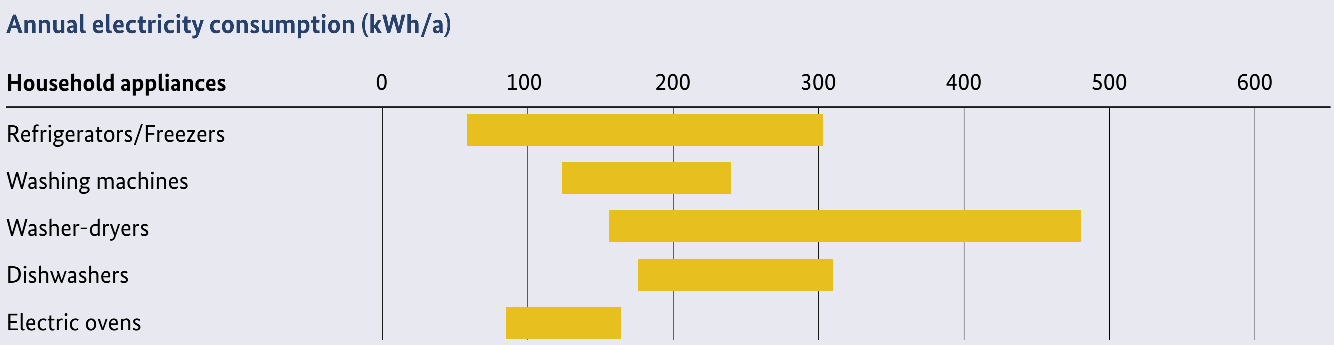
Stand-by consumption

This is the electricity used when an appliance is in stand-by mode. In other words, it is electricity that is consumed even when the appliance is not being used. With stand-by consumption it is important to remember the old adage that "every little counts". Each individual appliance makes hardly any difference but all appliances together definitely do. Consistently ensuring that appliances are not left in stand-by mode can save households up to 350 kilowatt hours of electricity a year.

! Tip

Households equipped with highly efficient household appliances (top runners) and lighting systems use roughly 50 percent of the amount of electricity needed by comparable households with standard appliances.

Figure 12: Range of electricity consumption of selected household appliances: Top runners 2017[2] compared to normal appliances



1 Federal Environment Agency, 2015 Environment Data (Daten zur Umwelt 2015)
2 www.ecotopten.de

"Plus"

Building an Efficiency House Plus involves integrating renewable energy generation systems. These usually take the form of photovoltaics or, more rarely, domestic wind turbines. Alternatively, surplus heat gains from waste heat or solar thermal systems that are fed into local or district heating systems can be included as energy credits. Depending on what fuel they use, cogeneration heating plants, fuel cells or micro CHP units may be eligible for a credit for primary energy, but in terms of final energy, they cannot count towards a net energy gain.

Photovoltaics

Solar energy is converted into direct current by solar cells connected to solar modules. Generated electricity can be used directly on site, stored in accumulators (batteries) or fed into the public grid. To use the energy in the power grid, an inverter is needed to convert the direct current voltage into alternating current voltage. Depending on the system used, photovoltaic modules are made of monocrystalline, polycrystalline or thin-film module (CIS/CIGS (copper-indium-gallium-die-selinide)) solar cells. The efficiency of monocrystalline photovoltaic modules is between 14 and 24 percent.

Efficiency House Plus, Pfuhler Strasse 12-14, Neu-Ulm, with photovoltaics integrated into the roof

The polycrystalline modules have an efficiency of between 13 and 18 percent, while thin-filmed modules have an efficiency of between 13 and 16 percent.

The rated output (maximum output) of a solar module is specified in W_p (Watt peak) and is determined under standard test conditions in the lab. As well as the efficiency of solar modules, another important parameter is the system performance factor. It indicates how much of the theoretically possible electricity yield is actually available for use, including losses caused by conversion in the inverter, the length of the electricity cables, shading and possibly other factors.

The system performance factor of a photovoltaic system should generally be at least 70 percent. Optimised systems achieve performance factors of up to 90 percent. When fitted, under ideal installation conditions, the electricity yield of a one-kilowatt-peak photovoltaic system (corresponding to an eight to ten square-metre surface) in Germany can deliver an annual yield of between 700 and 1,100 kilowatt hours depending on the location.

Wind turbines

In urban settings it rarely makes sense to site a wind turbine close to a building. Domestic wind turbines primarily serve to meet a user's own electricity needs and are only economically effective if they do that! Planning permission is usually only granted on provision of evidence that the applicants use at least 50 percent of the annual yield themselves.

! Tip

To ensure a positive result at the end of the year, plan your photovoltaic system to be 10 to 20 percent larger than is required to cover the energy demand for the technical building systems and household appliances.

Openness towards technology and diverse planning

The example of an average single-family home is used below to demonstrate how the Efficiency House Plus standard can be achieved using different technologies. The building cubature represents the tested building, which is used by software developers to make comparative calculations in accordance with DIN V 18599, with the following typical values:[3]

Characteristic values
- → Heated net floor area: 150.8 square metres
- → Roof area South/North: 71 square metres

U-values (in Watt per square metre per Kelvin)
- → Exterior wall: 0.11
- → Roof: 0.11
- → Top floor ceiling: 0.11
- → Basement ceiling: 0.12
- → Basement exterior wall: 0.28
- → Window: 0.80
- → Roof window: 1.20

(The above U-values are exemplary and represent good thermal insulation. Planning may result in different implemented U-values, in which case the efficiency of the systems technology must be adapted accordingly.)

The documented archetype building was equipped with different exemplary systems technologies to demonstrate the standard's versatile planning possibilities and openness to technology. The calculations show the

Figure 13: Archetype building: Single-family home

3 Source: BBSR, Erarbeitung einer Software-Lösung für die Anwendung der DIN V 18599 für den Wohnungsbau für Zwecke der Vergleichsrechnung für Förderfälle Akz 10.08.17.7-13.19

required size of the photovoltaic area for the selected technical system (moderate ventilation, polycrystalline silicon) to conform to the Efficiency House Plus standard and displays the information in the table below.

For instance a building equipped with a condensing gas boiler, a solar hot water system and a ventilation system with heat recovery (Version 1) requires around 130 square metres of photovoltaic modules to substitute the final energy demand. This requires extra suitable surfaces on the property in addition to the remaining space on the southern roof (garage etc.). When installing heat pumps to produce heat (Versions 2 and 3), the area of the southern roof alone is sufficient. The size of the photovoltaic system can be further reduced using a ventilation system with heat recovery (Version 3) compared to a building with natural ventilation (Version 2).

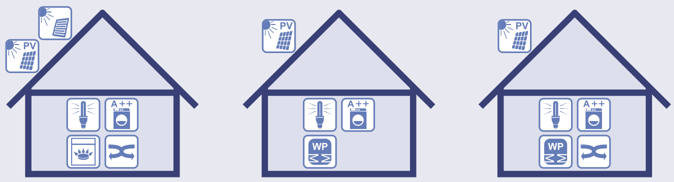
The comparative calculations show that a highly energy-efficient building is required to complement a photovoltaic system and thereby achieve an Efficiency House Plus standard. On their own, neither the installation of a photovoltaic system nor the implementation of an energy-efficient building will achieve that aim. The desired Efficiency House Plus standard can only be achieved by combining the two measures.

With respect to current underlying economic factors, such as low feed-in tariffs and the current high electricity costs, an improvement in the energy-efficiency of the building to reduce the size of the photovoltaic system is recommended despite the falling cost of photovoltaic systems. Furthermore, it is advisable to achieve as high self-use rates as possible for the self-generated electricity, e.g. by using batteries.

Figure 14: Comparative calculation to determine the required size of the photovoltaic system for a residential building

KEY

- Solar thermal energy
- Photovoltaics
- Lighting
- Electrical appliances
- Gas condensing boiler
- Ventilation system with heat recovery
- Heat pump



Gas condensing boiler
Apartment ventilation
80% heat recovery
Solar hot water

Exterior air heat pump
Window ventilation

Exterior air heat pump
Apartment ventilation
80% heat recovery

	Version 1:	Version 2:	Version 3:
Without taking photovoltaics (PV) into account			
Final energy demand [kWh/(m$^2_{\text{Heated net floor area}}$·a)]			
Heating, hot water, ventilation, auxiliary energy	58	24	21
Household and lighting	20	20	20
Overall	**78**	**44**	**41**
Primary energy demand (without PV) [kWh/(m$^2_{\text{Heated net floor area}}$·a)]	**98**	**79**	**73**
Taking photovoltaics (PV) into account			
Required photovoltaic area [m^2]	**128**	**56**	**51**
Final energy demand [kWh/(m$^2_{\text{Heated net floor area}}$·a)]	**-0.1**	**-0.8**	**-0.3**
Primary energy demand [kWh/(m$^2_{\text{Heated net floor area}}$·a)]	**-41.8**	**-1.3**	**-0.4**
Self-use rate [%]	**32**	**59**	**62**

Research

Efficiency House Plus: A federal initiative

Since 2011, the principle of the Efficiency House Plus has proven its practical applicability in a research funding programme. Various research institutions subjected 37 buildings to an intensive monitoring programme. Furthermore, the Fraunhofer Institute for Building Physics (IBP) carried out a cross-evaluation of all results. Key performance data included the recording and evaluation of heating energy consumption, electricity consumption, electricity generation, the self-use rate of renewable energy, primary energy consumption and comfort parameters.

In addition to a cross-evaluation of all projects with respect to performance data and fulfilment of the Efficiency House Plus standard in the practical test, the defined calculation values for electricity consumption of lighting, household appliances and household processes were validated.

The pilot projects have also been assessed in an accompanying sociological programme.

The results are being used to improve energy management of modern buildings and continuously develop the necessary components for energy-efficient building envelopes, as well as the use of renewable energy sources. The buildings were tested and evaluated in real, i.e. user-occupied conditions. All 37 projects were occupied by the summer of 2016 and had completed a two-year monitoring period by the autumn of 2018. The erected buildings include single-family homes, semi-detached houses and apartment buildings with between 6 and 74 housing units.

Further information on the "Efficiency House Plus" network is available at: *www.forschungsinitiative.de/effizienzhaus-plus*

Figure 15: Developing the Efficiency House Plus standard from a prototype to a district

From a research pilot project to an information centre

The first state-owned Efficiency House Plus with electric mobility represents the cornerstone of the research programme and network that has evolved out of it. The pilot building designed by Professor Werner Sobek is located at Fasanenstrasse 87a in 10723 Berlin-Charlottenburg, Germany and was opened on 7 December, 2011 by the German Chancellor Dr. Angela Merkel.

Usage

The research building was home to two test families, who lived there consecutively for a period of one year each. In between those periods, it provided over 30,000 interested parties with comprehensive public information and event programmes on energy-efficient buildings. Since 2017, the building has been reopened to the public as an information and competence centre for future building. It invites people to view, gather information and participate in shaping future building, acting as a platform for networking meetings, presentations, events and webinars.

Concept

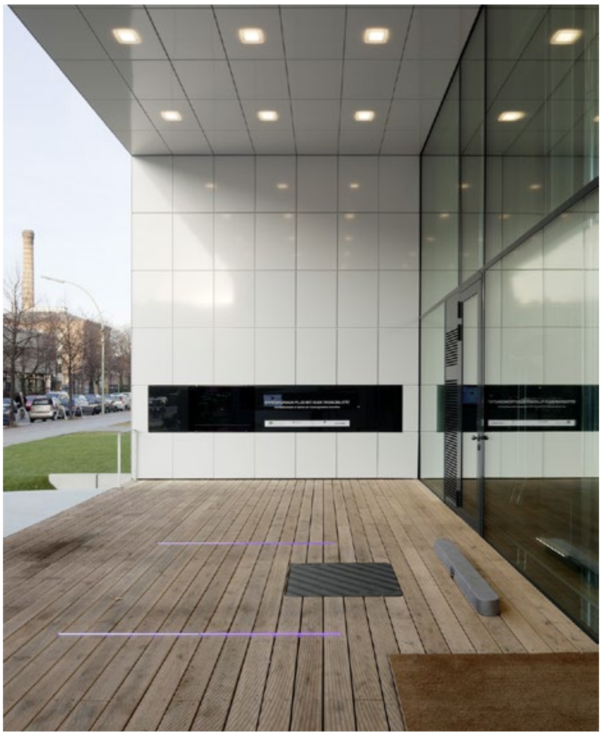
The detached house originally comprised about 130 square metres of living space and was designed for a family of four. The “glass showcase” in front of the house was designed to present information on energy-saving construction and for parking and charging electric vehicles (e-cars and e-bikes). The building’s load-bearing “energy core” is situated between the two-storey living space and the “showcase”. It houses all the technical building systems and the wet rooms.

Planning

The temporary building was designed to be energy-efficient, sustainable and flexibly usable, as well as being very comfortable. Today, it is clear that all of those demands have been fulfilled. One element of planning the Efficiency House Plus was dynamically coupled systems and building simulations. They included the physical properties of the building envelope, the intended use, expected user behaviour and local climate data.

Front side...

...and the “garden side” of the pilot project building in Berlin

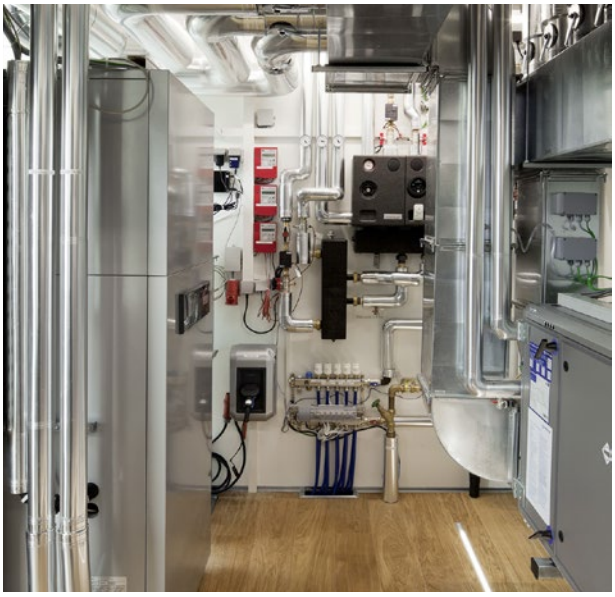


Show-case window with an entrance area

View of a children's room on the upper level

View of the parents' bedroom on the upper level

View of the ground floor dining area



View of the utilities room

View of the ground floor living room

However, in addition to energy aspects, the project was also aimed at providing answers to questions of sustainability. The building was awarded the Gold Certificate in accordance with the criteria of Assessment System for Sustainable Building (BNB). A second aim is to study the complete recyclability of this highly energy-efficient house.

Today

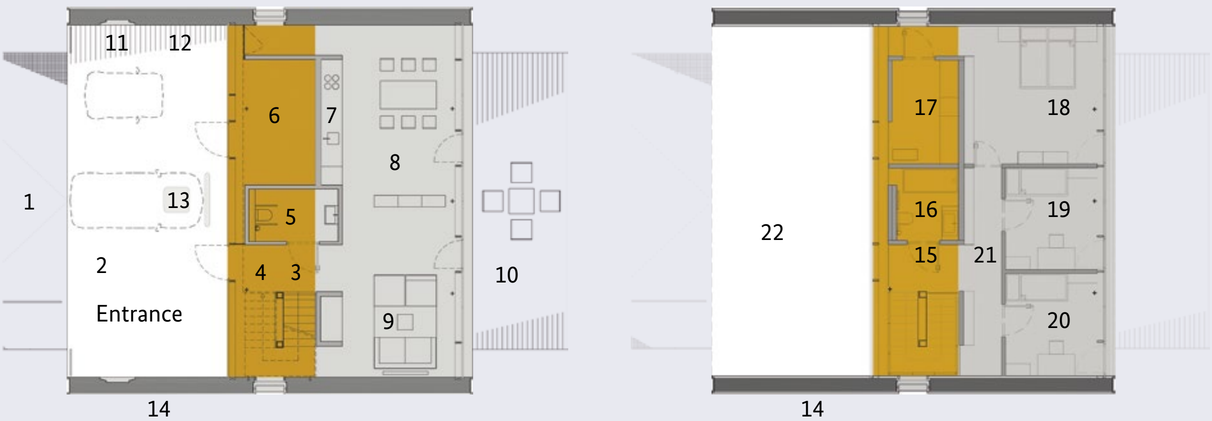
In 2016, the building was modified and designed to be barrier-free. It received external stairs to fulfil fire-safety regulations and also a larger exhibition space on the upper level by dismantling partition walls. Following the conversion period, the building was reopened to the public as the "Information and Competence Centre for Future Building". In its new function as a think-tank, it is intended to demonstrate innovation in the building sector and exchange knowledge in the field of building-related research, thereby leading the way towards a climate-neutral society by 2050 in the field of buildings.

Webinars on the "Efficiency House Plus":
- Independent of the location
- Expertise on various themes of building in the future
- Online Q&A sessions

Source: ZEBAU GmbH

Further information at *www.forschungsinitiative.de/effizienzhaus-plus/dialog-zum-bauen-der-zukunft*

Figure 16: Floor plan of the research pilot project (2011-2017)



Ground floor plan, residential uses

First floor plan, residential uses

1 Ramp
2 Show-case
3 Entrance area
4 Cloakroom
5 Barrier-free WC
6 Building systems
7 Kitchen
8 Dining
9 Living
10 Terrace
11 Information display and screen
12 Conductive charging
13 Inductive charging
14 PV façade
15 Stairs/hall
16 Bathroom/WC
17 Utilities
18 Parents
19 Child 1
20 Child 2
21 Hall
22 Entrance porch

The Efficiency House Plus Network

The Efficiency House Plus network consists of all active institutions accompanying the funded pilot projects and supplementary activities by the research initiative. In addition to funding bodies and recipients, as well as supervising architects, engineers and research institutes, the network now consists of well over 150 partners in the building and system sectors, who successfully multiply the building concepts on the market. Promising ideas, technologies and materials can thereby be implemented more quickly in practice. In the medium term, the aim is to help the Efficiency House Plus model to play a stronger role on the market and build it at even more attractive prices. The network consist of the following categories:

Single-family and semi-detached houses

The overwhelming majority of the research project's demonstration buildings so far are single-family and semi-detached houses. These are either used as show houses as in the case of "FertighausWelt" in Cologne/ Frechen and in Bremen or lived in by test families for a set period as in the cases of Berlin, Brieselang, Deggendorf, Burghausen and Hamburg. All the other buildings are permanently inhabited by families of between two and five people.

Apartment buildings

Whereas in the early years, concept implementation focused on detached houses, over the coming years the possibility of transferring the design method to apartment buildings will be trialled. To this end, large housing complexes have been built in Berlin and Frankfurt as Efficiency House Plus projects. Their ratio of roof area to façade area is different from a detached house. Façade areas therefore have to be increasingly used for generating renewable energy.

Refurbished existing buildings

The greatest challenge to Germany's energy transition is its existing building stock. The research initiative is currently testing and evaluating two housing rows in Neu-Ulm, along with two single-family homes in Hamburg and Darmstadt. It is possible to achieve the Efficiency House Plus standard, while ensuring a high level of comfort, through appropriate planning and building measures in the fields of floor plan design and improving both building envelope and the technical building systems.

International projects

The first pilot project in Japan was erected in 2013. Its aim was to demonstrate that a negative energy balance of a building is even possible in Japan in special user and climate-specific circumstances. Since the autumn of 2017, there has been international cooperation with the Czech Republic, where possible pilot projects are being developed for implementation.

Educational buildings

In addition to residential buildings, other types of buildings are also suitable to be built and run as Efficiency Houses Plus. This is particularly true of schools and other educational buildings, which use the most energy during the daytime, when power-generating systems provide electricity. Seven buildings are currently under construction as part of a separate funding programme initiated in 2015.

Solutions on a district level

If the inhabitants of residential areas unite to form energy communities, the locally generated renewable energy can often be used much more efficiently than is possible with single buildings. Estate solutions that follow a holistic energy concept, including decentralised generation, the intelligent networking of structures and the storage and use of renewable energy, are therefore of particular interest. The FertighausWelt Wuppertal is testing this approach with 19 detached houses that conform to Efficiency House Plus standards.

All projects are presented at:
www.forschungsinitiative.de/effizienzhaus-plus

Final reports at: *www.forschungsinitiative.de/effizienzhaus-plus/forschung/abschlussberichte-der-modellvorhaben/*

Figure 17: Demonstration buildings of the federal "Efficiency House Plus" funding programmes

- Single-family and semi-detached houses
- Apartment buildings
- Renovated existing buildings
- Educational buildings
- District

Single-family/semi-detached (new) houses

Berlin Federal pilot building
Heated net floor area: 149 m^2
Air-to-water heat pump, PV = 22.1 kW_{Peak}
Battery 40.0 kWh

Final energy surplus (kWh/a):

Prediction:	9,633
1^{st} year of monitoring:	906
2^{nd} year of monitoring:	5,530

Brieselang Elbe-Haus M1 Massivhaus
Heated net floor area: 137 m^2
Air-to-water heat pump, PV = 9.3 kW_{Peak}
Solar thermal 10 m^2, battery 24.0 kWh

Final energy surplus (kWh/a):

Prediction:	3,921
1^{st} year of monitoring:	1,454
2^{nd} year of monitoring:	1,495

Bremen HO Immobilien & Baukonzepte
Heated net floor area: 202 m^2
Brine-to-water heat pump
PV = 8.7 kW_{Peak}

Final energy surplus (kWh/a):

Prediction:	546
1^{st} year of monitoring:	–
2^{nd} year of monitoring:	2,213

Leonberg-Warmbronn Haus Berghalde
Heated net floor area: 260 m^2
Water-to-water heat pump, PV = 15.0 kW_{Peak}
Batteries 7.0 kWh + 20.0 kWh

Final energy surplus (kWh/a):

Prediction:	6,947
1^{st} year of monitoring:	3,160
2^{nd} year of monitoring:	6,096

Münnerstadt
Heated net floor area: 327 m^2
Brine-to-water heat pump, PV = 23.7 kW_{Peak}
Battery 11.0 kWh

Final energy surplus (kWh/a):

Prediction:	12,529
1^{st} year of monitoring:	11,710
2^{nd} year of monitoring:	13,399

Eußenheim
Heated net floor area: 288 m^2
Brine-to-water heat pump, ice storage 3,000 l
PV = 13.4 kW_{Peak}, Solar thermal 11.0 m^2

Final energy surplus (kWh/a):

Prediction:	8,816
1^{st} year of monitoring:	4,439
2^{nd} year of monitoring:	5,760

Key to technologies:

- Heat pump
- Photovoltaics
- Solar thermal energy
- Ventilation system with heat recovery
- Electric vehicle charging station
- Ice storage
- Battery storage

Single-family and semi-detached houses

Cologne HUF HAUS Green[r]evolution
Heated net floor area: 283 m^2
Brine-to-water heat pump, PV = 14.5 kW_{Peak}
Battery 13.2 kWh

Final energy surplus (kWh/a):	
Prediction:	2,980
1st year of monitoring:	-2,377
2nd year of monitoring:	1,886

Cologne SchwörerHaus Plan 550
Heated net floor area: 139 m^2
Air-to-air heat pump, PV = 11.0 kW_{Peak}
Solar thermal 8.4 m^2

Final energy surplus (kWh/a):	
Prediction:	2,263
1st year of monitoring:	4
2nd year of monitoring:	1,960

Cologne Bien-Zenker Concept-M
Heated net floor area: 194 m^2
Air-to-air heat pump + brine-to-water heat pump
PV = 16.3 kW_{Peak}, battery 8.4 kWh

Final energy surplus (kWh/a):	
Prediction:	4,957
1st year of monitoring:	1,235
2nd year of monitoring:	2,997

Cologne Fingerhaus VIO 400
Heated net floor area: 179 m^2
Air-to-water heat pump
PV = 8.5 kW_{Peak}

Final energy surplus (kWh/a):	
Prediction:	349
1st year of monitoring:	-1,388
2nd year of monitoring:	703

Cologne WeberHaus Generation 5.0
Heated net floor area: 159 m^2
Air-to-air heat pump, PV = 8.8 kW_{Peak}
Battery 3.5 kWh

Final energy surplus (kWh/a):	
Prediction:	2,067
1st year of monitoring:	-1,097
2nd year of monitoring:	-198

Cologne LUXHAUS frame
Heated net floor area: 193 m^2
Brine-to-water heat pump
PV = 9.9 kW_{Peak}

Final energy surplus (kWh/a):	
Prediction:	1,448
1st year of monitoring:	-1,166
2nd year of monitoring:	-1,941

Key to technologies:

- Heat pump
- Photovoltaics
- Solar thermal energy
- Ventilation system with heat recovery
- Electric vehicle charging station
- Ice storage
- Battery storage

Single-family and semi-detached houses

Stelzenberg ecolodge
Heated net floor area: 113 m²
Brine-to-water heat pump, ice storage 1,050 l
PV = 8.5 kW_{Peak}, solar thermal 14.0 m²

Final energy surplus (kWh/a):

Prediction:	1,920
1st year of monitoring:	2,774
2nd year of monitoring:	3,594

Schwabach
Heated net floor area: 244 m²
Air-to-air heat pump
PV = 14.4 kW_{Peak}

Final energy surplus (kWh/a):

Prediction:	2,648
1st year of monitoring:	6,868
2nd year of monitoring:	6,186

Weifa
Heated net floor area: 251 m²
Air-to-water heat pump, PV = 30.0 kW_{Peak}
Battery 14.4 kWh

Final energy surplus (kWh/a):

Prediction:	15,125
1st year of monitoring:	18,865
2nd year of monitoring:	19,495

Burghausen Schlagmann/BayWa
Heated net floor area: 176 m²,
Water-to-water heat pump, seasonal storage 48,000 l,
PV = 10.5 kW_{Peak}, solar thermal 51 m², battery 10.8 kWh

Final energy surplus (kWh/a):

Prediction:	5,961
1st year of monitoring:	2,239
2nd year of monitoring:	1,727

Unterkirnach
Heated net floor area: 282 m²
Brine-to-water heat pump, PV = 26.2 kW_{Peak}
Battery 12.0 kWh

Final energy surplus (kWh/a):

Prediction:	11,003
1st year of monitoring:	7,574
2nd year of monitoring:	9,666

Lüneburg
Heated net floor area: 129 m²
Electric direct heating
PV = 12.6 kW_{Peak}

Final energy surplus (kWh/a):

Prediction:	3,424
1st year of monitoring:	7,258
2nd year of monitoring:	8,152

Key to technologies:

- Heat pump
- Photovoltaics
- Solar thermal energy
- Ventilation system with heat recovery
- Electric vehicle charging station
- Ice storage
- Battery storage
- Long-term storage
- Direct electric heating

Single-family and semi-detached houses

Bad Homburg Pro Klimahaus
Heated net floor area: 169 m²
Air-to-water heat pump
PV = 9.4 kW$_{Peak}$

Final energy surplus (kWh/a):

Prediction:	711
1st year of monitoring:	-9,508
2nd year of monitoring:	-664

Kassel
Heated net floor area: 280 m²
Brine-to-water heat pump, PV = 15.8 kW$_{Peak}$
Battery 6.3 kWh

Final energy surplus (kWh/a):

Prediction:	3,118
1st year of monitoring:	2,366
2nd year of monitoring:	2,470

Bremen Solar Plus Haus
Heated net floor area: 166 m²
Brine-to-water heat pump, PV = 10.8 kW$_{Peak}$
Solar thermal 10.0 kWh

Final energy surplus (kWh/a):

Prediction:	938
1st year of monitoring:	-201
2nd year of monitoring:	391

Buchen-Hollerbach
Heated net floor area: 230 m²
Brine-to-water heat pump,
PV = 12.4 kW$_{Peak}$

Final energy surplus (kWh/a):

Prediction:	1,463
1st year of monitoring:	4,411
2nd year of monitoring:	3,687

Deggendorf
Heated net floor area: 167 m²
Buffer storage 9,200 l PV = 7.8 kW$_{Peak}$
Solar thermal 49.0 m², battery 8.0 kWh

Final energy surplus (kWh/a):

Prediction:	1,807
1st year of monitoring:	2,820
2nd year of monitoring:	1,389

Poing/Grub Baufritz "Alpenchic"
Heated net floor area: 248 m²
PV = 12.6 kW$_{Peak}$, battery 3.7 kWh,
fuel cell 20 kW$_{thermal}$

Final energy surplus (kWh/a):

Prediction:	236
1st year of monitoring:	-5,816
2nd year of monitoring:	-5,688

Key to technologies:

Heat pump
Photovoltaics
Solar thermal energy
Ventilation system with heat recovery
Electric vehicle charging station
Ice storage
Battery storage
Wind turbine
Fuel cell

Single-family and semi-detached houses

Riedstadt-Crumstadt
Heated net floor area: 183 m²
Brine-to-water heat pump
PV = 12.0 kW_{Peak}

Final energy surplus (kWh/a):

Prediction:	2,486
1st year of monitoring:	7,413
2nd year of monitoring:	7,457

Stuttgart Aktivhaus B10
Heated net floor area: 82 m²
Water-to-water heat pump, PV = 10.4 kW_{Peak}
Battery 11.0 kWh

Final energy surplus (kWh/a):

Prediction:	–
1st year of monitoring:	1,408
2nd year of monitoring:	-2,316

Key to technologies:

- Heat pump
- Photovoltaics
- Solar thermal energy
- Ventilation system with heat recovery
- Electric vehicle charging station
- Ice storage
- Battery storage

Apartment buildings (new)

Frankfurt am Main Aktiv-Stadthaus
Heated net floor area: 6,640 m², units: 74
Water-to-water heat pump, PV = 370.0 kW_{Peak}
Battery 250.0 kWh

Final energy surplus (kWh/a):	
Prediction:	43,622
1st year of monitoring:	2,732
2nd year of monitoring:	-5,046

Frankfurt am Main Riedberg
Heated net floor area: 1,599 m², units: 17
Brine-to-water HP, PV = 95.2 kW_{Peak}, Battery 60.0 kWh*

Final energy surplus (kWh/a):	
Prediction:	24,524
1st year of monitoring:	-20,149
2nd year of monitoring:	-3,241

** HP = heat pump*

Berlin LaVidaVerde
Heated net floor area: 1,207 m², units: 18
Air-to-water heat pump, PV = 78.1 kW_{Peak}

Final energy surplus (kWh/a):	
Prediction:	3,522
1st year of monitoring:	2,986
2nd year of monitoring:	-17,872

Tübingen Licht + Luft
Heated net floor area: 891 m², units: 9
District heat, PV = 36.0 kW_{Peak}

Final energy surplus (kWh/a):	
Prediction:	< 0*
1st year of monitoring:	-21,486
2nd year of monitoring:	-18,315

Frankfurt am Main Cordierstrasse
Heated net floor area: 1,170 m², units: 17
Cogeneration unit, PV = 49.7 kW_{Peak}
Solar thermal 40.0 m²

Final energy surplus (kWh/a):	
Prediction:	6,533*
1st year of monitoring:	-23,879
2nd year of monitoring:	-25,838

Geisenheim Internatsschule Hansenberg
Heated net floor area: 331 m², units: 4
Air-to-water heat pump, PV = 18.9 kW_{Peak}

Final energy surplus (kWh/a):	
Prediction:	4,816
1st year of monitoring:	2,426
2nd year of monitoring:	3,851

Bischofswiesen EFH-Plus in den Bergen
Heated net floor area: 628 m², units: 6
Water-to-water heat pump, PV = 41.6 kW_{Peak}
Battery 50.0 kWh

Final energy surplus (kWh/a):	
Prediction:	10,885
1st year of monitoring:	17,601
2nd year of monitoring:	13,143

* Negative final energy balance not achieved. Building-specific adaptation of the Efficiency House Plus standard by funding body.

Key to technologies:

- Heat pump
- Photovoltaics
- Solar thermal energy
- Ventilation system with heat recovery
- Electric vehicle charging station
- Ice storage
- Battery storage
- Pellet boiler
- Local and district heating
- Cogeneration unit / partially district-related

Refurbished existing buildings

Neu-Ulm Pfuhler Strasse 4 und 6
Heated net floor area: 600 m², units: 10
Brine-to-water heat pump, PV = 45.8 kW_{Peak}

Final energy surplus (kWh/a):

Prediction:	8,824
1st year of monitoring:	19,753
2nd year of monitoring:	18,781

Neu-Ulm Pfuhler Strasse 12 und 14
Heated net floor area: 678 m², units: 8
Brine-to-water heat pump, PV = 31.2 kW_{Peak}

Final energy surplus (kWh/a):

Prediction:	2,022
1st year of monitoring:	-8,730
2nd year of monitoring:	-9,198

Darmstadt Energy+ Home
Heated net floor area: 185 m²
Air-to-water heat pump
PV = 12.6 kW_{Peak}

Final energy surplus (kWh/a):

Prediction:	1,930
1st year of monitoring:	266
2nd year of monitoring:	-367

Hamburg VELUX LichtAktiv Haus
Heated net floor area: 132 m²
Brine-to-water heat pump, window ventilation,
PV = 8.8 kW_{Peak}, solar thermal 19.8 m²

Final energy surplus (kWh/a):

Prediction:	1,539
1st year of monitoring:	-2,155/2015
2nd year of monitoring:	-1,793/2016

Key to technologies:

- Heat pump
- Photovoltaics
- Solar thermal energy
- Ventilation system with heat recovery
- Electric vehicle charging station
- Ice storage
- Battery storage
- Free ventilation

Efficiency House Plus international

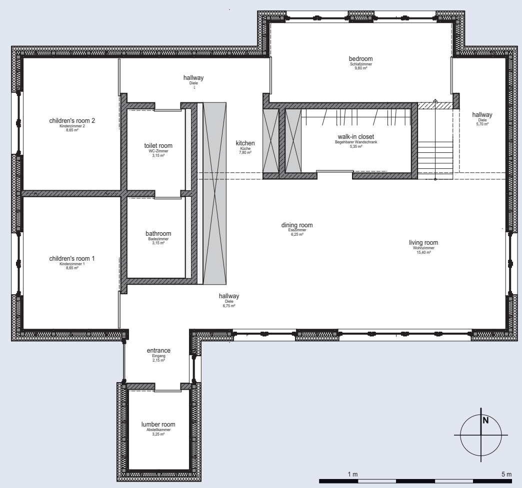
In 2013, the Efficiency House Plus approach was implemented on an international level with a pilot project in Japan. Special attention had to be paid to the specific conditions with respect to the users and the climate, as well as aspects of construction.

Compared to average single-family households in Germany, Japanese households consume around three times as much hot water. Furthermore, a cooling system is essential since the exterior climate at the building's location in Takamatsu, on the coast of Shikoku island (southwest Japan, Kagawa Prefecture), is hot and humid. Traditional Japanese building methods do not use air-tight building envelopes, as required by the Efficiency House Plus.

Implementation of the planning and technical details posed a great challenge, which was mastered with a great deal of new insight. The Öko-Zentrum Nordrhein-Westfalen provided expert supervision and implemented the long-standing cooperation between the Building Ministries of Japan and Germany. In Japan, the project attracted a great deal of attention both in politics and in the field of specialist research. The planning and completion period came after the Fukushima reactor disaster, when Japan experienced strong energy-saving pressure in view of the events. Numerous delegations, including from the Tokyo Building Ministry, visited the house, which contributed to the introduction of a law on minimum standards for housing.

The building was constructed with a timber frame and has a heated net floor area of approximately 100 square metres. It was planned as a low-energy house from the outset. Special attention was paid to the orientation, insulation quality, construction and efficient systems technology. A heat pump is used for heating (4.0 kilowatt) and cooling (2.8 kilowatt) by means of radiators and cooling ceilings. The hot water supply is supported by a solar thermal system (5.85 square metres). A central ventilation system with heat recovery supplies the entire building with fresh air. A 70 square-metre photovoltaic system with monocrystalline modules is installed on the south-facing roof with an incline of 35 degrees. It has a rated output of heat 10.8 kilowatt peak. In 2017, the building produced a power surplus of 6,023 kilowatt hours.

Figure 18: Floor plan, Efficiency House Plus in Takamatsu, Japan



Japan Takamatsu
Heated net floor area: 96,7 m²,
Air-to-water heat pump, PV = 10.8 kW_{Peak}
Solar thermal 5.85 m²

Final energy surplus (kWh/a):

Prediction:	1,199
1st year of monitoring:	6,023

Key to technologies:

- Heat pump (WP)
- Photovoltaics (PV)
- Solar thermal energy
- Ventilation system with heat recovery

Educational buildings

Educational buildings that conform to the Efficiency House Plus standard are among the most energy-efficient buildings of all. The funding programme "Efficiency House Plus Standard Educational Buildings" involves the study of eleven (sub-)projects until 2024, to achieve the aim of a negative energy demand in practice, while investigating which insight from these pilot projects can be applied to planning educational buildings in the future.
A total of seven building owners have assumed the challenge of erecting an educational building that produces more energy than it needs for its operation and use, measured on an annual basis. The scope of building tasks is great, ranging from an extension to a primary school in Giebelstadt near Würzburg to the new development of an entire faculty building for the Ulm University of Applied Sciences. In addition to a further research and seminar building (Ansbach University of Applied Sciences, Feuchtwangen Campus), two vocational schools (Hockenheim and Mühldorf am Inn) and two high schools (Kaufbeuren and Neutraubling) are also participating in the funding programme. The two high schools involve the special aspect of initially building an extension, before subsequently refurbishing the existing 1970s buildings according to Efficiency House Plus standards. Following their completion, all projects are subject to a 24-month period of monitoring, to optimise the buildings and verify fulfilment of energy targets.

Building form

The most important strategic steps for the energy performance of a building are already carried out during the design stage, where the two classic parameters of orientation and compactness are of varying importance.

Since a low building-envelope area-to-volume ratio decreases heating energy requirements, new buildings were consistently designed in a more compact way in the funding programme than the corresponding existing buildings. Six out of seven buildings have flat roofs that can be entirely used for energy-generating systems. South-facing glazed façades that are sensible in housing are not as essential in educational facilities. However, shading elements are especially important for classrooms, as is the necessity to prevent overheating during the summer, thereby limiting the use of solar heat gains.

Building envelope

All projects use highly thermally insulated building envelopes. In addition to building elements with low U-values, attention is paid to prevent thermal bridges wherever possible. The planned refurbishment of the two existing buildings will also include new façades. Compromises must only be made in the field of floor slabs, since only interior insulation is possible for the existing buildings.

Technical building systems

All projects use heat pumps to cover their basic heating requirements, although highly contrasting concepts were pursued for their design and operation. One can distinguish between two basic methods, either with a central, high-performance system or with smaller, decentralised heat pump systems that are connected to each other. Wherever possible, local resources are used. For instance, the reversible heat pumps for the schools situated near rivers in Neutraubling and Mühldorf am Inn use groundwater not only as a source of heat, but also for cooling in the summer. Local and district heating is partially used to cover peak load periods.

All projects have controllable ventilation systems. Three schools (in Kaufbeuren, Neutraubling and Giebelstadt) have decentralised, hydraulically connected ventilation systems with ceiling sails for heating/cooling. The result is an innovative system that can cope with only one room-by-room control that is already integrated into the ventilation system.

User electricity

In addition to electricity consumption in accordance with EnEV, when calculating the energy balance, Efficiency House Plus educational buildings are set a predefined flat user electricity consumption of 10 kilowatt hours of final energy per square metre of heated net floor area and year (or 15 kilowatt hours per square metre of heated net floor area and year, if highly energy-efficient appliances are not exclusively used).

Due to the greatly varying uses and equipment of the projects in the funding programme, the user electricity consumption of some buildings was forecast in detail in advance based on the connection load of all devices. In the case of the new university construction in Ulm, which accommodates the highly energy-intensive Faculties of Electrical Engineering and Information

Hockenheim LOP school
Heated net floor area: 3,766 m^2
Brine-to-water heat pump, ice storage 82 m^3, PV = 204.5 kW_{Peak}, solar thermal 40 m^2

Final energy surplus (kWh/a):	
Prediction:	15,850
1st year of monitoring:	–
2nd year of monitoring:	–

Neutraubling (1.BA) High school
Heated net floor area: 3,545 m^2
Water-to-water heat pump, PV = 71.6 kW_{Peak}

Final energy surplus (kWh/a):	
Prediction:	401
1st year of monitoring:	–
2nd year of monitoring:	–

Mühldorf am Inn (1.BA) Vocational school
Heated net floor area: 5,122 m^2
Brine-to-water heat pump, ice storage 380 m^3 PV = 262 kW_{Peak}, solar thermal 217 m^2

Final energy surplus (kWh/a):	
Prediction:	12,428
1st year of monitoring:	–
2nd year of monitoring:	–

Kaufbeuren (1. BA) Jakob Brucker High School
Heated net floor area: 1,615 m^2
Brine-to-water heat pump, PV = 73 kW_{Peak}

Final energy surplus (kWh/a):	
Prediction:	518
1st year of monitoring:	–
2nd year of monitoring:	–

Feuchtwangen (1. BA) Research hall
Heated net floor area: 533 m^2
Brine-to-water heat pump, ice storage 273 m^3 PV = 34.7 kW_{Peak}, solar thermal 46.8 m^2

Final energy surplus (kWh/a):	
Prediction:	5,430
1st year of monitoring:	–
2nd year of monitoring:	–

Giebelstadt Primary school extension
Heated net floor area: 624 m^2
Air-to-water heat pump, PV = 54.6 kW_{Peak}

Final energy surplus (kWh/a):	
Prediction:	241
1st year of monitoring:	–
2nd year of monitoring:	–

Ulm University New replacement building
Heated net floor area: 10,003 m^2
Heat pump, PV = 368.5 kW_{Peak}

Final energy surplus (kWh/a):	
Prediction:	16,814
1st year of monitoring:	–
2nd year of monitoring:	–

Key to technologies:

- Heat pump
- Photovoltaics
- Solar thermal energy
- Ice storage
- Ventilation system with heat recovery

Technology, calculations resulted in 16 kilowatt hours per square metre of heated net floor area and year. For school buildings, forecasts are in the region of 10 kilowatt hours per square metre of heated net floor area and year. One task of monitoring will be to assess the consumption of individual sections (especially the school kitchens) in practice.

Energy generation

All buildings in the funding programme use large-scale photovoltaic systems (PV) to generate electricity. While single and two-storey buildings provide enough roof space to cover the annual energy balance, especially compact buildings require extra areas.

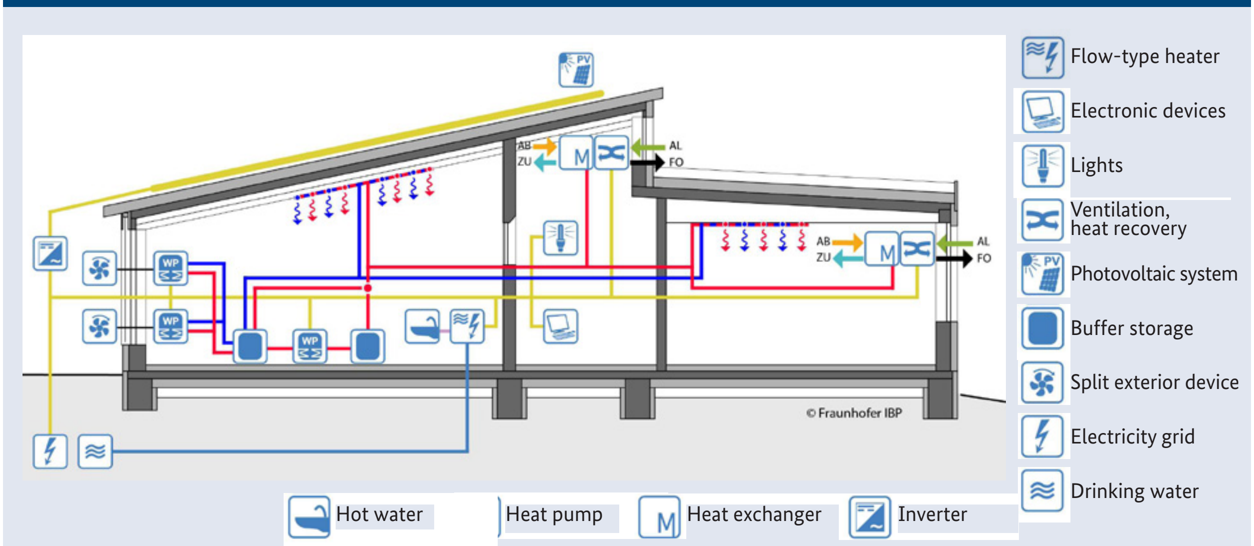
Aim: High self-use rate

The projects are not designed to achieve as high absolute energy surpluses as possible in order to feed them into the electricity grid. Instead, demand for at least a neutral energy balance is combined with the desire to consume as much of the renewable energy produced on-site as possible. The so-called self-use rate can be increased by temporarily storing surplus energy generated during the day.
In this respect, the projects take different paths. In Ulm, Neutraubling and Kaufbeuren, the hot water buffer storage can be charged using surplus electricity, thereby storing energy for hours or days. In Hockenheim and Mühldorf, large underground ice storage has been installed that can be regenerated using solar-thermal absorbers and are designed more to use seasonal effects.

Networked buildings

In some projects, conditions are suitable to use surplus energy directly in neighbouring buildings, without having to draw from the public electricity grid. In principle, the new extensions in Giebelstadt and Neutraubling can be directly connected to the existing buildings. In Feuchtwangen, the newly erected buildings on the university campus have preinstalled networking systems. In Ulm, a special method was used with an intelligent networking of already existent local energy sources: the building uses the return flow of a district cooling supply as an energy resource for a reversible heat pump. In doing so, the return flow is cooled down again, thereby saving the energy that the network's cooling centre would otherwise have required for the same task.
The aim to erect or refurbish a building that consumes less energy over the period of a year than is generated locally can be achieved in different ways in the field of educational buildings. Although it is already possible to construct such buildings with components that are available on the market, their planning still requires pioneering technical considerations: hardly any prior applicable experience exists for the planned component combinations and their technical interaction. Thus the scientific study of the pilot projects in the Efficiency House Plus standard programme for educational buildings forms an important basis for the widespread application of new energy-efficient technologies in the field of non-residential buildings.

Figure 19: Technical section of the new extension to the Giebelstadt primary school



Efficiency House Plus in districts

How can a storage concept be economically optimised to maximize the self-consumption of locally generated renewable energies in Efficiency House Plus buildings and relieve the burden on electricity grids? For this purpose the Federal Ministry of Building promotes scientific investigations on a central district storage solution: in the Living Lab of the "FertighausWelt" in Wuppertal, 19 Efficiency House Plus buildings are centrally networked in an estate. They also supply a reception building with "sisterly" renewable electricity. The estate is equipped with a central electric storage, which has a usable capacity of 130 kilowatt hours.
A detailed measurement programme demonstrated that the pilot buildings have an average consumption profile that is comparable to a typical German two-person household. Therefore, the results obtained in an exhibition settlement can be applied to "normal" inhabited estates with the same type of house. The advantage of the model estate is that unlike "normal" inhabited settlements, changes in energy supply and energy management can be easily carried out during operation, because all homeowners participate in the trial, allowing a real "Living Lab" to be implemented.

The unanimous opinion of the network partners is that the technology is mature. The Efficiency House Plus works in practice and can greatly contribute to the energy turnaround in the building sector. The Efficiency House Plus pilot projects funded by the Federal Ministry of Building are being emulated all around the country. The Association of the Prefabricated Housing Industry found that its market share of Efficiency House Plus residential buildings is already over 15%.

Figure 20: Electricity shift between individual buildings and the district

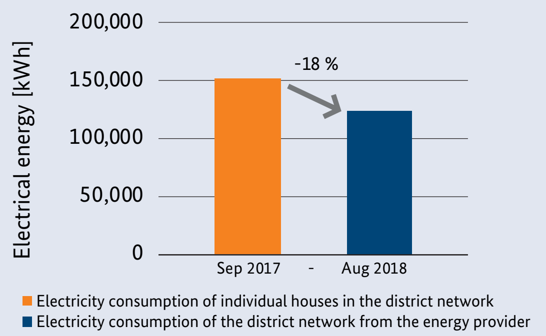
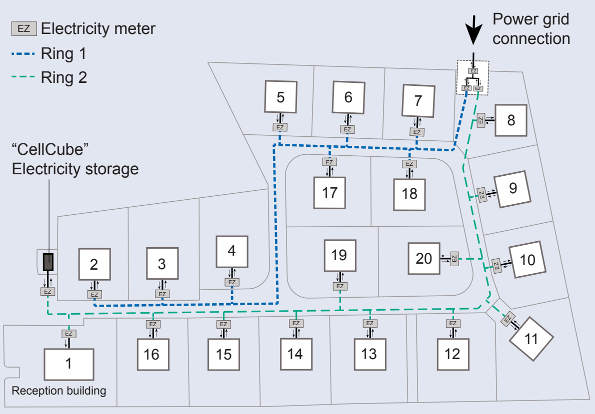


Figure 21: Plan of the FertighausWelt Wuppertal: Heated net floor area, predicted and measured final energy surplus of the individual buildings

		Heated net floor area [m²]	Predicted final energy surplus [kWh/a]	Measurement period 09.2017 - 08.2018 [kWh/a]
1	*Reception building*	–	–	–
2	**Schwörer Haus**	261	3,645	2,811
3	**Fingerhaus**	172	1,808	1,068
4	**Fingerhut Haus**	195	3,827	1,927
5	**WeberHaus**	217	1,064	762
6	**Partner Haus**	171	3,374	6,105
7	**HUF HAUS**	218	3,565	617
8	**Büdenbender**	184	512	-1,243
9	**KAMPA**	204	16	1,299
10	**ProHaus**	165	1,827	1,856
11	**RENSCH-HAUS**	168	8,541	3,673
12	**Bien-Zenker**	397	2,927	95
13	**holz & raum**	142	2,906	4,882
14	**Hanse Haus**	238	2,326	2,715
15	**allkauf Haus**	191	716	4,823
16	**OKAL**	343	293	2,402
17	**NORDHAUS**	164	956	1,780
18	**Schwabenhaus**	200	59	1,225
19	**GUSSEK HAUS**	206	595	-2,184
20	**Danhaus**	153	573	2,846
21	*Central storage*	–	–	–
	Total	**3,989**	**39,350**	**37,458**



Monitoring of energy flows in the district network showed an 18 percent reduction in the electricity consumption from the public grid through the use of the PV electricity surplus of the houses on a district level. During the monitoring period from September 2017 to August 2018, the individual buildings jointly consumed a total of approx. 151,400 kilowatt hours from the district network.

However, the district network only consumed 123,800 kilowatt hours from the public electricity grid. Around 27,600 kilowatt hours (18 percent) were drawn from the central district storage system and the district network within the estate and thereby represent self-used electricity that was not drawn from the public grid.

Figure 22: Individual buildings and technologies used

Technologies in all buildings: WP Heat pump | PV Photovoltaics | Ventilation system with heat recovery

Results from the network

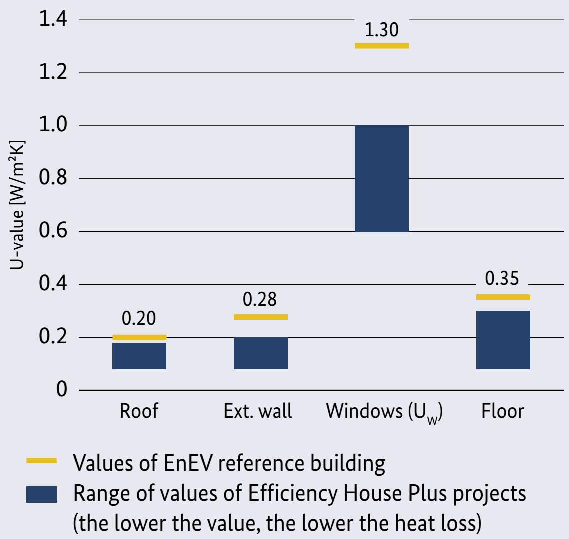
Accompanying technical research

The Fraunhofer Institute for Building Physics (IBP) cross-evaluated building-related figures and substantial measured data from all model projects. A data profile of each building and monthly updated consumption graphics for the buildings are published at: *www.forschungsinitiative.de/effizienzhaus-plus/*

Supplementary studies were also carried out on the federal pilot project. These included the validation and influence of the electricity storage used, the hygrothermal behaviour and long-term durability of the building envelope, the indoor climate and the heating of the highly thermally insulated building with different temperature zones. These results are also available online on the website of the research initiative.

Selected results of the supplementary research on the Efficiency House Plus network are presented below.

Figure 23: Thermal transmittance

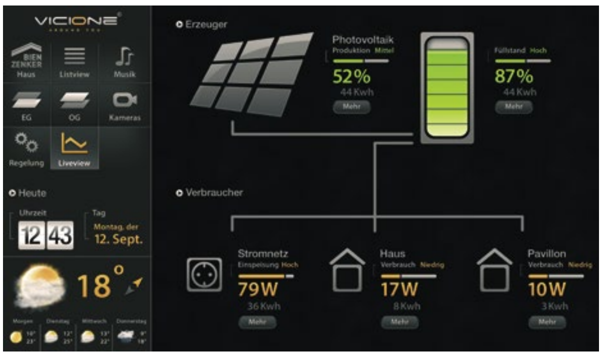


Structural thermal insulation

All model projects are predominantly compact in terms of structure and energy-optimised. Their thermal insulation is significantly better than that required by the Energy Saving Ordinance (EnEV). The transmission heat loss relative to the thermal envelope area for single-family to semi-detached homes is between 0.13 and 0.33 Watt per square metre per Kelvin ($W/m^2 \cdot K$) and is thus 18 to 62 percent lower than the permissible maximum value of the current EnEV (average 48 percent). The average energy performance of the model projects is mainly focused on the level of the KfW Efficiency House 55.

Heating

Most of the model projects use heat pumps in conjunction with surface heating. 44 percent use geothermal heat pumps, 38 percent air-to-water heat pumps and 18 percent of heat is generated by water-to-water heat pumps. Different combinations of external air, brine, and solar and ice storage systems are used as heat sources. The heat output of the installed systems ranges from between 1.5 and 20 kilowatt for single-family homes to between 7 and 120 kilowatt for apartment blocks.

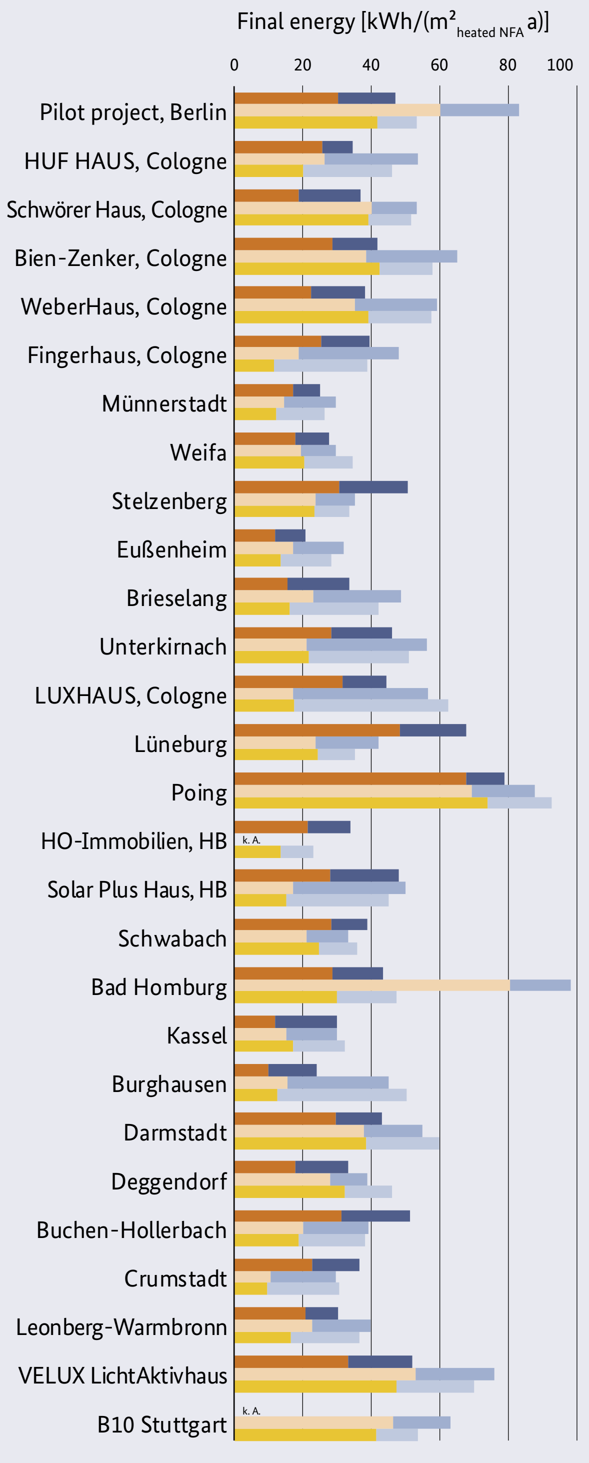


Building automation data display

Tip

An Efficiency House Plus does not have to comply to Passive House standards. A 40 percent better design compared to the heat insulation standard of the reference building of the Energy Saving Ordinance (EnEV) often suffices.

Figure 24: Final energy demand and consumption of single-family and semi-detached houses in the 1st and 2nd years of monitoring



Space heating, domestic hot water and auxiliary energy

- Calculation DIN V 18599
- First year of monitoring
- Second year of monitoring

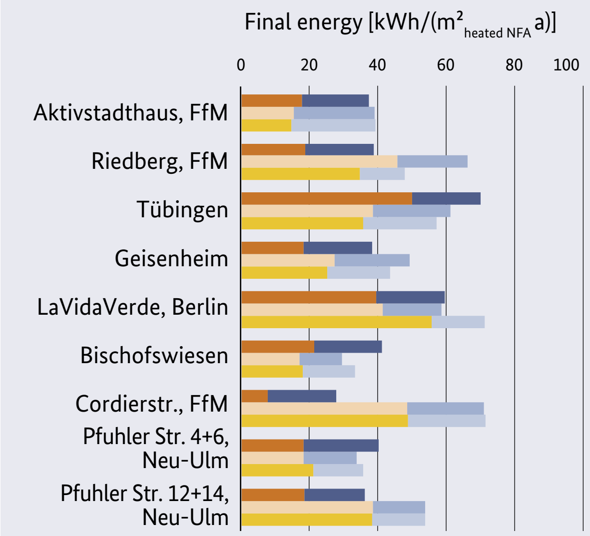
Household electricity

- Calculation, Efficiency House Plus standard
- First year of monitoring
- Second year of monitoring

Final energy consumption

The energy consumption in relation to heating, domestic hot water, auxiliary energy as well as lighting, household appliances, household processes and others are compared to the planned values for EnEV calculations in accordance with DIN V 18599 and Efficiency House Plus calculations. Almost all buildings consumed more final energy in the first years of operation than predicted. In the first year of measurement the average additional consumption was 20 percent, which could be reduced by optimization during the second measurement year to less than 10 percent. Both the building services and the household electricity consumption created deviations. The average room air temperatures during the heating period were sometimes 2 to 4 degrees Kelvin higher than the level defined in DIN V 18599, leading to higher heating energy consumption than predicted. In many cases, the building services systems operated inefficiently due to the high flow temperatures in the water circulation or because of the uncontrolled operation of the ventilation systems all year round, with high volume flow rates in some cases. Some heat pumps also failed to produce the expected annual performance figures. Moreover, the building automation and control technology sometimes had an unexpectedly high electricity demand.

Figure 25: Final energy demand and consumption of apartment buildings in the 1st and 2nd years of monitoring

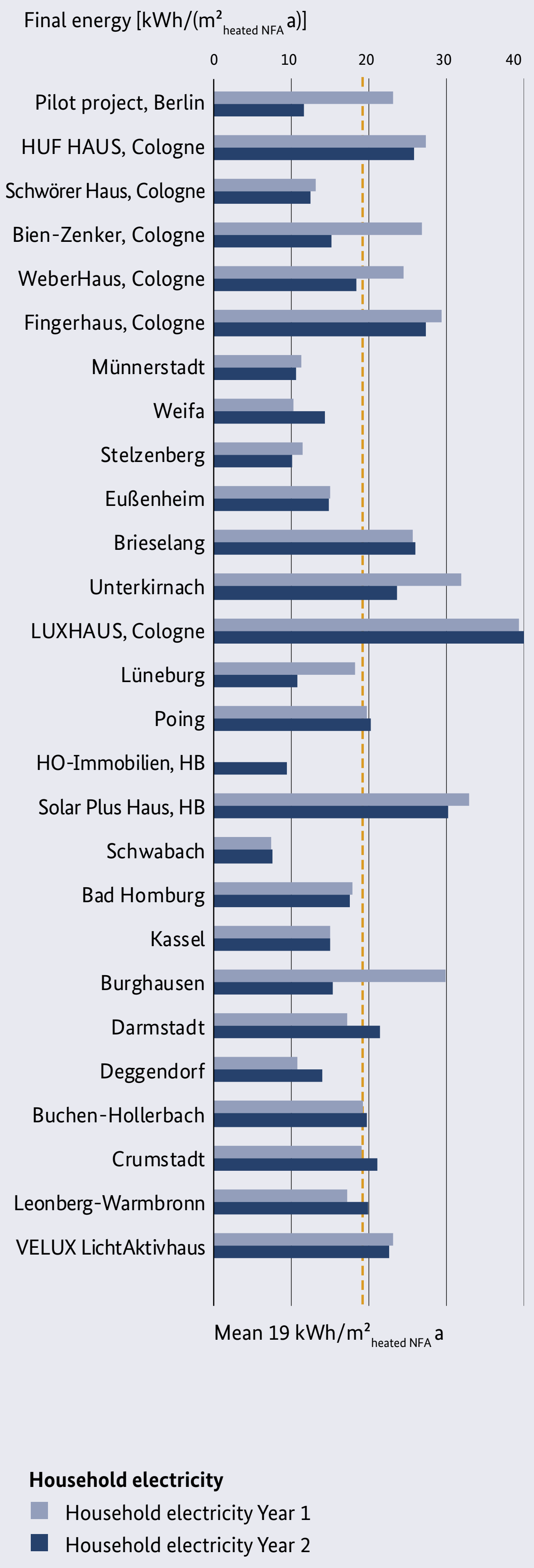


Key: see Figure 24

Tip

It is recommended to plan the photovoltaic system 10 to 20 percent larger than necessary to cover any non-optimal building performance and thereby ensure the generation of a surplus.

Figure 26: Final energy consumption for household electricity of single-family and semi-detached houses in the 1st and 2nd years of monitoring

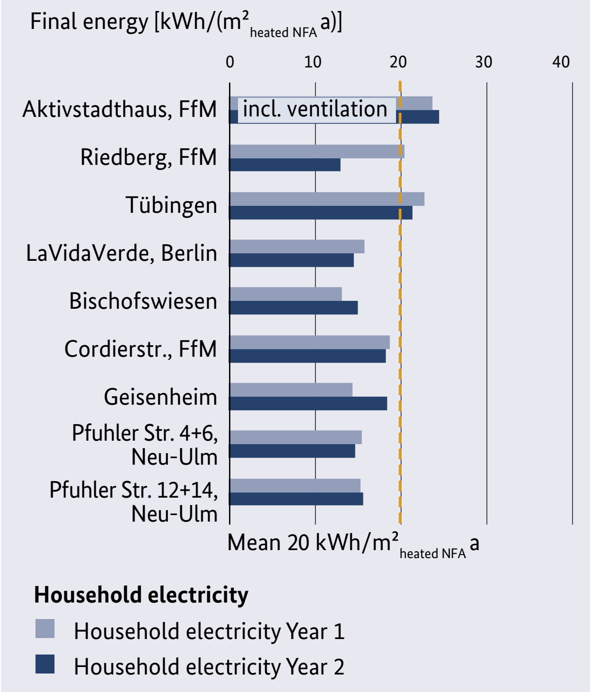


Household electricity

Household electricity is measured separately for lighting as well as for household appliances and processes in accordance with the Efficiency House Plus standard. An overall annual value of 20 kilowatt hours per square metre of heated net floor area, however, not exceeding an annual maximum of 2,500 kilowatt hours per square metre per housing unit was cited in the pre-calculation. A value of 3 kilowatt hours per square metre of heated net floor area is specified for lighting, while for household appliances and processes, an annual value of 17 kilowatt hours per square metre of heated net floor area was defined. The results show that the pre-calculation and measurements often correspond: in relation to the living space, the final energy demand for lighting excluding model homes was on average 3 kilowatt hours per square meter per year.

The results showed, in the case of single-family and semi-detached homes, an annual average household electricity consumption for both years of 19 kilowatt hours per square metre of heated net floor area. The figure increased to 20 kilowatt hours per square metre of heated net floor area for apartment buildings. Thus in the following, no further distinction is made in the definition of housing-unit related consumption and an annual value of 20 kilowatt hours per square metre of heated net floor area is defined for household electricity consumption. It is recommended to use appliances and lighting with the highest efficiency classification.

Figure 27: Final energy consumption for household electricity of apartment buildings in the 1st and 2nd years of monitoring



Photovoltaic areas

To date, highly efficient houses have primarily concentrated on minimising energy demand. By contrast, Efficiency House Plus buildings call for the pros and cons to be considered between whether it is appropriate to install photovoltaic panels or increase the thermal insulation for the building envelope. For several projects the designers began by ascertaining the maximum possible surface area of collectors and on that basis calculated the thermal insulation the building needed to comply with the specifications for the Efficiency House Plus standard.

Analysis of the pilot projects shows that on average 0.46 square metres of photovoltaic area per square metre of heated net floor area was installed per square metre of heated net floor area in single-family and semi-detached homes. Due to the lower roof areas in relation to the living space, the photovoltaic area for apartment blocks is on average 0.33 square metres per square metre of heated net floor area. The installed capacity of the photovoltaic systems is between 43 and 148 Watt peak per square metre of heated net floor area for single-family homes and averages around 67 Watt peak per square metre of heated net floor area. Apartment buildings have an average of 59 Watt peak achieved per square metre of heated net floor area.

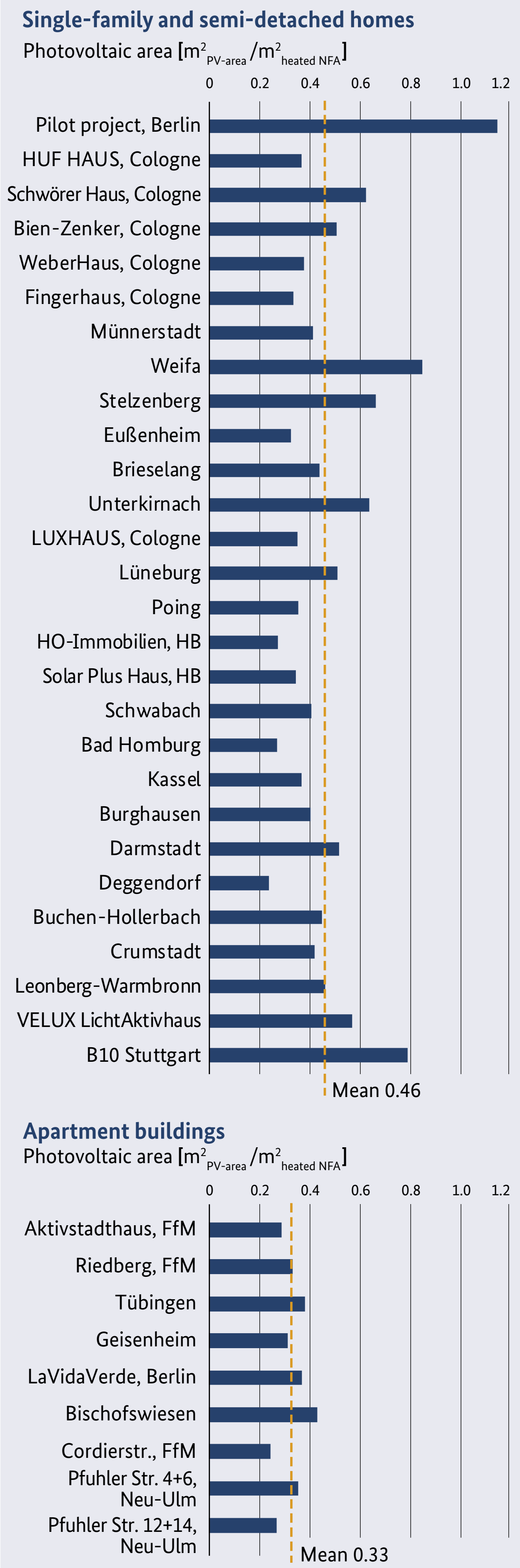
Pre-calculation versus measurement

A key issue that arises when building Efficiency Houses is whether the energy yields from the photovoltaic systems can be accurately predicted, since the houses' ability to meet the targets and their economic viability depend crucially on this. The measured results of model projects show a very high degree of agreement with the calculations made in advance. Any deviations are usually below 10 percent and can be explained by particular local weather conditions or shading factors that were not taken into account. Measurements to date confirm that the performance assessment method set out in DIN V 18599 can be used with sufficient accuracy as the basis for ex-ante evaluation and dimensioning of the Efficiency Houses.

! Tip

An EnEV 2016 standard building needs about 0.5 square metres of photovoltaic area per square metre of heated net floor area to be retrofitted to Efficiency House Plus standard.

Figure 28: Ratio of photovoltaic area and heated net floor area



Degree of self-sufficiency

The degree of self-sufficiency describes the proportion of a building's final energy demand that is supplied through self-generated photovoltaic electricity. This can be positively influenced using electric storage. The average degree of self-sufficiency in single-family and semi-detached home projects with electricity storage is almost 50 percent. Without electric storage, self-sufficiency falls to just below 30 percent. In apartment buildings, using electricity storage can increase the average self-sufficiency level from 18 to 42 percent.

! Tip

A one kilowatt peak photovoltaic system (with a surface between 8 and 10 square metres) can produce between 700 to 1,100 kilowatt hours of electricity per year in Germany.

Degree of self-use

The degree of self-use can be determined by dividing the photovoltaic yields into the share of self-generated electricity used by the house itself and the share fed into the public power grid. In view of falling prices for electricity fed into the grid, it is vital to aim for as high a level of self-use as possible. In the first year, the degree of self-use for single-family and semi-detached home pilot projects with electricity storage fluctuated between 16 and 60 percent and for such pilot projects without batteries between 11 and 40 percent. In the case of apartment buildings, the average degree of self-use in buildings without electric storage was 16 percent, while apartment buildings with electric storage achieved almost 50 percent.

The degree of self-use in the pilot projects could be almost doubled by the use of batteries. However, in small-sized storage facilities or excessively large-dimensioned photovoltaic systems, the degree of self-use was generally low. The size of the photovoltaic system and the capacity of the electric storage should therefore be adapted to the expected consumption.

Roof area with monocrystalline photovoltaic modules

Figure 29: Self-use and self-sufficiency of photo voltaic electricity in single-family and semi-detached homes during the first year

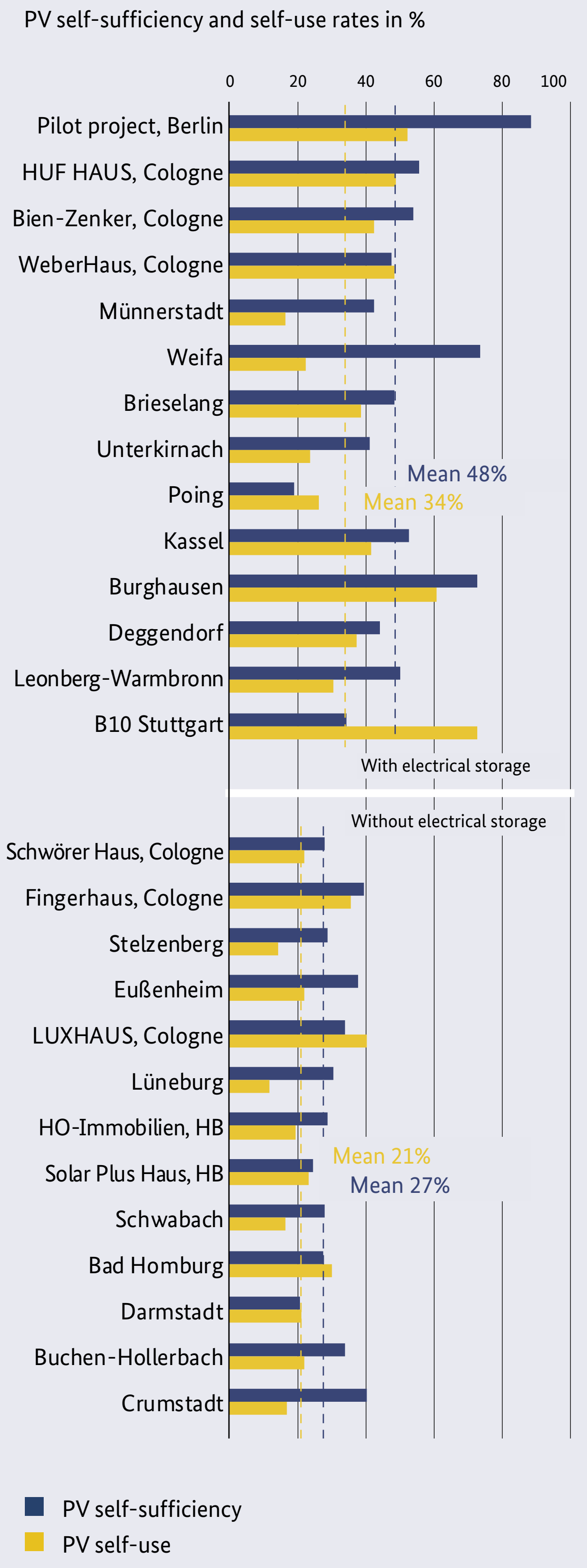
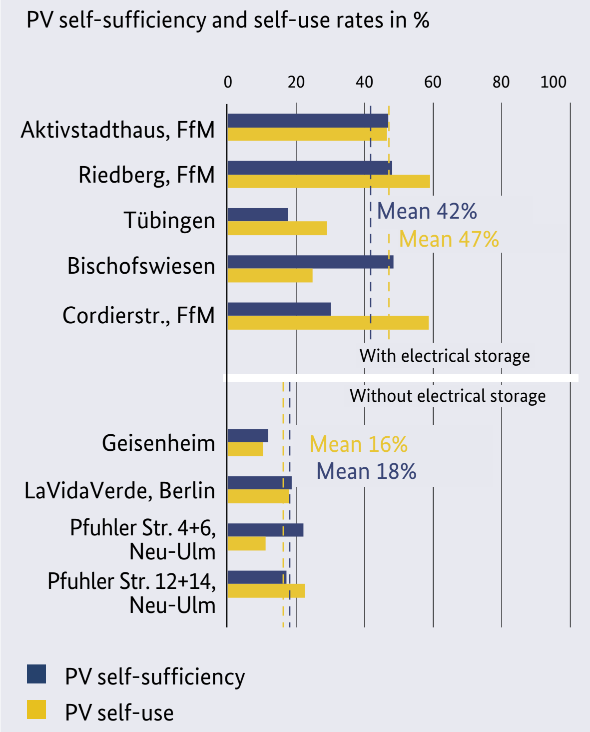


Figure 30: Self-use and self-sufficiency of photo voltaic electricity in apartment buildings during the first year



Heat pump efficiency in practice

The efficiency of the operated heat pump systems in practice was measured and determined in the form of a seasonal performance factor. It denotes the ratio between the heat performance provided by the heat pump for the purpose of heating and the domestic hot water and electrical energy required to operate the system over the period of one year. The pilot projects produced average seasonal performance factors of 2.6 for air heat pumps, and 3.2 for geothermal and water heat pumps. The targets of the Renewable Energies Heat Act (EEG) require electric heat pumps with drinking water systems to have a seasonal performance factor of at least 3.3 and all other heat pumps 3.8. Based on the measured data, these results could not yet be achieved by the majority of systems in the practical test. There was often a need to optimise implementation plans, which were not consistently carried out in a detailed manner, as well as a lack of hydraulic adjustment in some cases and a lack of sufficient controlling concepts for the overall systems. Oversized systems and insufficiently regulated network hydraulics can have a negative influence on the energy performance of the heat pump system.

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Electrical storage systems

As a result of changes to the feed-in tariffs, Efficiency House Plus building planners are responding with designs that significantly increase the percentage of solar electricity which the building could use itself. Whereas in the past it was virtually impossible (without incorporating batteries) for a building to use more than 30 percent of the electricity produced by the photovoltaic system, this percentage can now be easily doubled by integrating electric storage systems.

51 percent of the pilot projects have an electrochemical storage system (see Fig. 29).

Figure 31: Type and distribution of electrochemical storage in Efficiency House Plus model projects

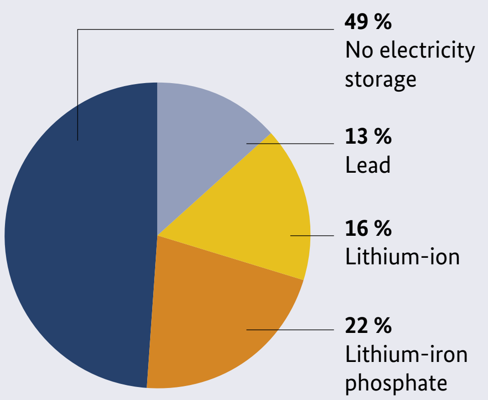
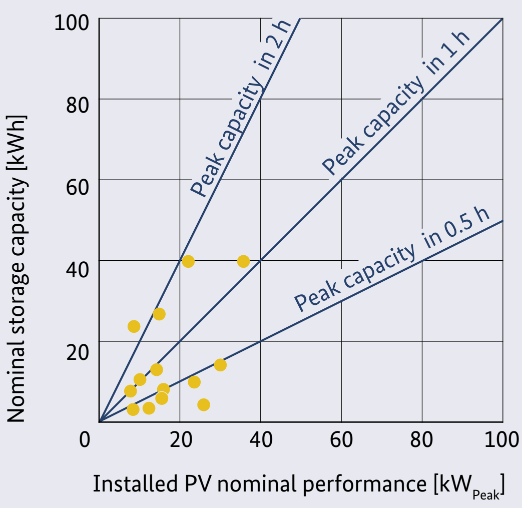


Figure 32: Storage capacity



Tip

Using an electric storage system (usable capacity between around 8 to 10 kilowatt hours) can easily double the self-use rate (percentage of renewable electricity generated and used by the house itself) in a single-family home.

The gross storage capacity is between 3.5 and 40 kilowatt hours in single-family homes and up to 250 kilowatt hours for an apartment block.

The dimensions of the photovoltaic storage systems can be aligned towards the installed power of the photovoltaic system or the power-based final energy demand of the house. The batteries used in the projects were analysed using peak power.

A peak power of one hour means that the electricity storage facilities store as much energy as the installed photovoltaic system can produce in an hour. This means that a system with a peak performance of 20 kilowatt requires a battery with a performance of 20 kilowatt hours. The installed batteries have peak power between 0.1 and 2.1 hours. To achieve a significantly higher rate of self-sufficiency, batteries with storage capacities of more than one hour are required. Buildings that have a charging capacity of two hours have the largest capacities.

Battery storage, 13.2 kilowatt hours

Monitoring buildings

Monitoring can assess the projects in an inhabited status to discover whether the requirements of the Efficiency House Plus standard are fulfilled in practice. To be able to carry out the assessment, it is necessary to continuously record the energy volumes (electricity, gas, oil etc.) supplied to the building and the energy volumes (electricity, heat etc.) fed into the grid by the building. Furthermore, for deeper analysis of the consumption structure, key balance proportions that are derived during assessment calculations should also be recorded. These include the exterior climate conditions and user behaviour.

The energy flow in a building begins with the input of final energy into the building. The processes "generation", "storage", "distribution" and "emission" are used together with supplied final energy to provide the required service (energy use).

The following rules apply in positioning the meters:

The overall energy input per energy carrier should be recorded. The electricity generated by the PV modules, the share transferred to the building and the electricity fed into the grid must be recorded.

If an energy flow is used to supply various energy services, at least one of the flows must be measured at each branch (it is recommended to record all energy flow for control purposes).

When using storage, the energy flows must be recorded before and after storage to establish storage losses. In the case of domestic hot water storage with a circulation pipe, the energy drawn is derived from the circulation pipe's domestic water heat recovery and the circulation losses. This requires the separate recording of those proportions.

Tip

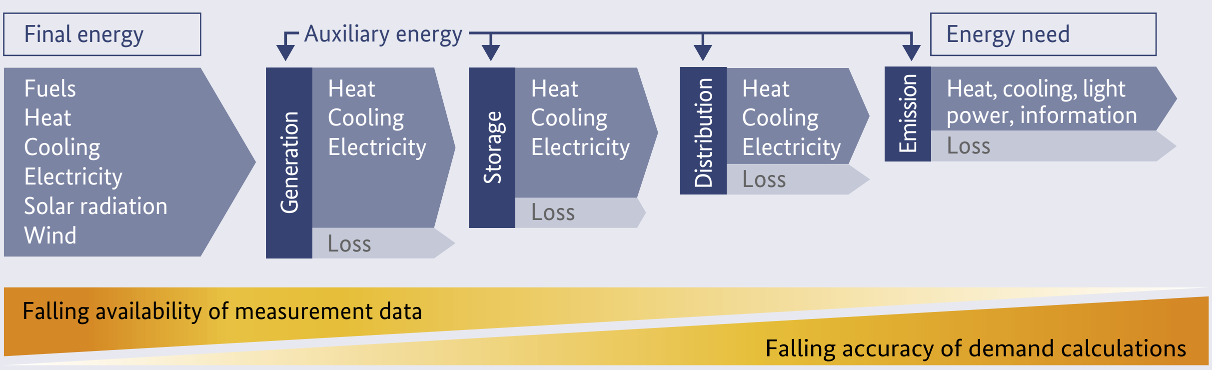
Innovative system technology should be combined with monitoring to continuously analyse its efficiency and initiate improvement. Thus monitoring should be integrated into planning and communication at an early stage.

In addition to the underlying assessment of the energy balance, which is the key theme of monitoring, the positioning of consumption meters allows further figures concerning the system to be directly determined.

Sensors must be installed at the same time as building implementation. Retrofitting significantly increases installation costs. Ultrasonic meters are recommended to record heat volumes. These devices' maximum flow-through volumes should be taken into account. To record electricity consumption correctly, attention should be paid to laying separate circuits for this purpose already at the installation stage. In this way, the electricity meters can be integrated into the meter box.

If no building control technology is installed in the building, the measuring data must be recorded using a separate measurement recording system, such as a web-based system.

Figure 33: Simplified diagram of the energy flows in a building, in accordance with DIN V 18599



Reducing carbon dioxide (CO_2) emissions

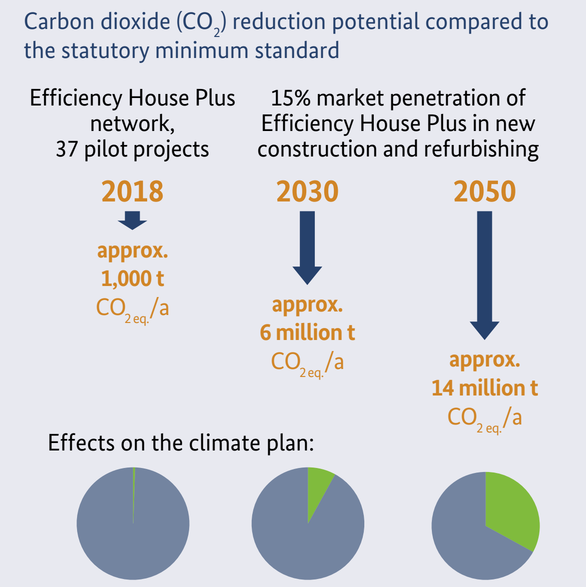
The Efficiency House Plus is an ideal module in view of climate protection targets for Germany, which require the 80 to 95 percent reduction of greenhouse gas emissions by 2050 compared to 1990, thereby demanding an almost climate-neutral building stock by 2050. Compared to standard houses, every Efficiency House Plus reduces both the fossil energy consumption and also greenhouse gas emissions in Germany. The buildings are reducing factors in our country's climate balance.

In addition to the most important greenhouse gas, carbon dioxide (CO_2), the use of various energy carriers also involves the emission of other greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O). The equivalent carbon dioxide (CO_2) burden is calculated according to their respective climate effect to create a holistic value as a carbon dioxide (CO_2) equivalent. According to DIN V 18599, carbon dioxide (CO_2) equivalents for electricity are set at 550 grams per kilowatt hour for electricity and 240 grams per kilowatt hour for natural gas.

In the field of buildings, consumption of a typical single-family home conforming to EnEV regulations for space heating and hot water supply (mainly gas) and the user electricity consumption produces around 38 kilograms of carbon dioxide (CO_2) equivalents per square metre and year. Constructed Efficiency House Plus buildings have an average electricity surplus of around 20 kilowatt hours per square metre and year, thereby relieving the burden on the global climate by around 12 kilograms of carbon dioxide (CO_2) equivalents per square metre and year. The savings potential compared to EnEV-standard buildings is therefore 50 kilograms of carbon dioxide (CO_2) equivalents per square metre and year. With respect to refurbishing projects, the savings potential is around 120 kilograms of carbon dioxide (CO_2) equivalents per square metre and year.

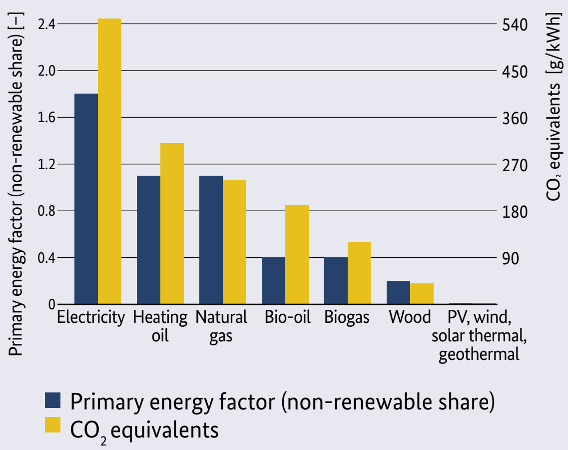
The entire Efficiency House Plus network with its 37 pilot projects delivers an annual savings potential compared to buildings erected according to minimum statutory standards of around a thousand tonnes of carbon dioxide (CO_2) equivalents per year. In the case of 15 % market penetration of Efficiency House Plus standards in new building projects and in refurbishing existing buildings, that represents savings of around 14 million tonnes of carbon dioxide (CO_2) equivalents by 2050.

Figure 34: Possible savings potential



Assessment of the energy demand of buildings is currently carried out on the basis of primary energy. Analogous assessment is possible on the basis of CO_2 equivalent emissions. However, a direct relationship between the assessment factors of primary energy and CO_2 equivalents does not exist for various energy carriers. In view of the climate targets in the field of buildings, the focus lies on minimising final energy while also reducing CO_2 emissions.

Figure 35: Comparison of energy carriers (DIN V 18599)



Costs

Since each building design is highly individual and design elements and investments in higher standards of comfort have the greatest impact on costs, it is difficult to make any prediction on economic aspects or the overall costs of buildings.

In the projects invoiced to date (as of 2016), gross costs according to DIN 276 for cost groups 300 (building design) and 400 (technical systems) amount to between EUR 1,000 and 4,500 per square metre of heated net floor area. Only the pilot project in Berlin caused significantly higher costs due to its strong research character. The overwhelming percentage (more than 75 percent) of all buildings incurred costs of between EUR 1,500 and 3,000 per square metre of heated net floor area.

It appears to be more sensible to compare costs to those of the same building constructed according to standard energy performance quality.

Highly energy-efficient building envelope

The Efficiency House Plus projects that have been built to date usually have a building envelope that is roughly a 40 percent improvement on the requirements of the Energy Saving Ordinance. This incurs extra costs of between EUR 65 and 100 per square metre of heated net floor area.

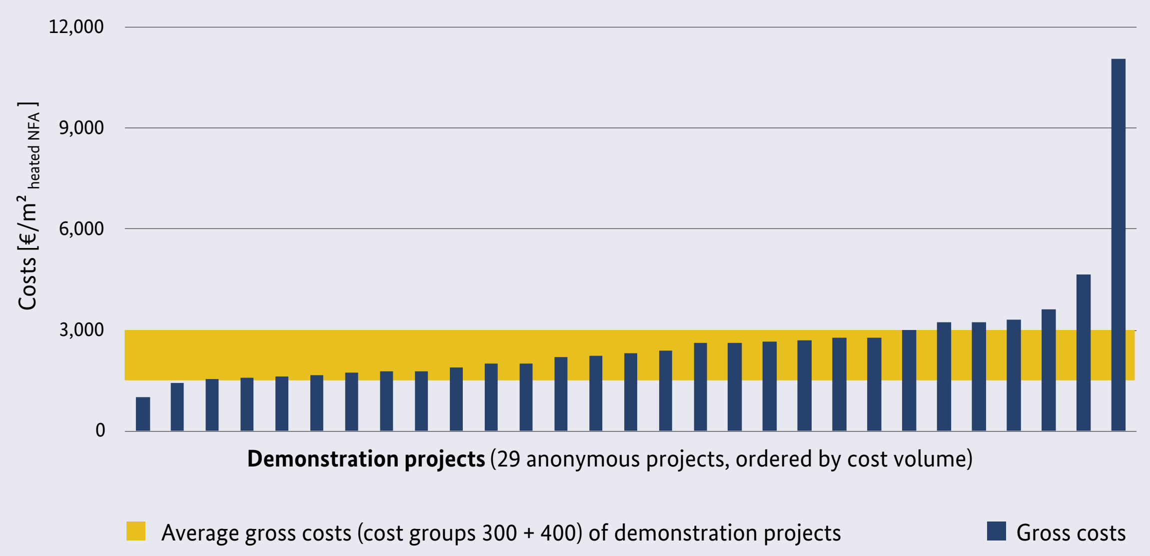
Highly efficient ventilation systems in residential buildings

It is essential to have a ventilation scheme in new buildings. Ventilation concepts have already become standard in residential buildings with higher energy efficiency. However, simple systems (air extraction) are more commonly installed. Installing a system that supplies and extracts air (balanced ventilation system) and has heat recovery rates of more than 80 percent adds EUR 40 to 65 per square metre of heated net floor area in new construction projects.

Heat pump systems with buffer storage tanks

In recent years, electric heat pumps have become increasingly popular in the new building market. The additional costs for heat pump systems in Efficiency Houses Plus are between EUR 45 and 65 per square metre of heated net floor area compared to a standard heating supply using a condensing boiler and a hot water tank.

Figure 36: Gross costs for cost groups 300 and 400 of Efficiency House Plus demonstration projects



Highly efficient household appliances

Using highly efficient household appliances can lower the electricity consumption in an average household by about 1,000 kilowatt hours per year. This reduces the photovoltaic capacity that needs to be installed by 1 kilowatt peak, which more than cancels out the additional costs for the appliances. All that is happening here is virtually a shifting of costs.

Photovoltaic systems

The installation costs for photovoltaic systems have fallen dramatically in recent years. Currently, the investment costs for ready-assembled medium-sized rooftop installations for single-family homes are EUR 1,500 to 1,700 per kilowatt-peak. Grid connection costs are around EUR 500 to 1,000. For an installed capacity of 67 Watt peak per square metre of heated net floor area, which was the average for buildings to date, the average investment costs are between EUR 100 and 150 per square metre of heated net floor area.

Electric battery systems

Electric batteries are not absolutely essential for an Efficiency House Plus. However, they do increase self-use rates. Until just five years ago, around 70 percent were lead acid batteries, but by 2017, almost all newly installed storage systems used lithium ion technology. Lead acid house batteries (approximately 8 kilowatt hours) cost about EUR 1,100 per kilowatt hour of usable battery capacity. More efficient lithium ion batteries cost around EUR 200 more per kilowatt hour. In the case of large battery storage systems, as in apartment buildings, costs of below EUR 1,000 per kilowatt hour of usable battery capacity can be achieved.

Overall additional investment

As the above analysis of the individual elements shows, an Efficiency House Plus requires an average additional investment of between EUR 250 and 380 per square metre of heated net floor area. Installing extra photovoltaic areas to support electro-mobility will increase the level of investment accordingly.

Lower operating costs

The operating costs for an average single-family home of EnEV 2016 standard can be estimated at around EUR 10 per square metre of heated net floor area and year for heating purposes and around EUR 13 per square metre and year for electricity, i.e. a total of EUR 23 per square metre and year. This operating cost potential can be best exploited in an Efficiency House Plus.

Even a few years ago, it was still possible to reduce the operating costs of an Efficiency House Plus to (less than) EUR 0 per square metre per year. Today, this is in practice no longer possible for houses that produce only slightly more solar electricity than they need, unless they incorporate batteries into the system. This is due to falling feed-in tariffs and the fact that payment for the electricity generated and used by the house itself has been abolished. Even assuming that including a large enough battery would increase the percentage of generated electricity used by the house itself to at least 65 percent, the operating costs would - despite an annual electricity surplus - still be between EUR 2 and 3 per square metre and year of usable floor area. Today, only a photovoltaic system that is about 35 percent “too large” produces operating costs below EUR 0.

Tenants’ electricity

Landlord-to-tenant electricity supply marketing models (so-called landlord-to-tenants or tenants’ electricity models) exist to market electricity that is generated on site on a building using a photovoltaic system, a cogeneration unit or similar systems and supplied to the residents who do not own the system, without using the public electricity grid as their general electricity supply, for use in the building. In 2017, the modifications to the Renewable Energy Sources Act also enabled the subsidising of tenants’ electricity. The system operator is provided a subsidy according to fixed underlying conditions. As an electricity supplier, the system operator also receives electricity payments from the consumers for the supplied electricity. The operator thereby becomes an electricity generating company with all rights and responsibilities. Housing associations see problems in this respect due to corporate tax and corporate law with a possible loss of the tax rebates enjoyed in the past. One solution to this aspect are rent models including heating with a monthly free electricity budget provided by the housing association.

! Tip

Additional investment costs for an Efficiency House Plus are reasonable compared to the achievable operating costs. Since feed-in tariffs are continually being revised, any consideration of economic aspects cannot be generalised and must always take account of the latest regulatory framework.

Cost reduction potential

The European project “CoNZEBs (Solution sets for the cost reduction of new Nearly Zero-Energy Buildings)”, which is funded by the European Union and the Federal Office for Building and Regional Planning (BBR), is compiling and developing model solutions throughout Europe that demonstrate how it is possible to build in an energy-efficient and nevertheless affordable way. The aim is to close the gap in costs between energy-efficient and cost-effective new buildings.

The following approaches offer particular cost-reducing potential:

- → Prefabricated and serial building
- → Integral planning and implementation with BIM processes
- → Compact, spatially efficient buildings using minimal technology

Prefabricated and serial building

In prefabricated building, elements made of various materials such as brick, lime sandstone, concrete, light concrete, porous concrete, wood etc. are prefabricated in the factory and assembled at the building site. The building elements have different grades of prefabrication: ducts, heating and heating piping, frames and façade cladding can already be integrated into the elements.[4] According to a market study by the Hamburg Beratungsgesellschaft für Wohnen, Immobilien, Stadtentwicklung mbH,[5] serial building offers good potential to reduce costs directly or indirectly in erecting and renovating apartment buildings. According to estimated cost analyses, up to 20 percent reductions in building and additional building costs of larger building projects are possible where the repetition factor plays a major role with building elements. However, significant savings potential also exists in smaller building projects.

In addition to the aspect of direct cost savings, the authors also indicated that indirect effects such as shortened building times and improved quality assurance are also advantages of serial and prefabricated building of single-storey apartments.

4 ZDB: Elementiertes Bauen im Wohnungsbau
5 Beratungsgesellschaft für Wohnen, Immobilien, Stadtentwicklung mbH: Marktstudie 2017 – Serielles Bauen

Integral planning and implementation with BIM processes

When planning and implementing building projects, constructive collaboration between all participants plays a key role in achieving success. The more different the respective software programs are, and the greater the number of participants, the greater effect of cooperation and communication in the planning and implementation process. This applies whether BIM processes are used or not.
BIM (Building Information Modelling) is a digital working method whereby people, processes and tools cooperate in a targeted way over the entire lifecycle of a building.[6] BIM is based on a building information model and is thereby able to virtually present all processes in the lifecycle of a building. In this way, a building process gains transparency, quality, cost security and schedule reliability.

Consistent application of BIM processes is only just beginning in Germany. Thus the monetary benefits of this method compared to standard planning and building processes cannot yet be reliably estimated. However, it is known that in Europe, around 10 percent of building costs are used to repair damage caused during planning and implementation. It is expected that these considerable capital losses can at least be reduced in part.

Compact, spatially efficient buildings using minimal technology

An especially large cost reduction potential is seen in minimising and preventing investment in building and systems technology. Compact buildings save costs in two ways compared to building volumes that are designed with many protrusions and recesses, since their compact nature requires many square metres less structure and their lower surface area leads to less thermal loss. Entrance and storage areas also represent great cost-reducing potential. Buildings without a basement or with exterior staircases can be built much more cheaply than those that have full cellars or internal staircases.

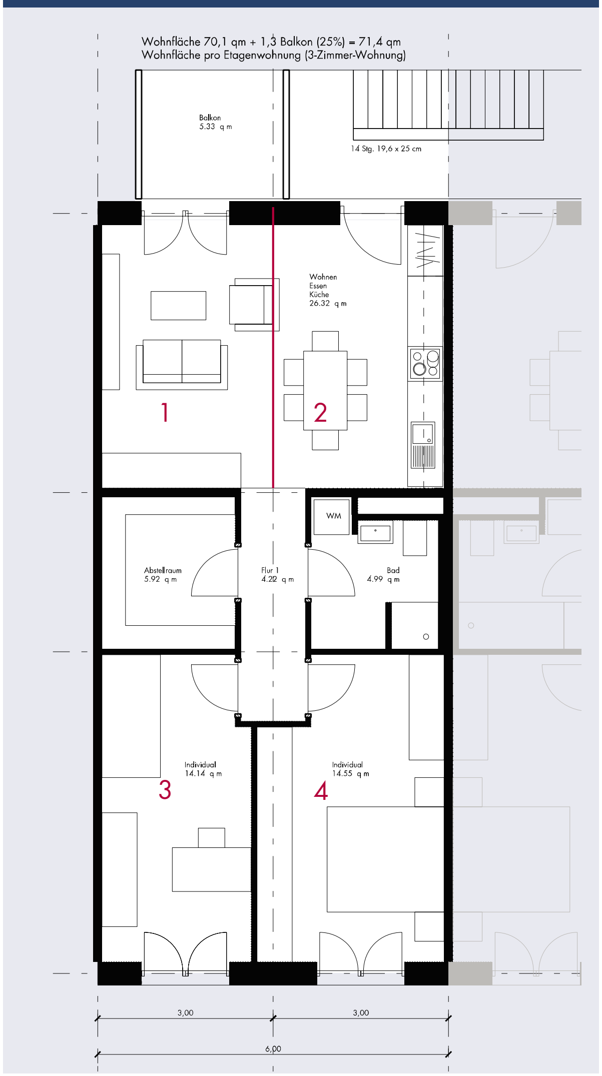
6 Allplan: BIM Kompendium – Theorie und Praxis

Reducing technical installations also has a major influence on investments. Buildings with central installation shafts and wet rooms enable considerably shorter piping lengths than apartment floor plans where the kitchen, bathroom and WC are distributed around the apartment. Compared to standard heating basements, utility centres situated in the attic lead to lower costs (fewer distribution piping in the basement and no chimney system), while domestic hot water (DHW) heat exchange modules instead of the otherwise standard circulation piping and separate storage tanks for the DHW supply are also beneficial.

Frankfurt Klimaschutzhaus

An apartment building erected by ABG FRANKFURT HOLDING that is both especially low in costs and also energy-efficient was selected for the EU research project CoNZEBs as a German "Solution Set". The new building with a total of 46 apartments fulfils the highest energy standards and its careful planning and implementation ensures low additional costs for tenants.

Figure 37: Floor plan, Klimaschutzhaus, Frankfurt am Main



Frankfurt Klimaschutzhaus

Measures

- → 4-room principle + exterior access
- → Variability despite standardisation
- → Neutral rooms, flexible apartment sizes (room additions possible)
- → Compact building
- → Room height limited to 2.75 m, building volume lighting depth 12 - 14 m
- → Storage room rather than basement
- → Highly efficient use of floor area
- → Access using exterior stairs and balconies (elevator-retrofitting possible)
- → Barrier-freedom possible
- → Funding for social housing possible
- → Structural optimisation (bulkheads)
- → Technical building systems placed in the attic
- → Reduced technology that is focused at the centre of apartments
- → Heat recovery from the exhaust air system (air inlet via façade)
- → Photovoltaic system (tenants' electricity)
- → Domestic hot water (DHW) heat exchange module
- → No radiators in the kitchen and storage room

Sociological monitoring

The process of the energy transition (Energiewende) requires scientifically consolidated insight on energy use, especially with respect to handling innovative technologies in the field of housing construction and living. Efficiency House Plus housing was therefore investigated in an accompanying sociological study carried out by the Berlin Institut für Sozialforschung (BIS) GmbH.

Method

In 2011, the process was begun by the pilot project in Berlin. From 2013 to 2014, building owners of single-family homes in the Efficiency House Plus network were asked about their motives and experiences. Before moving into their houses, they answered a questionnaire, followed by a second survey after six to twelve months' experience of living in the building. In the meantime, interviews with 11 building owners were carried out. The owner group provided the opportunity of a before/after study since they were known to the funding bodies at the time of moving into the building. This was not the case for the group of tenants. Tenants were surveyed twice between August 2015 and May 2017 (generally shortly after moving in and one year later).

110 residents took part in the first survey and 70 in the second survey of the 146 housing units. Three apartment buildings in Frankfurt am Main, two in Neu-Ulm and one in Berlin were involved in the study. Furthermore, the network included two tenant groups of the pilot project in Bischofswiesen and the housing for pupils of the Schloss Hansenberg boarding school. Holiday guests of the two holiday accommodation projects subsidised in the network were also asked to answer a short questionnaire concerning their impressions.

The sociological monitoring investigated the question of how suitable for everyday life the Efficiency House Plus building is for its residents with respect to the building technology, the indoor climate and energy use habits. It systematically recorded, measured or monitored all processes that affected or influenced residents/users of a building erected to Efficiency House Plus standards.

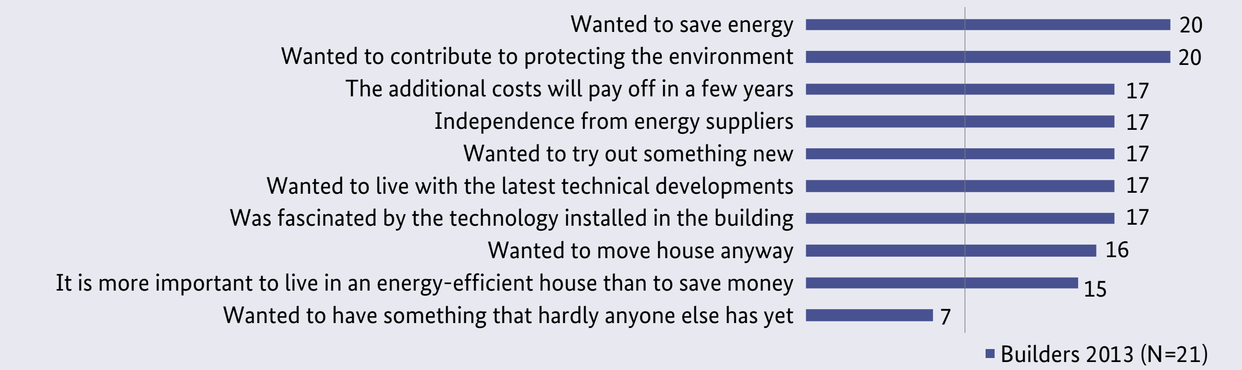
Motivation and expectations

The survey clearly showed that many similarities existed between building owners and tenants living in Efficiency House Plus buildings. Despite different primary motives for moving into or building such a house, ecological and economic reasons played an important part for both groups. The decision by tenants to move into an Efficiency House Plus was based on the location of the building, its energy concept and its floor plan. The fact that energy efficiency is ranked among the top three reasons to move into the house/apartment indicates the tenants' strong interest in resource-saving energy generation and efficient energy consumption.

Moving into what was for most people an unknown housing concept was associated with expectations and fears. Almost all those surveyed who expected lower energy consumption and reduced heating costs actually experienced those aspects. Fears of mould formation in the highly insulated buildings and limited means of opening windows proved unfounded.

The majority of tenants in an Efficiency House Plus building was prepared in principle to contribute to a positive energy balance in the building. According to their own

Figure 38: Motivation to build or move into an Efficiency House Plus



statements, they now consume less energy in their new homes than in their previous abodes. They are also now more aware of energy consumption and were motivated to save energy through the feedback on their energy use.

User interface in the Aktiv-Stadthaus in Frankfurt am Main

Feedback

Most residents found it very important to receive information on their energy consumption. Feedback formats on energy consumption differed in the individual buildings: they ranged from an app with daily updated information and internal building rankings, to information on consumption on a web platform and also a detailed consumption breakdown sent by post once a year. Calculating with the produced energy and visualisations of the energy yields and consumption of the respective building, as well as ranking compared to other residents, encouraged awareness of energy aspects and a more energy-saving lifestyle. Most of the surveyed residents had a fairly energy-conscious and energy-saving behaviour in daily life. Recommended behaviour to save energy (turning lights off, no long-term stand-by modes etc.) were adhered to by the majority of residents in the survey.

The high level of acceptance both by tenants and building owners can be regarded as a positive sign for the further distribution of the Efficiency House Plus standard. A key result of the study was a high degree of acceptance of the technology and its suitability in daily life in Efficiency House Plus buildings. Residents do not regard comfort and energy-saving as contradictory aspects in such buildings.

The "Plus" aspect of the standard can only be achieved with the help of the residents. Without their acceptance and appropriate behaviour, it will in most cases be impossible to generate more energy than the level of consumption.

"We will miss that good feeling."
The Welke/Wiechers family, who lived in the Efficiency House Plus in Berlin from March 2012 to June 2013, after moving out.

"What will we miss most after moving out? We've been asked that question very often in recent weeks and it's difficult to answer. We'll definitely miss the good feeling we had when having a bath or driving a car, since heating, hot water and electricity for our electric vehicles were provided by the household technology without creating any emissions."

"Living here was a great adventure."
The Heinzelmann/Brenner family, who lived in the Efficiency House Plus in Berlin from May 2014 to April 2015, shortly before moving out.

"You have enough space; the house is a little box of technology that can do many different things and also has its teething problems here and there. But it provides everything you need to live in, so you have a good feeling if you want to lead a responsible lifestyle. Living here was a great adventure."

Tips for planners and builders

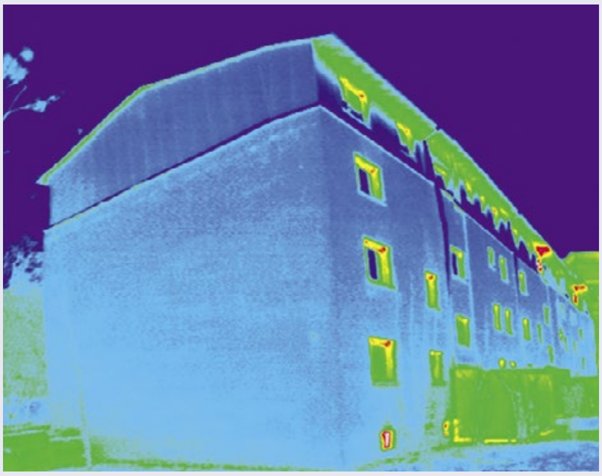
Greater demands are placed on planning and implementing Efficiency House Plus projects. The following checklist can help to systematically consider the challenges in the different stages.

Urban planning

- Orientate the building so that the façades with the main windows are south-facing.
- Ensure there is sufficient distance from other buildings to make use of solar radiation even when the sun is low.
- Roof pitches and ridge lines should be orientated towards the sun.
- Plant vegetation to provide shade in summer and influence the microclimate.

Planning

- Make the building as compact as possible, with only one wing. If the building is not very deep, arrange rooms on one side with as broad a south-facing façade as possible and access from the north. Alternatively, a two-winged building with equal east/west windows enables cost- and energy-saving construction.
- Site buffer spaces or parts of the building with less important functions on the northern side.
- Integrate the boiler room into the heated living area.



Thermal imaging is suitable for visually checking consistent implementation quality.

- Ensure the pipe runs for heating and hot water are short (site the boiler room and distribution shafts at a central location in the house).
- Site rooms that have a similar type of use (heated/unheated) together to minimise heat loss through inner surfaces.
- Prepare airtightness and thermal bridging schemes that are consistent and work together properly. Mark on the drawings places where special attention is required.
- Prepare specified tender documents with precise details of components or precise descriptions of required properties.

Passive use of solar energy

- The percentage of window area on south-facing façades should be greater than 50 percent; on all other parts of the building, windows should not be larger than is needed to provide adequate natural light.
- Optimise the orientation and pitch of surfaces to allow passive and active use of solar energy.
- Zone the building according to uses with different room temperatures.
- Place internal building components that have storage capacity taking the sun's path into account.

Structural thermal insulation

- Avoid thermal bridges at structural connections (floor supports, roller shutter boxes, roof flashings).
- Make sure all connection details that could have an impact on energy are described in the working drawings and tender documentation (as a rule 20 to 25 detail drawings are needed), specifying on the drawings all key data relating to the thermal, hygric and sealing properties of the building component. Do not let on-site work on any detail start until you have worked out the exact specification!
- Choose the highest quality roof lights possible because the heat emission from these surfaces is even greater than from walls (clear, cold atmosphere). (We are familiar with these effects from iced-up car windscreens.)

- Use heat insulating interior components on unheated ancillary and buffer spaces.
- Install high-quality insulation to protect jamb walls, dormer and ceiling surfaces from outside air.

Ventilation concept

- If using window ventilation, ensure cross-ventilation is possible.
- It is not necessary to be able to open every window.
- In multi-storey apartment blocks, fire regulations often make ventilation technology more expensive; decentralised schemes can be helpful here.

Heating technology

- Set the temperature of the heating system as low as possible to allow alternative energy sources to be integrated and keep distribution losses low. Take competing factors such as larger heating areas, volume flows and operating power into account when specifying the temperature.
- Insulate pipes to a higher standard, including when they are in building components and at penetration points.
- Ensure that valves, flanges and modules in the heating distribution system are insulated. (The boiler room must not be the warmest room in the house!)
- Check the possibility of thicker insulation than is already used for heating and process water tanks.
- Fit timers to controllable circulation pumps, lighting etc.

Construction work

- Use only appropriate materials and combinations of material that are approved by building control authorities. Use the same materials throughout wherever possible to avoid mistakes on site.
- Use the highest quality glazing possible in thermally insulated window frames (especially for roof lights). Check that the glazing delivered matches the thermal insulation certificate.
- Supervise workmanship on difficult details in the building.
- Make sure all connections are permanently airtight and wind tight (rafters, dormer, interior and outside wall connections, ensure that windows have not just been fitted using expanding foam!).
- Ensure thermal isolation of building components that are cantilevered and project into cold areas (balconies, canopies).
- Check the key thermal data and approvals as given on product documentation and delivery notes.
- Avoid damage to sealing layers (air and vapour barriers) when electrics, flue pipes etc. are being installed. If necessary, re-seal afterwards.
- Run a blower door test to check airtightness before the interior fitting is completed.
- Monitoring construction work: thermal imaging can detect manufacturing defects in roof and wall insulation.

Commissioning the building

- Users (tenants, owners) should feel comfortable in their buildings. The better the building concept is communicated to users, the more likely they will be able to identify with the idea of sustainable buildings. Information events and brief, easy-to-understand operating instructions can also significantly contribute to the energy balance of a building in the long term. Low-tech solutions and building technology with intuitive design help to simplify use and maintenance.

Monitoring operations

- Include installation of a small-scale monitoring system in the design.
- As a minimum, the efficiency of the heat generating unit should be recorded (ratio of the heat produced by the unit to its fuel intake (electricity, gas, wood)).
- The solar energy system's yields should be monitored.

Key links for research and funding

→ Federal Ministry of the Interior, Building and Community
www.bmi.bund.de

→ Federal Office for Building and Regional Planning
www.bbr.bund.de

→ "Future Building" Research Initiative
www.forschungsinitiative.de

→ Fraunhofer Institute for Building Physics
www.ibp.fraunhofer.de/eer

→ KfW Bank Group
www.kfw.de

→ Deutsche Energie-Agentur GmbH (dena)
www.dena.de

→ Efficiency House Plus calculator
www.effizienzhaus-plus-rechner.de

→ Efficiency House Plus network
www.forschungsinitiative.de/effizienzhaus-plus/

List of abbreviations

BBSR	Federal Institute for Research on Building, Urban Affairs and Spatial Development at the BBR
BHKW	Cogeneration heating plant (CHP)
BIM	Building Information Management
BMI	German Federal Ministry of the Interior, Building and Community
BNB	Assessment System for Sustainable Building
CIGS	Copper-indium-gallium-diselenide
DH	District heat
DHW	Domestic hot water
EEG	Renewable Energy Resources Act
EEWärmeG	Act on the Promotion of Renewable Energies in the Heat Sector
EFH	Single-family home
EnEG	Energy Conservation Act
EnEV	Energy Saving Ordinance
EnVKV	Ordinance on Energy Consumption Labelling
EU-RL	EU guidelines
KfW	German Reconstruction Loan Corporation
KWK	Combined heat and power generation (CHP)
l	Litre
LED	Light Emitting Diode
m^2	Square metre
MFH	Apartment building
OSB panels	Oriented strand board
PP/PE	Polypropylene/polyethylene
PV	Photovoltaics
ψ	Linear thermal transmittance (in Watt per metre per Kelvin)
Q_h	Energy need for space heating
Q_{tw}	Energy need for DHW heating
Q_f	Final energy (delivered energy)
Q_P	Primary energy
S/V-value	Surface area-to-volume ratio
U-value	Thermal transmittance
W/m^2K	Watt per square metre per Kelvin
WE	Housing unit
WRG	Heat recovery
WSVO	Thermal Insulation Regulation

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Glossary

Heated net floor area	Available usable floor area in a heated building volume.
Degree of photovoltaic self-sufficiency	Proportion of self-generated renewable electricity from photovoltaic systems compared to the overall electricity consumption of the building.
Degree of photovoltaic self-use	Ratio between self-used electricity and the total amount of renewable electricity generated on the plot.
Final energy (delivered energy)	Volume of energy of the used energy carriers required to supply the building with energy (e.g. electricity, natural gas, wood pellets, district heating). It includes auxiliary energy required to operate the systems technology.
Energy performance certificate (EPC)	Document on the energy assessment of a building stating requirements, based on calculations and as proof of consumption based on measurements. The principles, underlying basis, type, presentation and use is regulated by the Energy Saving Ordinance (EnEV).
Seasonal performance factor (SPF)	Figure to describe the energy-efficiency of heat pumps. It indicates the relation between volume of heat delivered by the heat pump system for heating and hot water to the required electricity consumption of the system. The higher the SPF, the more efficient the heat pump.
Primary energy	Volume of energy that, in addition to the energy consumed by the required fuels and auxiliary energy for the systems technology (final energy), also includes the volumes of energy created by previous process chains outside the building in generating, converting and distributing the fuels used.
Thermal transmittance (U-value)	The thermal transmittance (U-value) describes the thermal insulation properties of building elements in (W/(m^2K)). It indicates the thermal flow in a Kelvin temperature difference per square metre. The smaller the value, the better the building element's thermal-insulating effect.
Heat recovery	Technology to use the heat in exhaust air or wastewater. Ventilator-supported ventilation systems use the technology e.g. with a heat exchanger.