Federal Ministry for the
Environment, Nature Conservation,
Building and Nuclear Safety

Strategies for Efficiency Houses Plus

Principles and examples of energy-generating buildings

Imprint

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Introduction

By mid-century, we intend to have our building stock virtually climate-neutral. This will only be possible if we gradually introduce new developments in the building sector and bring new technologies to the market, providing the highest level of energy efficiency and cost effectiveness. The Efficiency House Plus is a development that offers a valuable and innovative way of achieving this.

Buildings are being constructed as micro power plants that do not compromise aesthetic appeal or quality of life. Calculated over the entire year, they produce more energy than is required for operation and use. The idea is to use the surplus energy for electric mobility or for the neighbourhood's energy needs. In 2011, the German government set up its own pilot project in Berlin – an Efficiency House Plus with electric mobility, designed to test this new standard and at the same time explore possible synergy effects between the new generations of buildings and electric vehicles.

The aim is not just to carry out one-off beacon projects but to work with different solutions and optimise different technologies within the Efficiency Houses Plus network. This makes it possible to put different approaches to the test and ascertain how efficient and economical they are. Overall, 37 buildings are currently part of the nationwide Efficiency Houses Plus network. Many were completed between 2013 and 2015 and have been scientifically monitored and compared ever since. In addition to 36 new builds, a major modernisation project has been carried out on multi-storey residential buildings in Neu-Ulm: 1930s apartment blocks with a high energy demand of over 500 kilowatt-hours per square meter per year have been converted into plus energy houses. An energy review is currently being carried out with 19 buildings in Wuppertal as part of a neighbourhood solution. The next stage will entail transferring the idea to the non-residential buildings sector under the new programme, "Educational buildings built to Efficiency House Plus standard".

We would like to invite you to get to know this climate-friendly generation of buildings. This brochure provides information about this innovative, climate-neutral building standard and the scientific findings from the Efficiency Houses Plus network.

Pioneers of the building standard Efficiency Houses Plus supported by the Federal Building Ministry:

Solar Decathlon winner 2007, TU Darmstadt (Professor Manfred Hegger)

Solar Decathlon winner 2009, TU Darmstadt (Professor Manfred Hegger)

Efficiency House Plus with electromobility, beacon project in Berlin in 2011 (Professor Werner Sobek)

FORSCHUNGSINITIATIVE Zukunft BAU   PLUS EffizienzHaus

Brands of the two Research Initiatives: "Future Building" and "Efficiency House Plus".

Development of energy-saving buildings

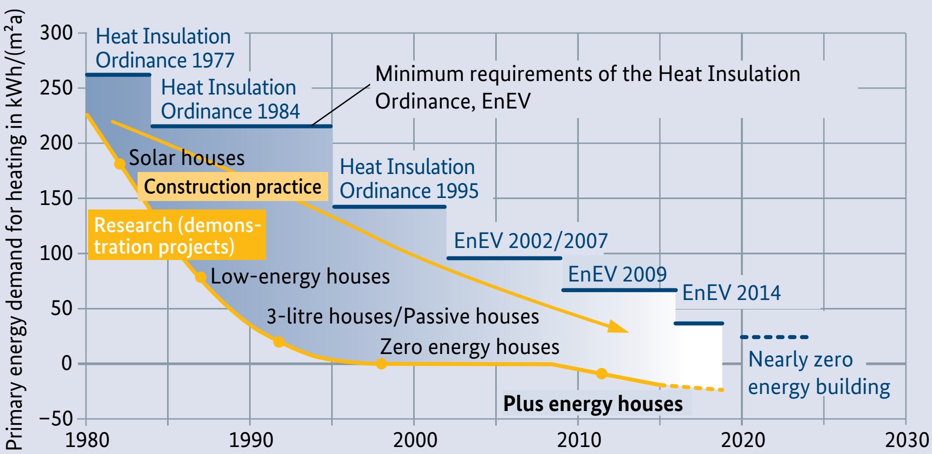
There is a long tradition of energy-saving buildings in Germany. Research into the buildings of the future that can be inhabited without having any impact on the climate has been ongoing for over 30 years. The low-energy building has been a minimum statutory requirement for new builds for over 15 years.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

The Plus Energy House presentation and exhibition pavilion, pictured here in Munich in 2009

In 2007, Technische Universität (TU) Darmstadt developed a plus energy house as part of its "Zukunft Bau" research initiative to enable it to take part in the renowned "Solar Decathlon" competition in Washington DC. (USA). The competition is open to scientific institutions and universities worldwide. The competition looks at the performance of the demonstration buildings in ten different areas but the most important goal is that they produce more energy than they consume when fully used. TU Darmstadt won this competition in 2007 and 2009. The Federal Building Ministry of the time – BMVBS – erected its own pavilion based on TU Darmstadt's 2007 building and used it for presentations and an exhibition on the concept during a unique tour of Germany that went to six metropolitan regions between 2009 and 2011. The building's final location is the Phoenixsee development in Dortmund.

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. In other words, it is an approach that embraces all possible technologies.

Figure 1: Primary energy demand of a semi-detached house



Developmental progress of the primary energy demand of semi-detached houses over the last 36 years. The bottom curve shows pilot research projects, whereas the top curve records the statutory minimum requirements. Innovative construction practice is somewhere between these two curves.

Source: Fraunhofer Institute for Building Physics

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 shall contribute to the attainments of 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 specific transmission heat loss for new residential buildings that must be complied with. 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 builds 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.

As a result of their high energy standards, Efficiency House Plus buildings meet both these requirements. Nevertheless, they also have to provide evidence of their energy performance as required under the Energy Saving Ordinance (EnEV) and Act on the Promotion of Renewable Energies in the Heat Sector (EEWärmeG).

Figure 2: Requirements in accordance with the German Energy Savings Ordinance (EnEV) and the German Act on the Promotion of Renewable Energies in the Heat Sector (EEWärmeG)

Requirements of the Energy Saving Ordinance (EnEV)

A new residential building's maximum annual primary energy demand is the value of a reference building that has the same geometrical configuration, aspect and use as the building to be built and meets certain specifications regarding its building envelope and services.

Definition of annual primary energy demand

This is the amount of energy needed to meet the annual heating energy demand QH and energy required to deliver hot water QHW (both the actual energy required and the energy used by the heating and hot water system itself). It also includes the additional amounts of energy used by upstream processes beyond the building itself to extract, convert and distribute the particular fuel used.

Implementation of the European Directive on the Energy Performance of Buildings (EPBD) in Germany

→ **EU Directive**
Overall energy performance of buildings

↓

→ **EnEG Energy Conservation Act**
Specification of economic viability

↓

→ **Amendment to the EnEV**
Material regulations regarding requirements, methods, energy performance certificates, inspections

↓

→ **Technical guidelines, standards** (for example simplified data acquisition, energy consumption values),
→ **DIN V 18599** "Energy efficiency of buildings",
→ **DIN V 4108-6**,
→ **DIN 4701-10 Supplement 2**,
→ **DIN V 4108** …

Requirements of the German Act on the Promotion of Renewable Energies in the Heat Sector (EEWärmeG)

100 percent compliance with the Renewable Energies Heat Act based on		Minimum requirement
Renewable energies	Solar radiation	**15 %**
	Solid biomass	**50 %**
	Liquid biomass	**50 %**
	Gaseous biomass in GHP	**30 %**
	Geothermal energy and ambient heat	**50 %**
Acceptable alternatives	Waste heat recovery systems	**50 %**
	CHP plants	**50 %**
	Energy saving measures	**~15 %**
	Local or district heating with renewable energy in the above-mentioned percentages or acceptable alternatives	

Source: Fraunhofer Institute for Building Physics (IBP)/Hegner, Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB)

Figure 3: Energy performance certificate for residential buildings to Efficiency House Plus standard, established in June 2012

ENERGY CERTIFACTE[1)]for residential buildings

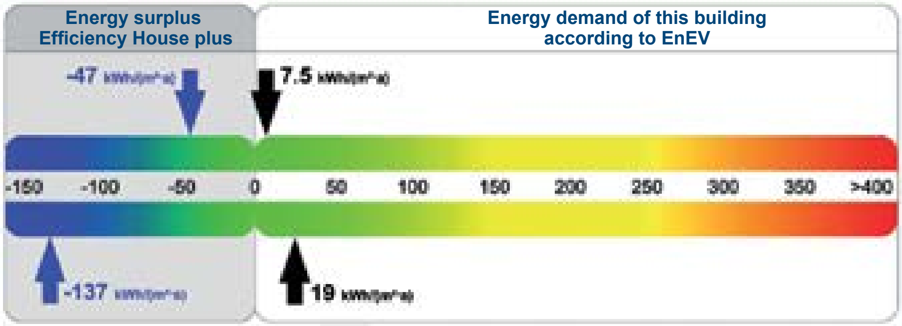
according to section 17, subsection 4 German Energy Saving Ordinance (EnEV)

Calculated energy demand of the building

Adress, building part: Fasanenstraße 87, 10623 Berlin (Germany)

2

Energy surplus Efficiency House plus and energy need acc. to EnEV



Method used for calculating the energy demand

Acc. to Efficiency house plus assessment (DIN V 18599)

Energy surplus

Final energy -47.4 kWh/(m²·a)

Primary energy -137.4 kWh/(m²·a)

Requirements acc. to EnEV[2)]

Primary energy demand

Actual value 19.4 kWh/(m²·a) Required value 86.9 kWh/(m²·a)

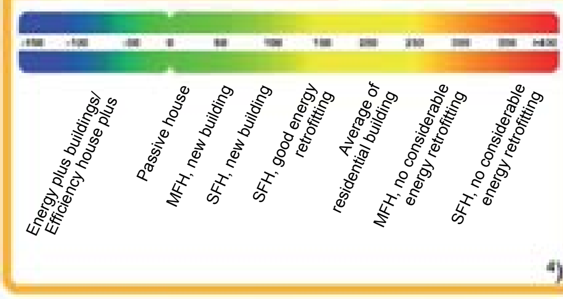
Energy quality of the building envelope H

Actual value 0.33 W/(m²·K) Required value 0.40 W/(m²·K)

Final energy in kWh/m² · a)

Energy carrier	Annual energy demand acc. to EnEV: Heating	Hot water	Auxiliary equipment[3)]	Total	Additional elements: Domestic appliances	Electricity fed into the grid	Electricity fed into the grid	Final energy surplus (total)
electricity	6.5	0.97	-	7.5	0.62	3.5	-59.0	-47.4

Reference values energy demand



Commentary on calculation methods

The calculations are based on extended EnEV verification according to DIN V 18599, including a normalized energy demand for lighting and domestic appliances, excluding surplus renewable energy that was generated within the balancing zone and fed into the grid (as set out in BMUB brochure "What makes an Efficiency House Plus?"). Due to standardized boundary conditions in particular, the reported values do not allow to draw conclusions with regard to the actual energy consumption. The given demand values are specific values determined per square metre of usable floor areas (AN).

1) as set out in BMUB brochure "What makes an Efficiency House Plus?"

2) for new and retrofitted buildings acc. to section 16 subs. 1 clause 2 EnEV

3) including cooling (if applicable)

4) SFH: single-family homes, MFH: multi-family homes

Page of additional information supplementing the energy performance certificate for Efficiency Houses Plus as required under Section 17 of the Energy Saving Ordinance (can be generated using the calculation tool, see next page)

Source: Fraunhofer Institute for Building Physics

Definition: Efficiency House Plus

Definition: Efficiency House Plus[1]

The Efficiency House Plus standard[2] is deemed to have been achieved if a building has both a negative annual primary energy demand (∑Qp < 0 kilowatt hours per square meter per year) and a negative annual delivered energy demand (∑Qe < 0 kilowatt hours per square meter per year). All other requirements of the Energy Saving Ordinance (EnEV), such as those relating to insulation to improve heat insulation in the summer, must also be in compliance with them.

Evaluation method: extended Energy Saving Ordinance certificate as specified under DIN V 18599

The currently applicable Energy Saving Ordinance (EnEV) requires that certification shall be provided as set out in DIN V 18599. The networks total injected current shall be assessed analogously to the repression power 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 delivered and primary energy demand values for user energy consumption must be included in the calculations. An overall delivered energy demand of 20 or 35 kilowatt hours per square meter per year (however, not exceeding a maximum of 2,500 kilowatt hours per square meter per housing unit) is used for residential buildings depending on the building type (detached house or apartment block). For educational buildings depending on the energy efficiency of the appliances used, 10 or 15 kilowatt hours per square meter per year is assumed.

Boundary for the purpose of the performance assessment: Boundary of the property

The boundaries used in the performance assessment (also for the purposes of including renewable energy facilities) are the boundaries of the plot on which the house is to be built. As an extension to the area for assessment as defined in the Energy Saving Ordinance (as being directly connected to the building), the sum total of all the energy generated from renewable sources within the site boundaries (on-site generation) can be counted. The site 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.

Supplementary requirement: Use appliances with the best energy efficiency rating

Any building to be funded must be equipped throughout with smart meters and with appliances that have the highest possible energy efficiency rating (usually labelled A++ or higher under the Energy Consumption Labelling Ordinance of 30 October 1997 [Federal Law Gazette I page 2616], last amended by Article 1 of the Ordinance of 24 October 2014 [Federal Law Gazette I page 1650].

Additional information required on the certificate: The percentage of renewable energy generated used on site

In addition to the single values – “annual primary energy demand and annual delivered energy demand” – the ratio of renewable energy generated on siteto energy used within the boundaries of the area covered by the performance certificate must be shown. The calculation must be done as set out in the Energy Saving Ordinance on the basis of monthly performance.

Calculation tool

The standardised calculations for an Efficiency House Plus can be carried out using free online software (*www.effizienzhaus-plus-rechner.de*).

1 The Efficiency House Plus is also known in common parlance as the “Plus Energy House”.
2 Notification by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety on the awarding of grants for pilot projects built to the Efficiency House Plus standard.

The component parts: Energy efficiency and renewable energy sources

By comparison with traditional building practices, the Efficiency House Plus is based on three key principles:

- → Increase the building's energy efficiency as much as possible
- → Lower the energy demand of the household processes as much as possible
- → Use renewable energy to meet the remaining energy requirement

Since this design concept requires all the energy needed in the building to be supplied from renewable energy sources in the building's immediate surroundings, it makes sense to reduce the amount of energy needed by improving energy efficiency as far as possible.

Energy efficiency is reduced by building design (compact building form, optimum orientation), thermal insulation (highly efficient windows and thermal insulation systems for the building envelope), optimised workmanship (no thermal bridges with zero tolerance and airtight structures and structural connections), and energy-conscious behaviour on the part of the occupants (supported, for example, by energy use displays, smart metering). At the same time, occupant comfort is usually increased by the measures to reduce energy demand, since the warm surfaces produced generate a greater feeling of 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 amounts of energy needed to operate pumps and fans), by heat recovery systems in the ventilation and waste water systems, hydronic balancing in all systems (which means lower amounts of energy needed to operate 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 in conjunction with demand-controlled systems).

Renewable energy can be actively and passively used in the building. On the one hand, passive solar gains through the windows can be used at no cost at all to reduce the need for heating energy and, on the other hand, the need to reduce artificial lighting. Renewable energies can also be actively harnessed using thermal solar collectors, biogenic fuels, geothermal and ambient heat. What makes the "plus" of the buildings are electricity-generating systems such as photovoltaics or wind turbines. In the meantime, the surplus produced can be stored in the building and, if there is still a surplus, fed into the grid of the energy suppliers.

Figure 4: The energy columns of a Efficiency House Plus

Efficiency House Plus

Build energy efficiency

- → Design a compact building
- → Optimum orientation
- → Thermal zoning
- → Heat insulation
- → "Super windows"
- → Avoid thermal bridging
- → Airtightness
- → Screens to depict behaviour visually
- → Low system temperature
- → Short pipe runs
- → Hydronic balancing
- → Efficient operating systems
- → Demand-controlled systems
- → Efficient appliances
- → Efficient lighting
- → Heat recovery

Use renewable energy sources

- → Solar gains through the windows
- → Use daylight
- → Solar collectors
- → Biogenic fuels
- → Geothermal or ambient heat
- → Heat recovery
- → Photovoltaics
- → Wind turbines

Source: Fraunhofer Institute for Building Physics

Key parameter: Building design

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

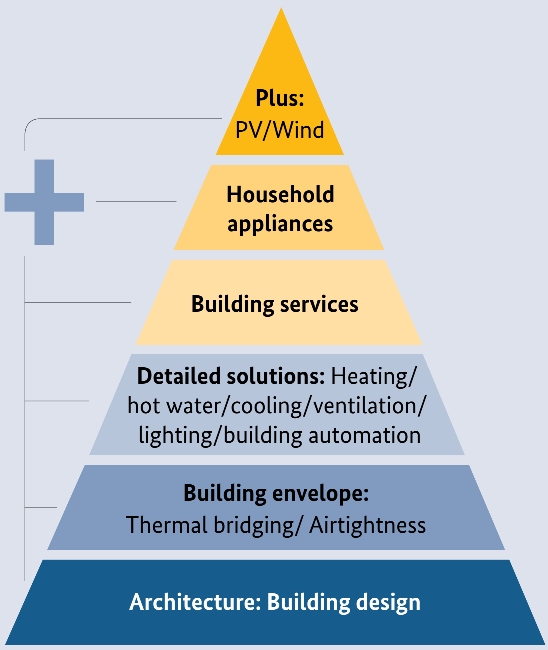
Compactness

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 (A/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 surface area and usually have poorer thermal insulation.

Figure 5: The design pyramid for the Efficiency House Plus

Design factors that influence energy

- → Compactness
- → Thermal insulation measures
- → Orientation
- → Ventilation design
- → Zoning of the building
- → Heating design



Source: Fraunhofer Institute for Building Physics

Orientation

Optimal use of solar energy through windows relies on as many surfaces as possible facing south. South-facing roofs with an incline of about 30 grad enable optimum 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 shallow pitch.

Zoning of the building

Rooms that are not heated as much, such as parents' bedrooms or the kitchen, should be north-facing. A lower temperature can be set in rooms with direct sunshine than in shaded rooms. The layout should be organised in order 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 heat losses of the entire building. Open-plan designs over several storeys may pose a problem in terms of energy consumption.

Focus on building services

The layout of the building should be such that the boiler room/plant room is in the centre of the building 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 pipe runs between solar collectors and the storage tank and for exhaust gases are as short as possible. The service shafts should also be in a central position in the heated area of the building, to keep distribution pipe runs short and heat losses low.

! Tip

A more compact building pays off twice over: a reduction in surface area to volume (A/V) ratio of 0.1 meter^{-1} usually lowers heat-energy demand by up to ten kilowatt hours per square meter per year and at the same time lowers construction costs by 50 to 80 euros per square meter. The use of bay and dormer windows in particular should be reconsidered.

Key parameter: Building envelope

The quality of a building's thermal insulation is the main factor determining its need for heating energy. Between 50 and 75 percent of heat lost from an average building is a result of transmission heat losses through the building envelope. Insulating external building components thus has huge energy saving potential and has proven to be the most reliable way of reducing the need for heating energy. Without high-quality thermal insulation it is not possible to achieve an Efficiency House Plus.

External walls

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

Windows

As a rule, it is windows that have the lowest insulation value of all external building components. However, windows can also permit significant solar gains to be achieved, so that with appropriate siting and orientation the passive solar gains from windows can completely compensate for heat losses. Modern triple glazed windows usually have U values of 0.9 watt per square meter per kelvin (W/m²·K) or less.

Basement ceilings/floor slabs

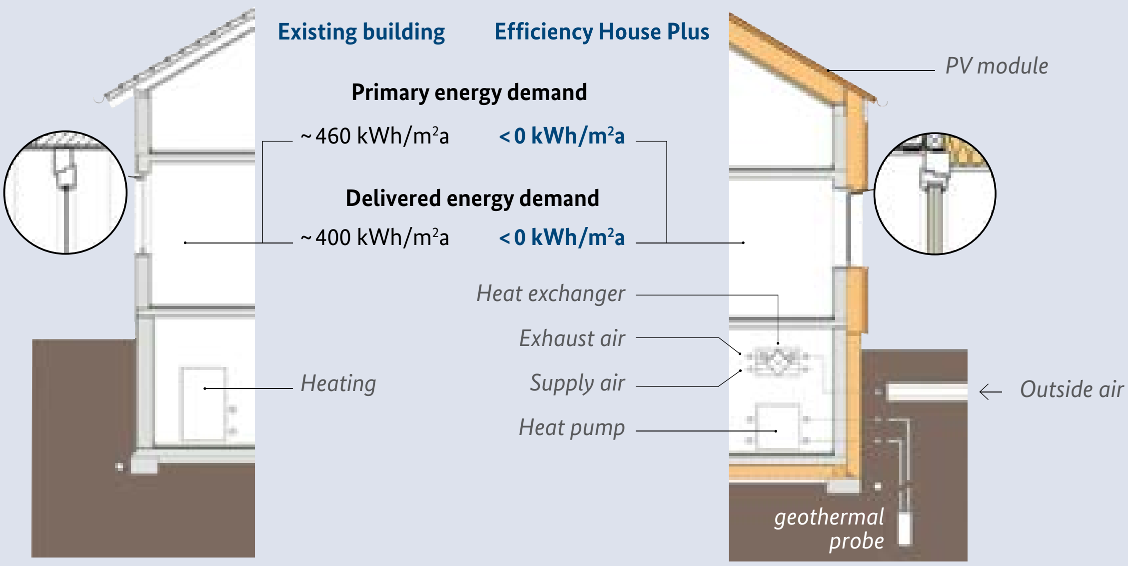
The average difference over a year between the temperature above a floor slab and the ground beneath it is only about half as much as the temperature difference when building components have contact with outdoor air. This means that heat insulation measures in these areas of a building are not as effective.

! Tip

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

Figure 6: Comparison between existing building and Efficiency House Plus

Example of the structure and heating system of an Efficiency House Plus and an indication of its energy demand as compared with a 50-year old building.



Source: Hauser, Fraunhofer Institute for Building Physics (IBP)/Technical University of Munich

Key parameter: Specifics

Prevent thermal bridging

The additional energy losses from thermal bridges can be calculated as heat loss per unit length of thermal bridge [W/mK]. The influence of thermal bridges on heating energy demand is easy to calculate once the linear thermal bridge loss coefficient has been determined. Additional heat losses through thermal bridges are between 0percent in a best-case design and 25 percent in a minimum-case scenario. For a detached house with 150 square meters of heated living space this produces an additional demand for heating energy of up to 1,500 kilowatt hours per square meter, depending on the standard of the building. A stringent inspection of the workmanship is therefore crucial, since well-designed connection details that have been unsatisfactorily carried out can often cause weak points in terms of energy.

Make the building airtight

In addition to the air change rate at that can normally be ensured by opening windows or using mechanical ventilation systems, additional uncontrolled infiltration air change occurs at connections between building components, points where the building's envelope is not airtight and more. 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 degree of tolerance is comparable with the influence of thermal bridges (about ten kilowatt hours per square meter per year). To achieve an airtight building envelope an airtightness plan must be prepared in the scheme design phase. 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 needs to be taken with converted loft spaces that have purlin and trussed rafter roofs since their structure means there are many points at which the shell of the building is pierced. During construction of a building, care must be taken to ensure that after the airtight skin has been completed no leaks are caused by subsequent work. Possible leaks can be located by blower door tests.

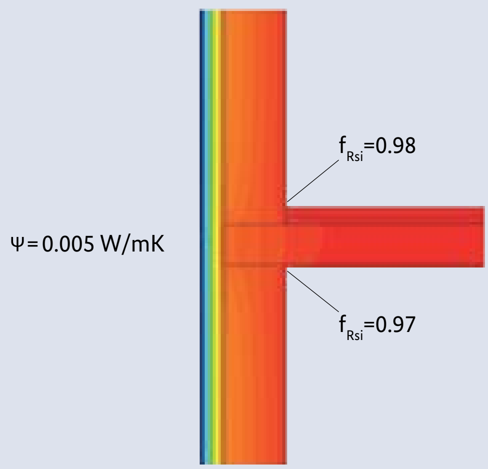
! Tip

Airtightness and minimising thermal bridges have comparable energy saving potential of more than 10 kilowatt hours per square meter per year.

Figure 7: Calculation of the influence of thermal bridges on the temperature and heat flows

Structural connections	Coefficient for heat loss per unit length of thermal bridge Ψ [W/mK]	
Corners of external walls	-0.30	-0.07
Window/reveal	0.06	0.12
Window/wall beneath	0.13	0.20
Window/lintel	0.06	0.25
Floor supports	0.00	0.15
Basement floor supports	-0.14	0.20
Roof/eaves	-0.20	0.11
Roof/verge	-0.03	0.10

The range of heat loss per unit length of thermal bridge in common structural connections: There is significant potential for savings between a design that minimises thermal bridging (minimum) and a standard design (maximum), which must be exploited when planning an Efficiency House Plus.



Example of floor supports: Thermal bridging can almost be avoided completely with well planned connection details.

Source: Hauser, Fraunhofer Institute for Building Physics (IBP)/Technical University of Munich

Key parameter: Building services

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

Heating

Heat losses during heat generation can easily be as great as those from the space heating demand it is meant to be covering. 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). A common way of using ambient heat for heating purposes involves heat pumps to utilise the thermal energy contained in the ground, ground water or ambient air. Thermal solar systems are sometimes used as supplementary heating, in conjunction with seasonal storage systems, to provide base load heating. 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 the same as the space heating demand to be covered. Circulation pipes can easily cause the energy demand to more than double. 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. Solar water heating is now well developed and works reliably; it can save up to two thirds of the energy demand for hot water.

Cooling

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

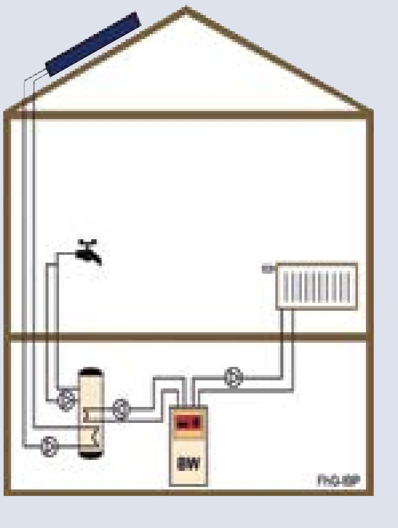
! Tip

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

Figure 8: Use of ambient heat by means of a heat pump and geothermal probe

Source: German Heat Pump Association (BWP)

Figure 9: Schematic diagram of the heating system with solar water heating



Source: Fraunhofer Institute for Building Physics

Ventilation

Controlled residential ventilation systems with heat recovery units can significantly reduce ventilation heat losses. Heat recovery rates of 80 percent are not at all 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 five 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. 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 lighting solutions (in kitchens or studies, for example) can also have a significant effect. 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 a good idea to consider using lighting management systems (for example, presence detection) in hallways, basements and for outdoor lighting.

LED lighting in the living area

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 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 their energy use will cancel out any savings!

! Tip

Check the power rating of your ventilation system. If possible, it should be less than 50 watts per housing unit. Every additional watt of power uses ten kilo watt hours of electrical energy a year.

Key parameter: Household appliances

The average amount of electricity used by Germany's 40 million households for household processes and lighting (not counting space and water heating) is currently 2,650 kilowatt hours per year (30 kilowatt hours per square meter per year), and the trend is rising slightly.[3] Of this total, 33 percent is accounted for by household processes (cooking, drying laundry, and ironing), approximately ten percent by lighting and the remaining 57 percent by household appliances and consumer electronics. About 13 percent of households' electricity consumption is accounted for by stand-by losses, especially from consumer electronics and computer equipment.

Labelling is mandatory for the following household appliances:

- → Refrigerators and freezers
- → Fully automatic washing machines
- → Tumble dryers
- → Washer dryers
- → Dishwashers
- → Electric ovens
- → 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 given precise information about this. Providing this information to consumers is a statutory requirement and is regulated in Germany by the Energy Consumption Labelling Ordinance (EnVKV). Tumble dryers have the highest level of consumption but also the greatest potential for savings, followed by refrigerators and freezers.

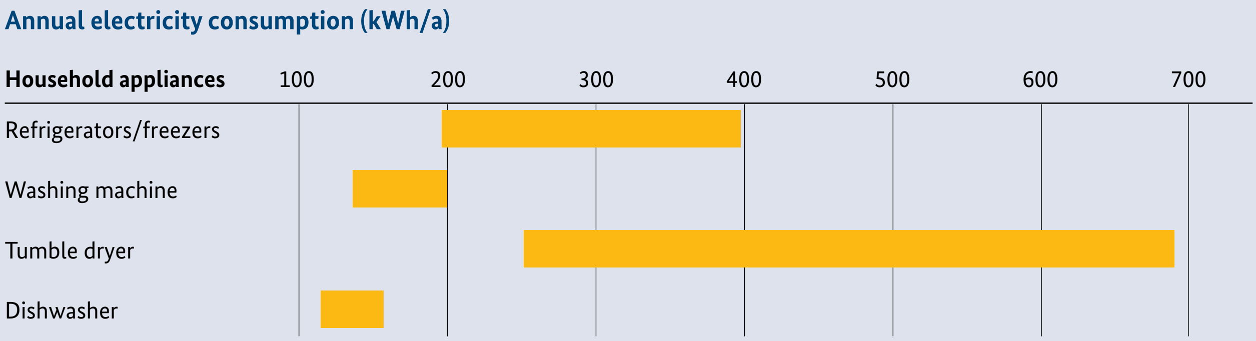
Stand-by consumption

This is the electricity used when an appliance is in standby 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 hour of electricity a year.

! Tip

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

Figure 10: **Range of electricity consumption of selected household appliances: Top runner in 2010 compared to standard appliances**



Source: Fraunhofer Institute for Building Physics

3 German Federal Statistics Office; Press release of 18 October 2010.

Key parameter: What makes the "plus" of Efficiency Houses?

Building an Efficiency House Plus involves integrating renewable energy generation systems. These usually take the form of photovoltaics or domestic wind turbines. Alternatively, surplus heat gains from waste heat or thermal solar 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 (Combined Heat and Power) units may be eligible for a credit for primary energy, but in terms of delivered energy they cannot count towards a net energy gain.

Photovoltaics

Solar energy is converted into direct current by solar cells that are connected to solar modules. Generated electricity can be used directly on site, can be 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. The photovoltaic modules are made of monocrystalline or polycrystalline solar cells. The efficiency of monocrystalline photovoltaic modules is between 14 and 24 percent. The polycrystalline modules have an efficiency of between 13 and 18 percent. The rated output (maximum output) of a solar module is specified in Wp (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.

! Tip

Obtain a guarantee of your photovoltaic system's system performance factor from the installer. It is common practice to provide this to investors and banks.

The system performance factor of a photovoltaic system should generally speaking 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 eight to ten square metre surface) in Germany can deliver an annual yield of between 700 and 1,100 kilowatt hours per year depending on 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.

Efficiency House Plus by the firm BAUFRITZ in Poing with a wind power tower and a fuel cell heating system.

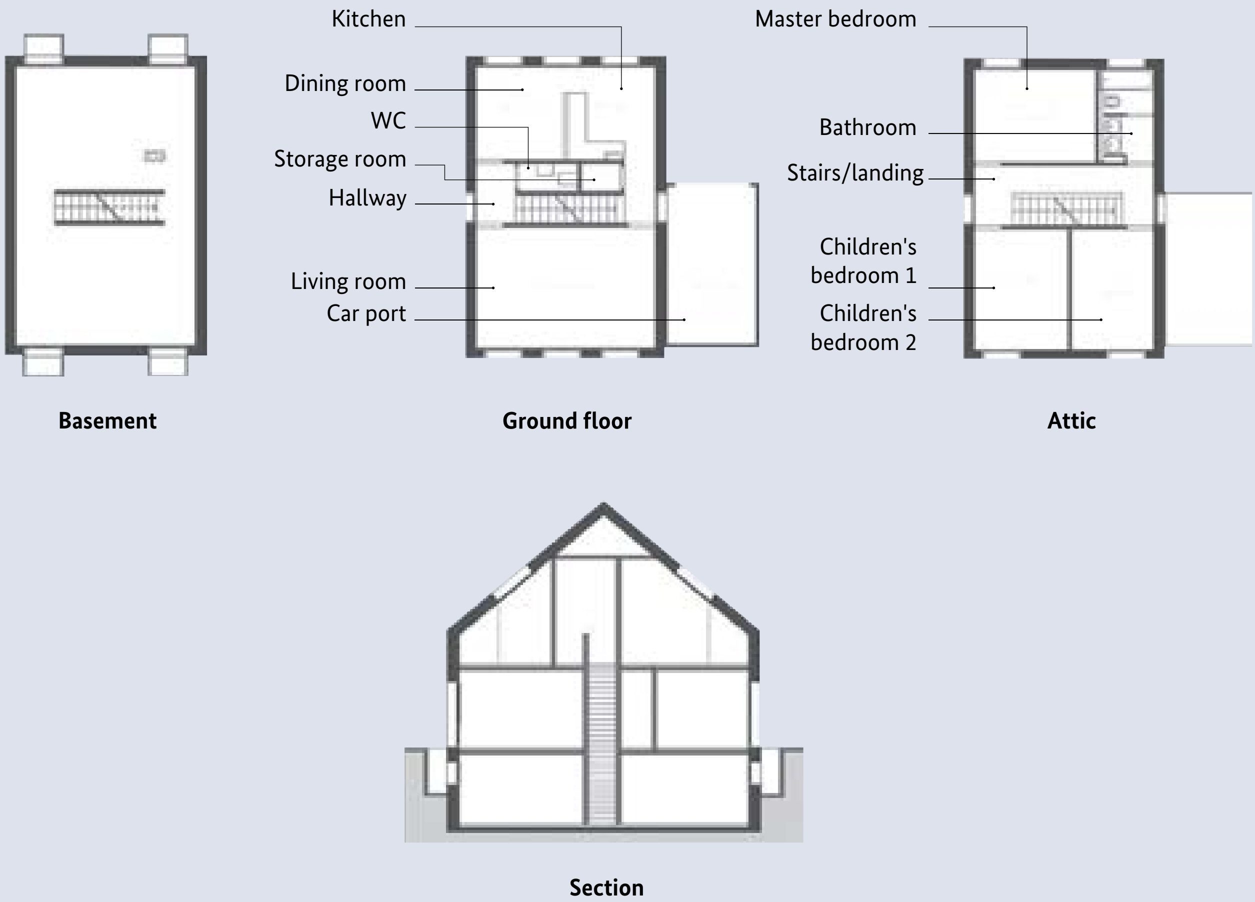
Typical values for a model house

Below we have taken the example of an average detached house to illustrate the wide range of options for building an Efficiency House Plus. In terms of size, the building represents the average for all detached houses built in Germany since 1990. The building form and the room layout are simply examples; in practice there is great diversity.

Typical values
- → Living space: 108 square meter
- → South-facing roof area: 71 square meter

U values (watt per square meter per kelvin [W/m²K])
- → external wall: 0.11
- → roof: 0.11
- → top floor ceiling: 0.11
- → basement ceiling: 0.12
- → windows: 0.80
- → roof lights: 1.20

Figure 11: Building type: detached house



Source: Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB). The floor plans are by Luis Ocanto-Arciniegas, Ourstudio, Dortmund.

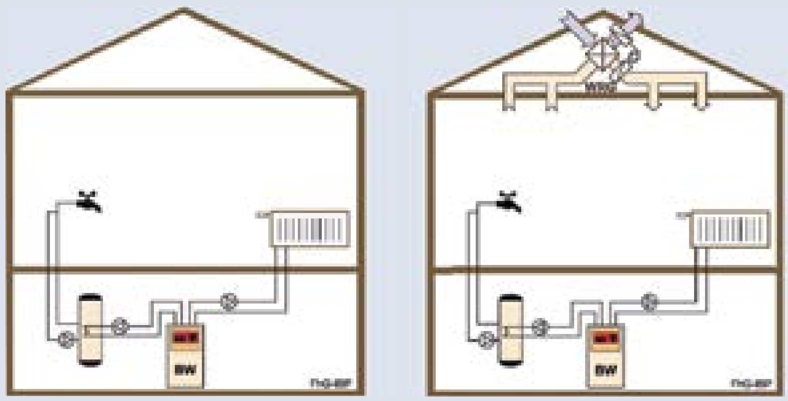
Model house options

The model building studied was equipped with four different building services systems. The table below shows calculations that were done to ascertain how large the photovoltaic area needs to be to make this building into an Efficiency House Plus. Whereas the building conventionally equipped solely with a condensing boiler needs a photovoltaic area of 98 square meters (which is larger than the available roof area), the same building with an efficient residential ventilation system needs only 83 square meters photovoltaic area (for which there is almost enough space on the south-facing roof). Option 2 (condensing boiler, residential ventilation system and solar water heating) and option 3 (air heat pump and residential ventilation system)

Figure 12: Comparative calculations to determine the required PV surfaces

Option 0:
Condensing boiler, window ventilation

Option 1:
Condensing boiler, residential ventilation system and an 80 percent heat recovery rate



	Option 0: Condensing boiler, window ventilation	**Option 1:** Condensing boiler, residential ventilation system and an 80 percent heat recovery rate
Not including photovoltaics (PV)		
Delivered energy demand [kWh/m²a]		
Heating and hot water	65.2	48.6
Auxiliary energy	3.4	5.7
Household and lighting	20.0	20.0
Total	**88.6**	**74.3**
Primary energy demand (not including PV) [kWh/m²a]	**106.7**	**94.4**
Including photovoltaics (PV)		
Photovoltaic area required [m²]	**98**	**83**
Delivered energy demand [kWh/m²a]	**-0.1**	**-0.7**
Primary energy demand [kWh/m²a]	**-118.7**	**-91.5**

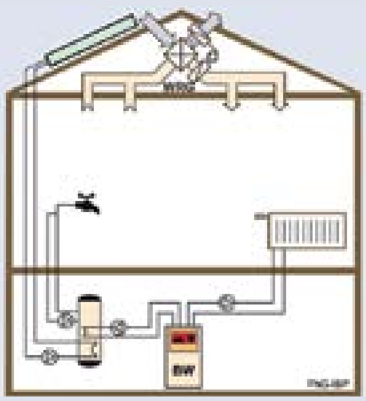
Source: Fraunhofer Institute for Building Physics

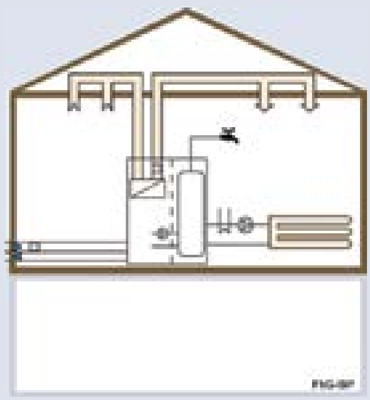
need only 63 and 44 square meters photovoltaic area respectively, for which there is sufficient available space on the southern roof slope.

The comparative calculations illustrate that a very energy-efficient building is required, in conjunction with photovoltaic systems, to achieve an Efficiency House Plus. Neither installing a photovoltaic system alone, nor an energy-efficient building alone, is sufficient to achieve this goal. It is only the combination of all the different measures that produces the desired Efficiency House Plus.

Option 2:
Condensing boiler, residential ventilation system and an 80 percent heat recovery rate, solar water heating

Option 3:
External air/exhaust heat pump, residential ventilation system and an 80 percent heat recovery rate





	Option 2: Condensing boiler, residential ventilation system and an 80 percent heat recovery rate, solar water heating	**Option 3:** External air/exhaust heat pump, residential ventilation system and an 80 percent heat recovery rate
Not including photovoltaics (PV)		
Delivered energy demand [kWh/m²a]		
Heating and hot water	30.2	12.5
Auxiliary energy	6.0	6.9
Household and lighting	20.0	20.0
Total	**56.2**	**39.4**
Primary energy demand (not including PV) [kWh/m²a]	**76.7**	**70.9**
Including photovoltaics (PV)		
Photovoltaic area required [m²]	**63**	**44**
Delivered energy demand [kWh/m²a]	**-0.8**	**-0.4**
Primary energy demand [kWh/m²a]	**-58.9**	**-18.9**

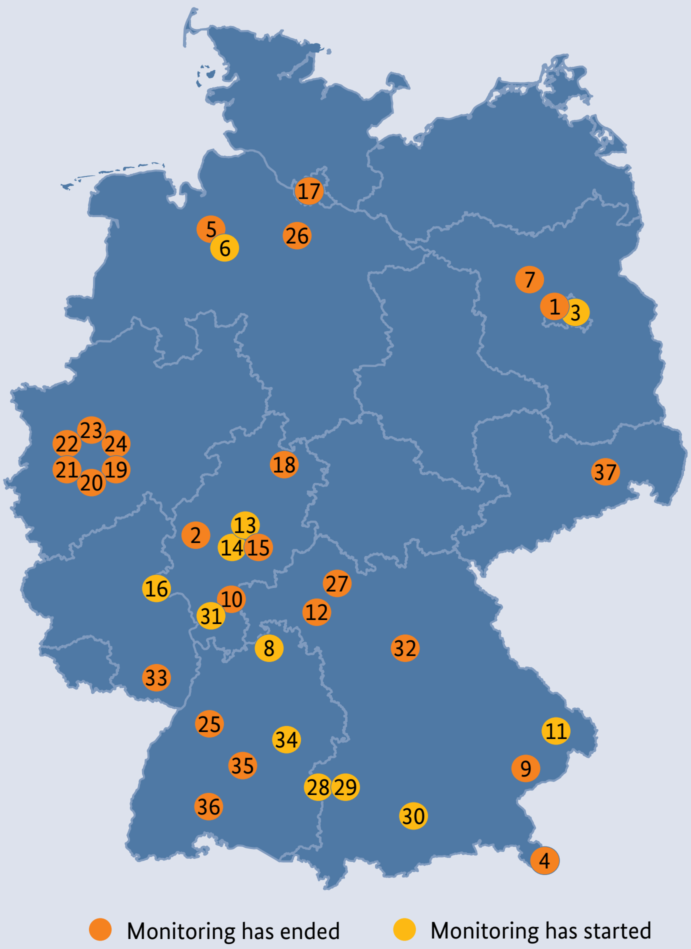
Efficiency House Plus: a German government research initiative

In 2011, the first state-owned Efficiency House Plus was constructed as a pilot building in Berlin. At the same time, the Federal Building Ministry launched a research funding programme for pilot houses that meet the specifications of the Efficiency House Plus standard. The programme is supporting 37 building owners throughout Germany in constructing or renovating residential buildings that produce significantly more energy than is needed to run them. The pilot projects are being evaluated as part of a technical and social-scientific framework programme.

The findings will be used to improve energy management in modern buildings and further develop the components needed for energy-efficient building envelopes and renewable energy generation. The buildings are tested and evaluated under real-life conditions; in other words, with occupants. 37 projects were included up to summer 2016, 25 buildings of which have already completed a two-year monitoring period and six buildings a one-year monitoring period. The buildings constructed to date include both single and dual family homes and apartment blocks with between 6 and 74 housing units.

Further information on the "Efficiency House Plus" network can be found at: www.forschungsinitiative.de/effizienzhaus-plus

Figure 13: Locations of the demonstration buildings in the German government's "Efficiency House Plus" funding programme



Number	Town	Page:
1	Berlin, Pilot project	21
2	Bad Homburg	38
3	Berlin	40
4	Bischofswiesen	37
5	Bremen	35
6	Bremen	39
7	Brieselang	35
8	Buchen-Hollerbach	39
9	Burghausen	38
10	Darmstadt	37
11	Deggendorf	39
12	Eußenheim	35
13–14	Frankfurt am Main	40
15	Frankfurt am Main	38
16	Geisenheim	40
17	Hamburg	37
18	Kassel	38
19–24	Cologne	36
25	Leonberg-Warmbronn	35
26	Lüneburg	37
27	Münnerstadt	35
28–29	Neu-Ulm	40
30	Poing/Grub	39
31	Riedstadt-Crumstadt	39
32	Schwabach	37
33	Stelzenberg	35
34	Stuttgart	39
35	Tübingen	38
36	Unterkirnach	38
37	Weifa	37

Source: Fraunhofer Institute for Building Physics (IBP)

The German government‘s pilot project

With its first state-owned Efficiency House Plus with electric mobility, the Federal Building Ministry has laid the cornerstone for its research programme and the network that has evolved from this. The pilot building designed by Professor Werner Sobek is located at Fasanenstraße 87a in 10723 Berlin-Charlottenburg, Germany. It was opened on 7 December 2011 by German Chancellor Dr. Angela Merkel.

Usage

The research building was home to two test families over a year-long period. In between times, it provided any interested parties with comprehensive public information and events programmes on energy-efficient buildings. From 2017, the building will reopen to the public as an information centre for presentations and exhibitions.

Concept

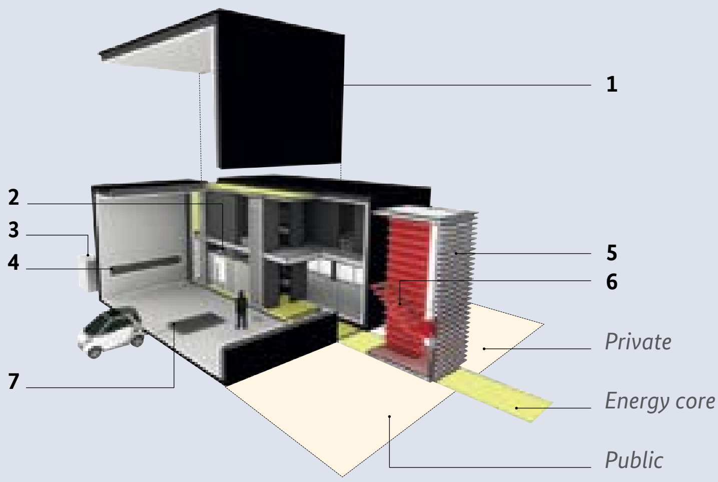
The detached house comprises about 130 square meters of living space and is designed for a family of four. The “glass showcase” in front of the house is designed for parking and charging electric vehicles (e-cars and e-bikes). Between the two-storey living space and the “showcase” is what is known as the building’s “energy core”, which houses all the building services and the wet rooms.

The Front …

… and the garden of the pilot model building in Berlin

Figure 14: Key design elements

1 Photovoltaic module, integrated into the façade and on the roof
2 Energy and technology centre
3 Battery
4 Information display and conductive charging system
5 Fixed slats
6 Stairs
7 Inductive charging system



Source: Werner Sobek, Stuttgart

Planning

Dynamically linked system and building simulations are integral to the planning process of an Efficiency House. They include the structural properties of the building envelope, the intended use, the probable use, the building services and the local climate data.

In addition to the energy aspects, the project is also intended to provide a response to sustainability issues. The building has been analysed according to the Assessment System for Sustainable Building (BNB) criteria and has received the gold certificate as proof of its high standard. One of the aims was that the house should achieve complete recyclability. As a temporary construction, it is also designed to allow flexible use and ensure a high level of comfort.

Building envelope

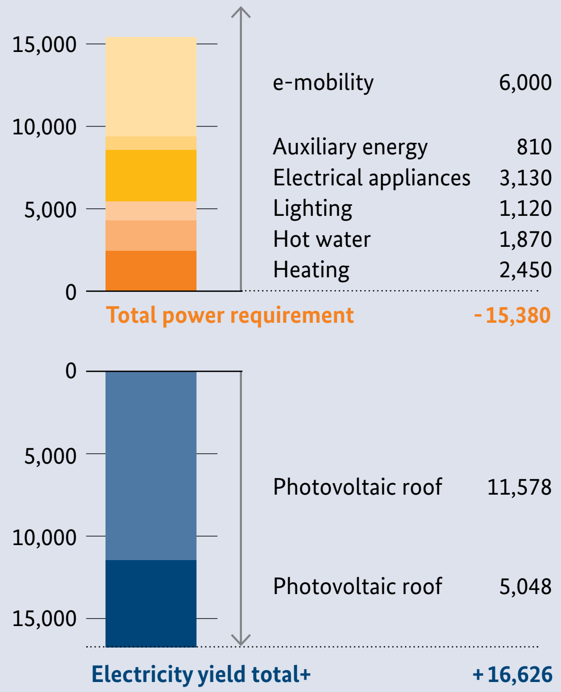
The building envelope is marked by its low u-values. The floor, external load-bearing walls and ceiling and roof have all been constructed using a timber panel construction system. The 56 centimetre-thick walls have thin-film photovoltaic modules on the south façade. They act as a curtain-like façade element. Cellulose has been installed in the external building components as heat insulation. The spaces between the wooden bridges have been filled. The thickness of the cellulose insulation in the roof varies between 40 and 52 centimetre. In addition, hemp mats in the installation levels not only provide thermal insulation but also improve the room acoustics.

All the components of the building envelope cited have a U-value of 0.11 watt per square meter per kelvin. The glass façades on the south-east and north-west sides of the building have insulated triple glazing with a UW-value of 0.7 watt per square meter per kelvin. The south-east side of the building is fitted with external sun shading made of aluminium louvres.

An important concern was to integrate the energy-generating systems into the architectural design. It has been predicted that the roof, which is made up of 98 square meters of monocrystalline photovoltaic modules, should deliver a total output of 14.1 kilowatt peak and the façade of 73 square meter of thin film modules should deliver a total output of eight kilowatt peak. The annual electricity yield would therefore be 16

Figure 15: Projected annual energy production and demand (prediction per year)

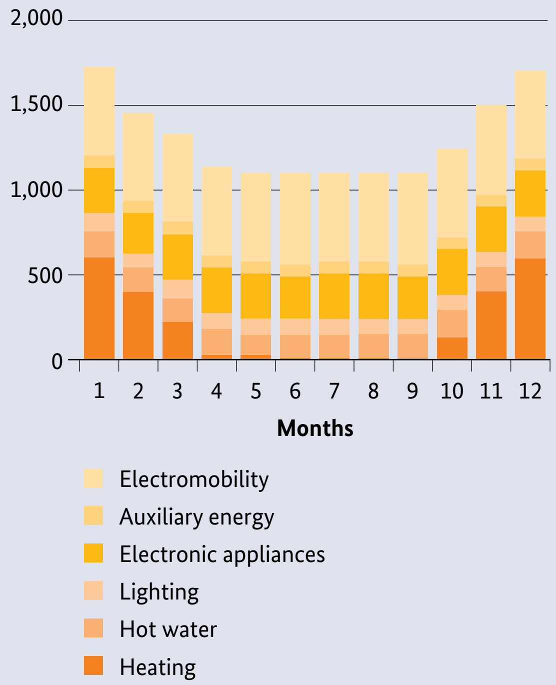
Data in kWh/a (Status October 2011)



Source: Werner Sobek, Stuttgart

Figure 16: Projected energy demand

Data in kWh/a



Source: Werner Sobek, Stuttgart

Table 1: Technical data

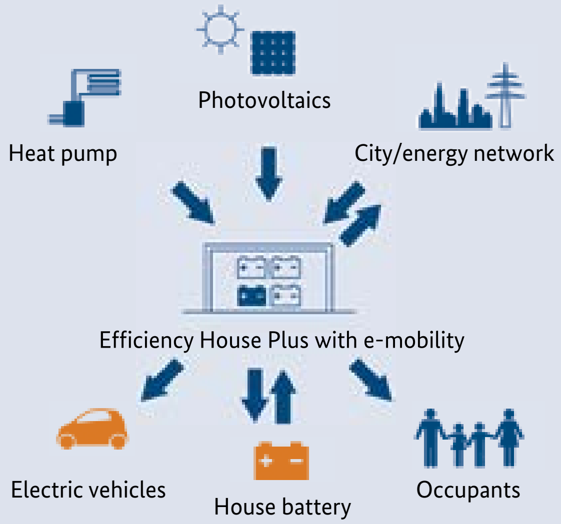
Gross floor area	181 m²
Net floor area	147 m²
Gross volume	645 m²
Heating energy demand	21.2 kWh/m²a
Heating	
Air-to-water heat pump	
Compact ventilation device	
Heat output	5.8 kW
Hot water tank	288 l
Cooling	
Mechanical ventilation	400 m³/h
Heat recovery	> 80 %
Photovoltaic roof	98.2 m² 14.10 kW_p
Photovoltaic façade	73.0 m² 8.0 kW_p
Projected energy generation	16,625 kWh
Projected energy consumption (including 30,000 km driving performance per year)	16,210 kWh
Projected balance	**+ 415 kWh**
Source: Werner Sobek, Stuttgart	

megawatt-hours per year. It was predicted that the house and its occupants would use about ten megawatt-hours of that and the vehicles six megawatt-hours.

Building services

The house has a central heating system that uses an air-to-water heat pump. The heat is transmitted to the rooms through underfloor heating. A mechanical ventilation system provides a fresh air supply to the rooms. Manual ventilation is also possible in all inhabited areas. The heat in the exhaust air is recovered. A building automation system that centrally processes all the measured data and transfers it to an openly programmable system facilitates energy management. The autonomous system enables energy flows to be optimised throughout the entire system. The system includes the photovoltaic system, public power grid, the vehicles as well as the thermal and electrical energy storage. Users can communicate with the system using touchpads or smartphones. An element of the overall concept is a battery bank. This enables the house to mainly use the electricity it produces. As a research project, a battery with a storage capacity of around 40 kilowatt hours was made up of a total of 7,250 used battery cells.

Figure 17: Energy influences on Efficiency House Plus with electromobility



Source: Werner Sobek, Stuttgart

Information concept

Monitors and displays integrated into the “showcase” provide information about the building‘s energy balance and the history and development of the German Efficiency Houses Plus.

Integration of electric mobility

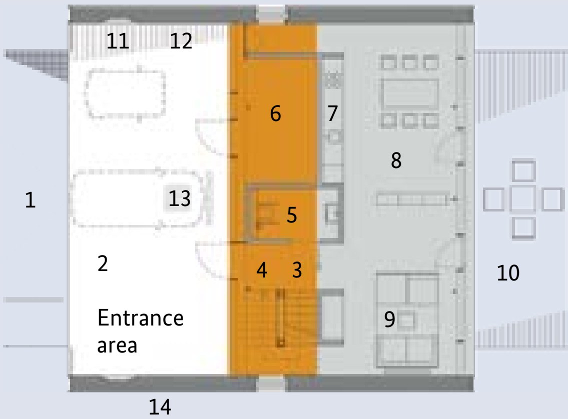
The Efficiency House Plus with electric mobility shows the synergies which exist between living and mobility: Completely in line with the motto: “My home, my filling station”, the home supplies the vehicle, right at the door. As a result, conductive and inductive charging systems have been tested within the project.

Energy management and charging technology that can be controlled via a smartphone has been used. Based on user requirements and the house‘s energy state, the control system then determines the optimum charging strategy for the vehicles. The house battery ensures that the vehicles can also be charged during the night if the photovoltaic elements do not supply electricity.

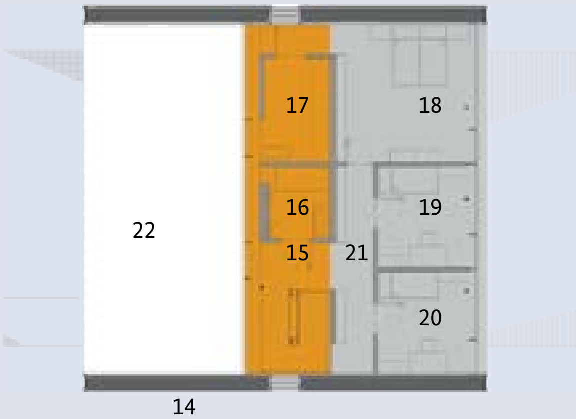
View from the master bedroom onto the top floor landing

View into bathroom

Figure 18: Floor plan for the pilot building



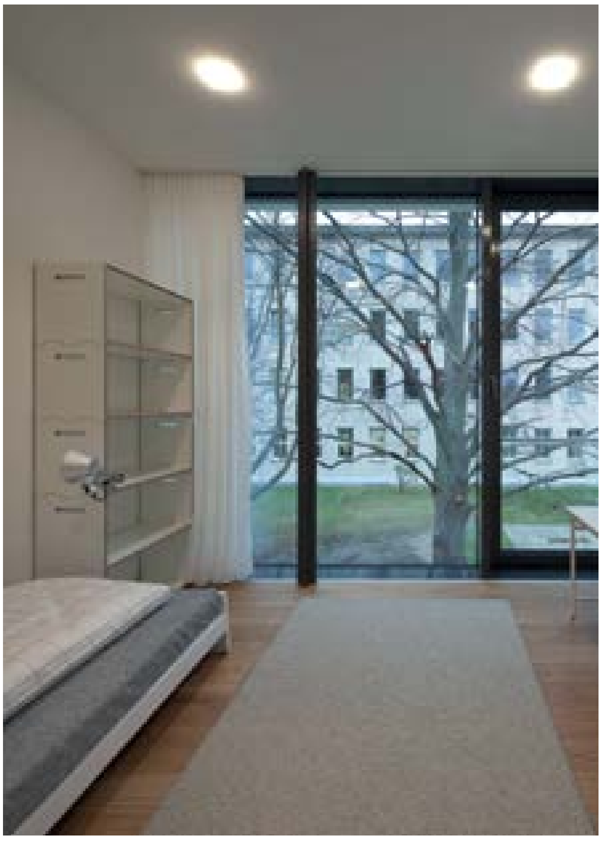
Plan of ground floor living space



Plan of top floor living space

1 Ramp
2 Showcase
3 Entrance area
4 Cloakroom
5 Barrier-free WC
6 Building services
7 Kitchen
8 Dining area
9 Living area
10 Terrace
11 Information display and screen
12 Conductive charging system
13 Inductive charging system
14 PV façade
15 Staircase/landing
16 Bath/WC
17 Utility room
18 Master bedroom
19 Children's bedroom 1
20 Children's bedroom 2
21 Hallway
22 Atrium Showcase

Source: Werner Sobek, Stuttgart


View inside one of the children's rooms on the top floor

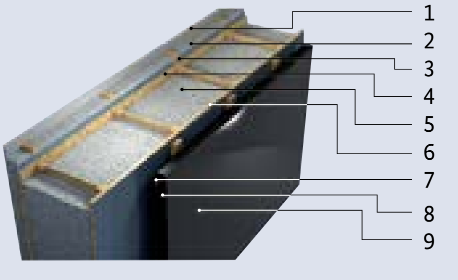

Open-plan kitchen in the living and dining area

Material and recycling concept

The entire structure can be demolished at any point following conclusion of the project. All used materials can be fed back into the materials cycle. A portion of the building materials will be recovered by the manufacturers for immediate reuse in other building projects (for example, photovoltaic system); all remaining materials will be recycled.

In order to be able to sort materials into separate material groups during demolition, approximately 20 application types were defined to be collected as separate fractions during demolition. In addition to the selection of the materials, the connection technology plays a decisive role when it comes to making the materials separable. The majority of connections are made by means of easily separable screw, click and clamp connectors. With the aid of this recycling concept, not only can large volumes of waste be avoided, but the energy balance is also positively influenced. With the recycling process a significant proportion of the "grey energy" used for manufacturing the primary materials can be retained and savings can therefore be made in the production of recyclable building materials.

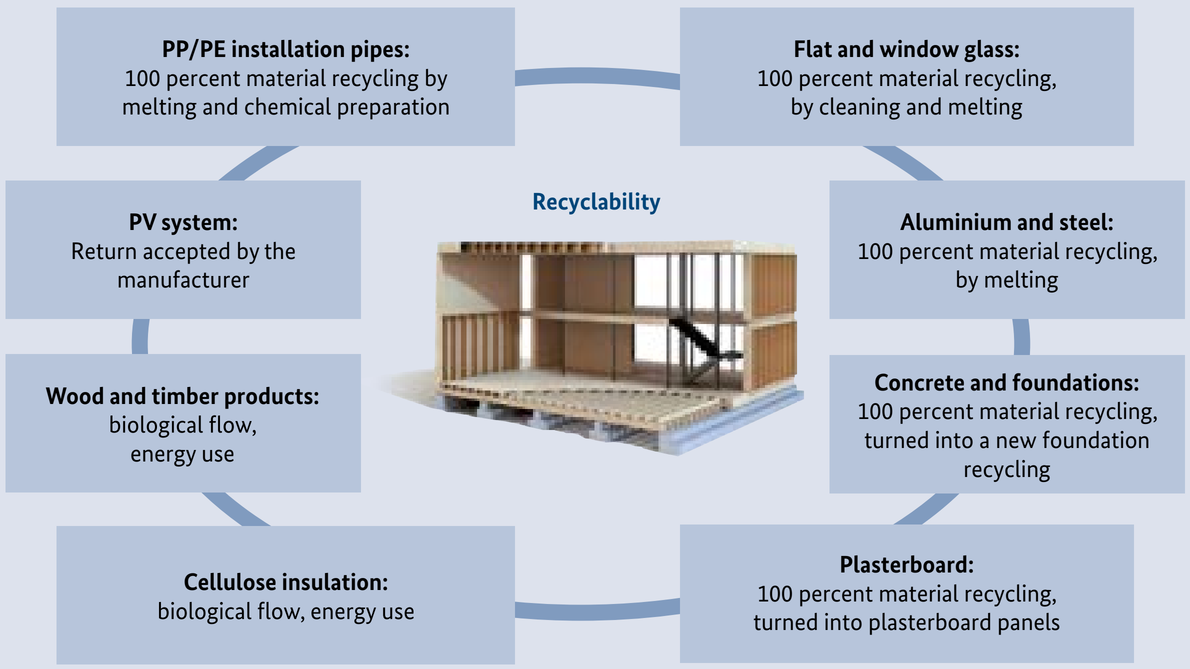
Figure 19: Structure of the insulated, opaque exterior wall



	Wall structure	
1	Plasterboard panels, painted	12.5 mm
2	Installation level with hemp insulation vapour barrier	60 mm
3	Vapour barrier	
4	OSB panel	20 mm
5	Cellulose insulation	360 mm
6	OSB panel Moisture barrier	20 mm
7	Vertical panels	30 mm
8	Agraffe profile (aluminium)	
9	Thin-film PV modules creating a curtain-type façade element	30 mm

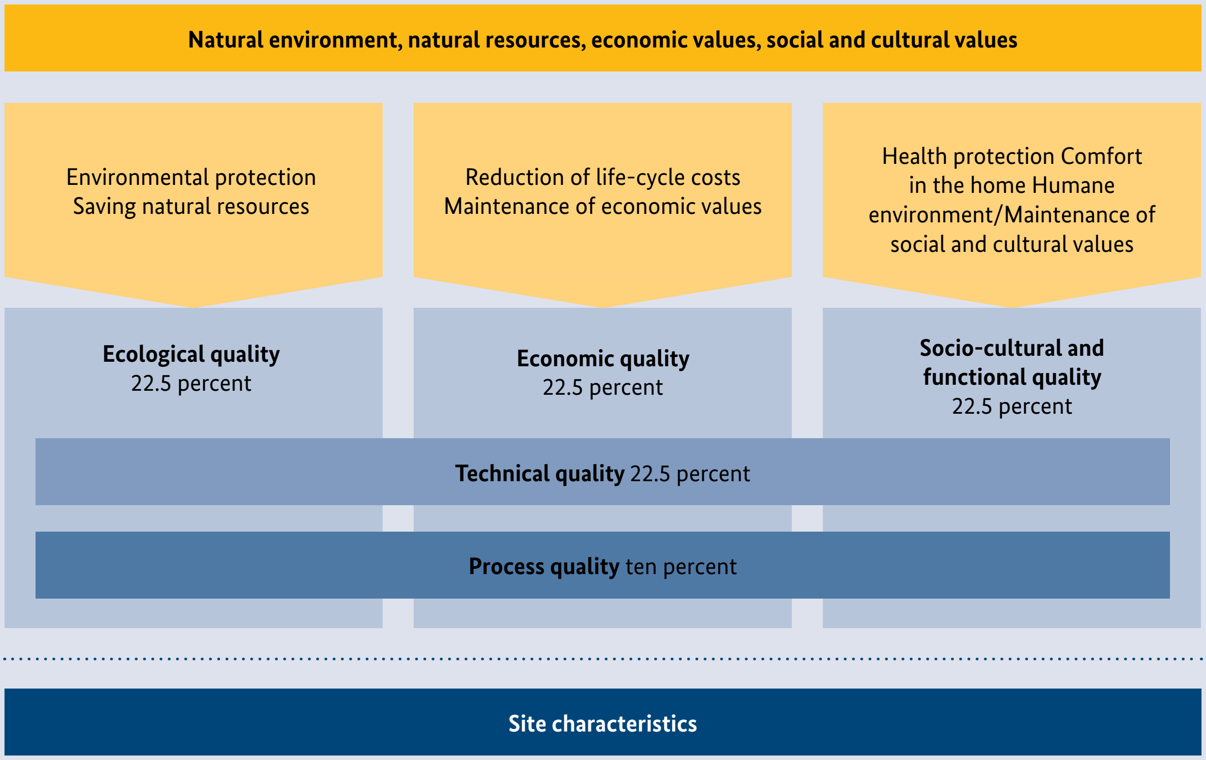
Source: Werner Sobek, Stuttgart

Figure 20: Material selection and recyclability



Source: Werner Sobek, Stuttgart

Figure 21: Overview of the factors influencing sustainability



Source: Werner Sobek, Stuttgart

Social scientific research on Efficiency House Plus with electric mobility

Before moving in and during its use, the Berlin-based Institute for Social Research (Berliner Institut für Sozialforschung) asked the test families in the house about their expectations and experiences of the Efficiency House Plus. The social-scientific investigation study delivered findings on the interfaces between people and innovative technology, the level of take-up and use of new technologies and the use of intelligent networks to operate the building and the electric mobility. The final report on the phase of the project which was occupied by test families can be found at: *www.forschungsinitiative.de/effizienzhaus-plus/forschung/begleitforschung-bmub-haus/sozialwissenschaftliches-monitoring/*

"We will miss the feel-good factor."
That was what the Welke/Wiechers family, who lived in the Efficiency House Plus in Berlin from March 2012 to June 2013, said after they had moved out.

"What we will miss most after moving out? We have been asked that question countless times in the last few weeks and it is difficult to find an answer. We will definitely miss feeling good about taking a bath or using our car because we knew the heat, hot water and electricity for our electric car was supplied from our building's own service technology without causing any emissions."

"Living here was a wonderful adventure."
These were the words of the Heinzelmann/Brenner family shortly before moving out. The family lived in the Efficiency House Plus in Berlin from May 2014 to April 2015.

"There is enough space; the house is a little box of technology that can do lots of things and from time to time also has its flaws. But it offers that feel-good factor if you're looking to convert to a more environmentally-responsible way of life. Living here was a wonderful adventure."

Research on Efficiency House Plus with electric mobility

The building is a research subject and test laboratory par excellence. In addition to extensive validation of measuring techniques, a variety of scientific examinations were also carried out. These especially included:

Thermal and moisture transfer through highly insulated external building components

Using measuring sensors installed in the highly insulated, wood external walls, the temperature, humidity as well as the temperature flow are continuously measured and analysed in real time in the external walls, its roof and its floor. In particular, this is intended to better describe and assess the behaviour of moisture in the open-pored insulation material.

Energy management

Using weather reports as a basis, the building's energy management system is designed to estimate the amounts of energy produced and the energy consumed by the house. From this, it should be possible to deduce the battery storage utilisation rate. This will permit improved utilisation of the generated solar cell current.

Power grid stabilisation

The stabilising effect of the battery storage unit on the public power grid must be examined. At the same time, the basic principles are being developed in relation to how multiple battery storage units can be combined to create a "virtual power station". This will allow regulating current generated from renewable sources to be made available uniformly in minutes. The final report can be found out:
www.forschungsinitiative.de/effizienzhaus-plus/forschung/begleitforschung-bmub-haus/stabilisierung-des-stromnetzes/

Battery cell reuse

Used lithium ion battery cells from the electric mobility area will be examined with regard to their ageing, their residual power level and their use in house batteries with the newly employed battery management system and the charging/inverter unit.

Market overview: house batteries

As part of the energy storage evaluation, a market overview was complied on the storage systems available. The final report from 2013 not only contains the description of the different systems, but also statements on the specific costs and on issues relating to building regulations as well as on funding opportunities and on disposal at the end of the battery lifecycle. Download from:
www.forschungsinitiative.de/effizienzhaus-plus/forschung/begleitforschung-bmub-haus/marktuebersicht-hausbatterien/

House battery sizing

With regard to sizing house batteries (battery storage) for the Efficiency House Plus, a software tool is being developed for the first time to economically ensure the specific costs of house batteries in the future. As a result of this work, a spreadsheet tool is available which can be used to perform the calculation of practical storage capacities for houses. The final report can be found out:
www.forschungsinitiative.de/effizienzhaus-plus/forschung/begleitforschung-bmub-haus/stromspeichersysteme/

Heating highly thermally-insulated buildings with different temperature zones

The energy performance of the first heat pump for heating the building lagged way behind expectations. The cause for this was the constant need to have an excessively high flow temperature, triggered by the "non-standard" use of the house. In the quest to find the causes and quantitative proof of the energy flows, there are three research reports on control technology, heating systems and on the quantifying of room air flow. Download the report at:
www.forschungsinitiative.de/effizienzhaus-plus/forschung/begleitforschung-bmub-haus/sonderthema-beheizung/

Efficiency House Plus in Berlin: the first years of operation

The Fraunhofer Institute for Building Physics (IBP) has measured and evaluated the energy consumption data of the Efficiency House Plus in Berlin over a three-year period. The results show that, after the first twelve months of monitoring from March 2012 to February 2013 and despite unfavourable climate conditions, the photovoltaic systems produced more energy than was needed for the building services and for operation. The surplus energy met 25 percent of the energy demand of the electric vehicles.

In the first year of monitoring, the photovoltaic system generated 13,306 kilowatt hours. 6,555 kilowatt hours, of which were used in the house itself, and 6,751 kilowatt hours of which were fed into the public grid. Approximately 5,800 kilowatt hours of electricity were taken from the public grid. That compares with the building's energy consumption of 12,400 kilowatt hours. This figure does neither include electric mobility, nor project-specific energy consumption. Thus, the photovoltaic system achieved a surplus of 906 kilowatt hours. However, that was not enough to completely cancel out the energy expended for electric mobility.

47 percent of the building's energy was used for running the heating and domestic hot water systems. 24.5 percent was used in each case by the auxiliary energy, for ventilation, building automation, circulation pumps as well as for electrical appliances in the house. The remaining four percent was used for lighting.

In 2013 – the second year of monitoring – the house was mainly unoccupied. It was used for exhibitions and as a conference room and had a 2,011 kilowatt hours surplus.

In 2014, prior to the second test family moving in, the building underwent some remodelling in the form of a structural partitioning of the floors. The uncontrolled air-to-water heat pump was also replaced by a modulating one. The conversion and the somewhat mild weather during the winter of 2014/2015 meant that the energy consumption dropped by 35 percent.

In the third year of monitoring, the photovoltaic system generated 13,490 kilowatt hours. 6,974 kilowatt hours of which were used in the house itself, and 6,516 kilowatt hours of which were fed into the public grid. The building's energy consumption amounted to 12,400 kilowatt hours. Only 39 percent of the building's energy was required to run the heating and domestic hot water systems and 39 percent was needed for the auxiliary energy. 18 percent was used for household appliances and processes, with four percent still being used for lighting. Therefore during the test phase involving the second family, the energy consumption required to run the heat pump and the household appliance was reduced. The energy consumption for the auxiliary energies of ventilation, automation and circulation pumps remained at a high level and relatively constant – offering a potential for optimisation.

Showcase window providing a view of the plant room at the Efficiency House Plus in Berlin.

Efficiency House Plus and electric mobility in a five years interim result

Opening in December 2011

German Chancellor Dr. Angela Merkel opens the first state-owned Efficiency House Plus as a founding venture of Germany's nationwide network of Efficiency Houses Plus at the Berlin City West "future technology axis".

Living in the house of the future

The Welke/Wicher family lived in the research building in Berlin from March 2012 to June 2013. They tested the functionality of the building and were impressed with the high quality of living in the house.

Research and network

The model project is supported from a technical and social-scientific perspective during all periods of use. A comprehensive events programme on energy efficiency is on offer during the phases when it is open to the public.

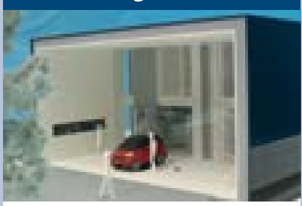
Special feature weeks ...

... "Energy + Building", "Energy + Energy", "Energy + Mobility" and "Energy + Policies and Law" offer presentations, advice, exhibitions and test drives to visitors.

Public operating period | Practical test period | Public operating period

2011/2012 | 2013 | 2014

Competition, planning and building



The building is the result of a competition run by the BMVBS (now the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety) at the end of 2010. The design, which was submitted by the consortium under the leadership of Dr. Werner Sobek won 1st prize.

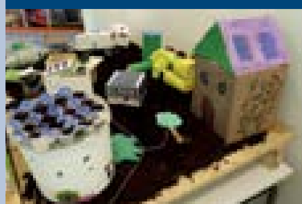
View, experience, inform

Interested local and professionals can visit the display model. Special presentations and themed evenings create a mixed programme of efficient building, sustainability, electromobility and future-focused thinking.

Exchange of experience

The initial scientific results were presented at several trade events and trade fairs. The network exchanges pivotal experiences in this new generation of building with the conclusion: The Plus house is an achievable concept.

Holiday programme



In the school and university holidays, children and young people can take part in a comprehensive and age-appropriate programme filled with information, project work and lots of creative fun. Upcycling, animated films, discovering renewable energy sources and much more.

Living in the house of the future

The Brenner-Heinzelmann family lived in the house from May 2014 to April 2015 with positive energy balance and were delighted with their many newly acquired and valuable experiences.

In figures:

- **81** presentations
- **11** themed weeks
- **144** group tours
- **6** newsletters
- **25** themed evenings
- **40 t** t CO_2 reduction
- **20** energy consulting days
- **19** client consultations
- **15** holiday workshops
- **18** months public usage
- **25** film shoots in the house
- **37** special events
- **6** accompanying research projects
- **35** networked houses
- **27** months residential usage
- **7** networking meetings

Practical test period

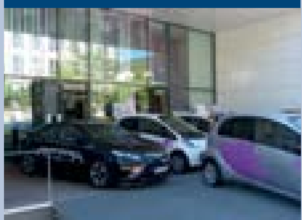
Public operating period

Information and skills centre for sustainable building

2015

2016

Test electromobility …



Do you fancy taking a look under the bonnet of the e-car or test-driving an e-bikes or Pedelec? No problem! Different electric vehicles from VW, OPEL, Daimler, Toyota, Tesla and Mercedes as well as Pedelecs, eBikeboards and SMART bikes are ready and waiting.

The Efficiency house on television

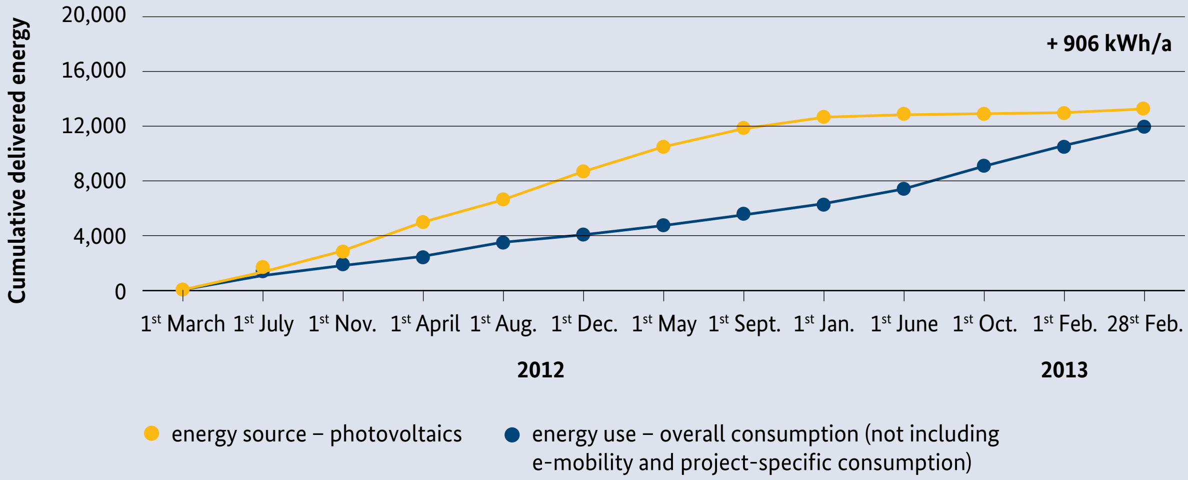
Various national and international television crews provide information to the different target audiences within the company. On “Open Doors Day”, children are able to explore the house with the help of the mouse.

International dialogue platform

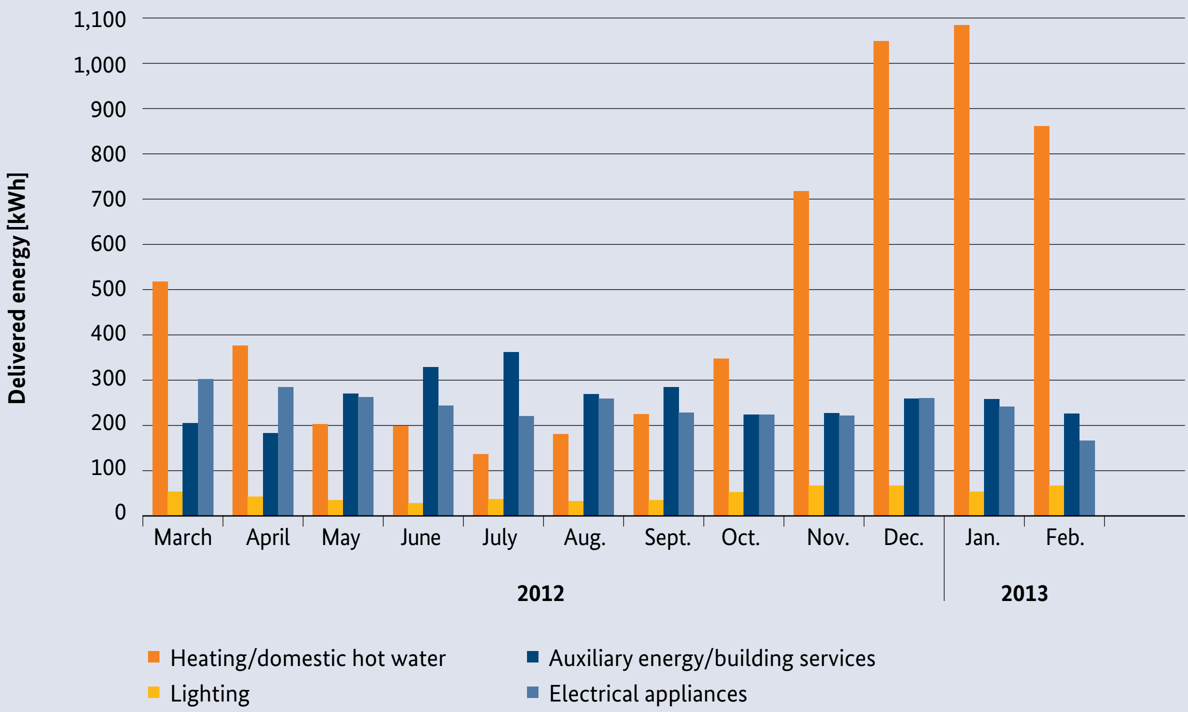
Guided tours in English provide delegations from all over the world with clear information about this innovative building standard. The Efficiency House Plus has proven itself as a platform for international contacts and knowledge exchange.

Figure 22: Comparative values for the first year of monitoring – 2012/2013 period (first test family)

Cumulative delivered energy

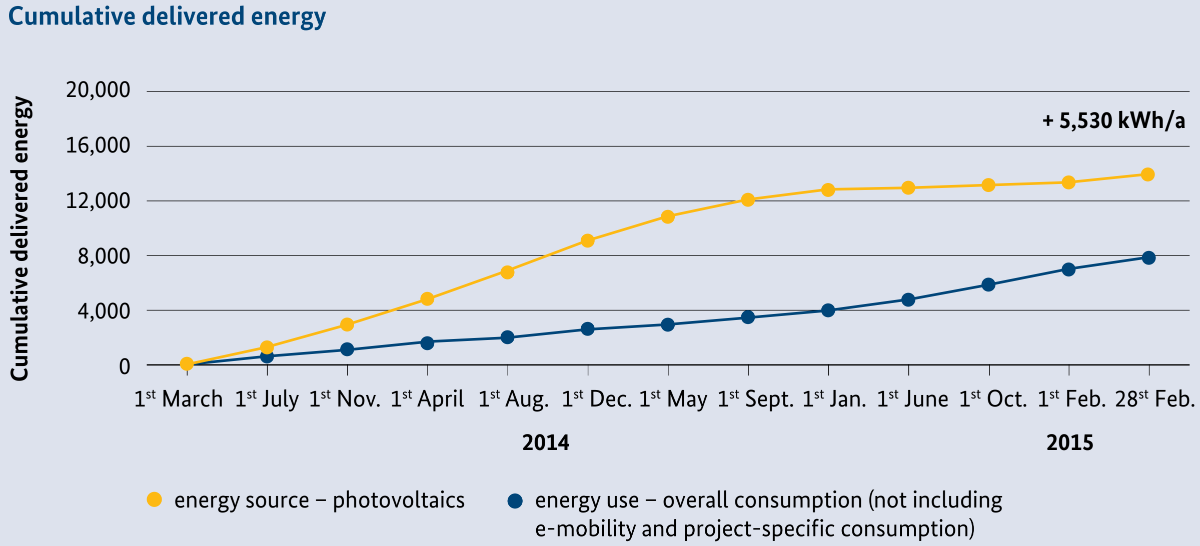


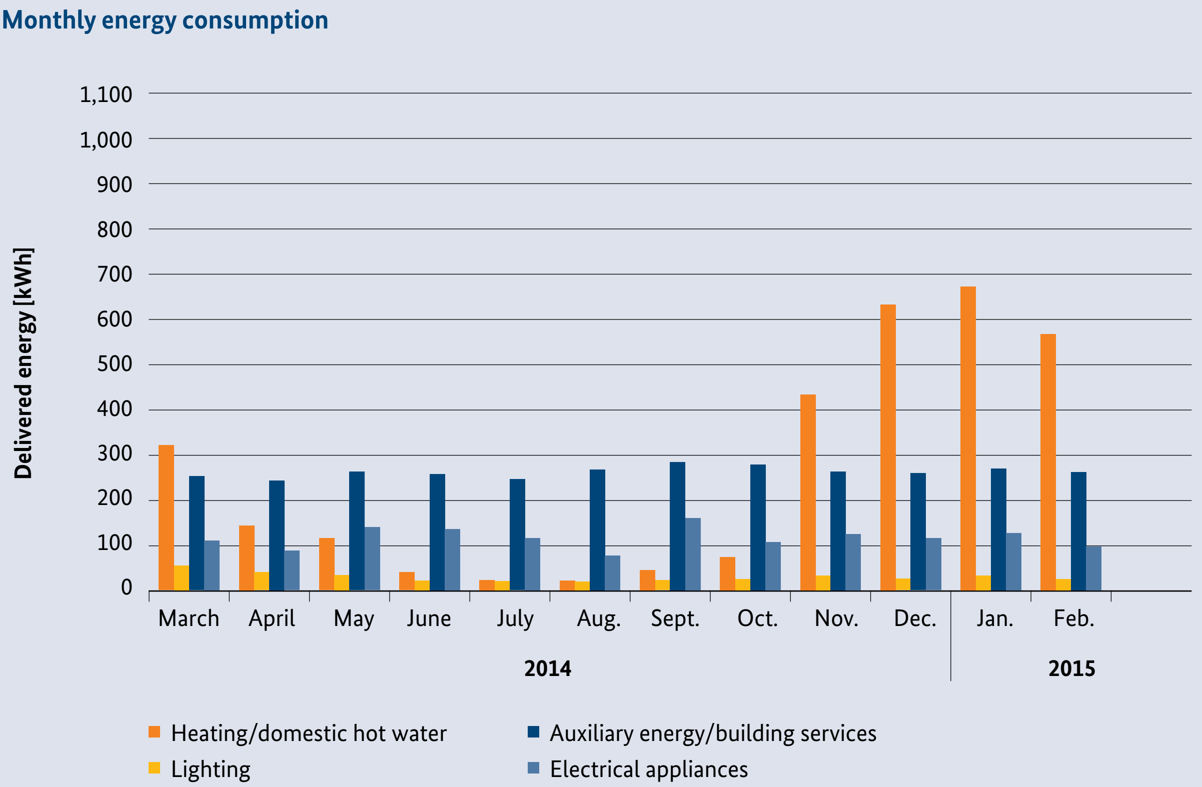
Monthly energy consumption



Source: Fraunhofer Institute for Building Physics

Figure 23: Comparative values for the third year of monitoring – 2014/2015 period (second test family)





Source: Fraunhofer Institute for Building Physics

The Efficiency House Plus network

The aim of the German government's research funding programme is to try out and continue to optimise different technologies within a network of different solutions.

This should enable promising ideas, technologies and materials to make a faster transition into practice. In the medium term, the goal is to build Efficiency Houses Plus at attractive prices. The network now consists of over 100 partners from the construction and building services industry who are successfully acting as multipliers for these building schemes in the market. The buildings are subject to an intensive monitoring programme carried out by various research institutes. A cross-evaluation of all the results will be conducted by the Fraunhofer Institute for Building Physics (IBP). In this, key performance data such as heating energy consumption, electricity consumption, electricity generation, the percentage of renewable energy generated in the building, and primary energy consumption along with comfort parameters will be recorded and analysed. As well as carrying out a comparison across all the projects with regard to the key performance data and compliance with the Efficiency House Plus standard, the variables used to calculate the electricity consumption of the lighting, household appliances and processes will be validated.

Detached houses

The vast majority of the research project's demonstration buildings so far are 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 time period as in the cases of Berling, Brieselang, Deggendorf, Burghausen and Hamburg. All the other buildings are permanently inhabited by families of between two and five people.

Apartment blocks

Whereas in the early years the implementation of the concept concentrated on detached houses, over the coming years the possibility of transferring the design method to apartment blocks will be trialled. To this end, large housing complexes are being built in Berlin and Frankfurt as Efficiency Houses Plus. Their ratio of roof area to façade area is different from that in a detached house. Façade areas therefore have to be increasingly used for generating renewable energy. Heat for space heating and hot water systems is predominantly provided by heat pumps, and recovered heat from waste water is also integrated into the schemes. Both centralised and decentralised ventilation systems are used.

Refurbishing existing buildings

The greatest challenge to Germany's Energiewende (energy transition) is its existing building stock. The focus of the next few years in the small-house sector will therefore turn to renovation solutions. Two residential lines shall be tested and evaluated in Neu-Ulm, which should reach after refurbishment with different technologies an energetic plus. You can find further information on this on page 50 and 51 of this brochure.

Quarter solutions

If the inhabitants of residential areas unite to energy communities, the locally generated renewable energies can often be used much more effectively than possible with singular objects. Settlement solutions that follow a holistic energy concept, ranging from distributed generation on the intelligent networking of structures up to the storage and use of renewable energy are therefore of particular interest. In the prefab world FertighausWelt Wuppertal this approach is tested with 19 detached houses in Efficiency House Plus. You can find further information on this on page 54 of this brochure.

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 educational buildings. This area has had its own funding programme since 2015. You can find more detailed information on this on page 52 of this brochure.

All the projects are published on the website:
www.forschungsinitiative.de

Built projects

Monitoring has ended

Brieselang Elbe-Haus M1 Massivhaus
Living space: 137 m²
Air-to-water heat pump, PV = 9.3 kW$_{Peak}$
Solar thermal energy 10 m², Battery 24.0 kWh

Final energy surplus (kWh/a):	
Forecast:	3,921
1st year of monitoring:	1,389
2nd year of monitoring:	1,495

Bremen HO Immobilien & Baukonzepte
Living space: 202 m²
Brine-to-water heat pump
PV = 8.7 kW$_{Peak}$

Final energy surplus (kWh/a):	
Forecast:	546
1st year of monitoring:	–
2nd year of monitoring:	2,213

Leonberg-Warmbronn Haus Berghalde
Living space: 260 m²
Water-to-water heat pump, PV = 15.0 kW$_{Peak}$
Batteries 7.0 kWh + 20.0 kWh

Final energy surplus (kWh/a):	
Forecast:	6,947
1st year of monitoring:	3,160
2nd year of monitoring:	6,096

Münnerstadt Haus Miller
Living space: 327 m²
Brine-to-water heat pump, PV = 23.7 kW$_{Peak}$
Battery 11.0 kWh

Final energy surplus (kWh/a):	
Forecast:	12,293
1st year of monitoring:	11,710
2nd year of monitoring:	13,399

Eußenheim Haus Höfling
Living space: 288 m²
Brine-to-water heat pump, ice storage system 3,000 l
PV = 13.4 kW$_{Peak}$, solar thermal energy 11.0 m²

Final energy surplus (kWh/a):	
Forecast:	8,816
1st year of monitoring:	4,439
2nd year of monitoring:	5,760

Stelzenberg ecolodge
Living space: 113 m²
Brine-to-water heat pump, ice storage syste 1,050 l
PV = 8.5 kW$_{Peak}$, solar thermal energy 14.0 m²

Final energy surplus (kWh/a):	
Forecast:	1,920
1st year of monitoring:	2,774
2nd year of monitoring:	3,594

Legend for technologies:

Heat pump
Photovoltaics
Solar thermal energy
Ventilation system with heat recovery
Battery charging station for electric vehicles
Battery storage
Ice storage system

Monitoring has ended

Cologne HUF HAUS Green[r]evolution
Living space: 283 m²
Brine-to-water heat pump, PV = 14.5 kW_{Peak}
Battery 13,2 kWh

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

Cologne SchwörerHaus Plan 550
Living space: 139 m²
Air-to-air heat pump, PV = 11.0 kW_{Peak}
Solar thermal energy 8.4 m²

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

Cologne Bien-Zenker Concept-M
Living space: 194 m²
Air-to-air heat pump + Brine-to-water heat pump
PV = 16.3 kW_{Peak}, Battery 8.4 kWh

Final energy surplus (kWh/a):	
Forecast:	4,705
1st year of monitoring:	1,235
2nd year of monitoring:	2,997

Cologne FingerHaus VIO 400
Living space: 179 m²
Air-to-water heat pump
PV = 8.5 kW_{Peak}

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

Cologne WeberHaus Generation 5.0
Living space: 159 m²
Air-to-air heat pump, PV = 8.8 kW_{Peak}
Battery 3.5 kWh

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

Cologne LUXHAUS frame
Living space: 193 m²
Brine-to-water heat pump
PV = 9.9 kW_{Peak}

Final energy surplus (kWh/a):	
Forecast:	974
1st year of monitoring:	-1,166
2nd year of monitoring:	-1,941

Legend for technologies:

- Heat pump
- Photovoltaics
- Solar thermal energy
- Ventilation system with heat recovery
- Battery charging station for electric vehicles
- Battery storage

Monitoring has ended

Hamburg VELUX LichtAktiv Haus
Living space: 132 m²
Brine-to-water heat pump, window ventilation,
PV = 8.8 kW_{Peak}, solar thermal energy 19.8 m²

Final energy surplus (kWh/a):

Forecast:	180
1st year of monitoring:	-1,888/2014
2nd year of monitoring:	-2,155/2015

Schwabach Haus Hausner
Living space: 221 m²
Air-to-water heat pump
PV = 14.4 kW_{Peak}

Final energy surplus (kWh/a):

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

Weifa Haus Wagner
Living space: 180 m²
Air-to-water heat pump, PV = 30.0 kW_{Peak}
Battery 14.4 kWh

Final energy surplus (kWh/a):

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

Bischofswiesen EFH-Plus in den Bergen
Living space: 628 m², Number of units: 6
Water-to-water heat pump, PV = 41.6 kW_{Peak}
Battery 50.0 kWh

Final energy surplus (kWh/a):

Forecast:	10,885
1st year of monitoring:	17,601
2nd year of monitoring:	13,143

Darmstadt Energy+ Home
Living space: 185 m²
Air-to-water heat pump
PV = 12.6 kW_{Peak}

Final energy surplus (kWh/a):

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

Lüneburg Haus Molt
Living space: 129 m²
Direct electrical heat
PV = 12.6 kW_{Peak}

Final energy surplus (kWh/a):

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

Legend for technologies:

- Heat pump
- Photovoltaics
- Solar thermal energy
- Ventilation system with heat recovery
- Battery charging station for electric vehicles
- Battery storage
- Direct electrical heating (DEH) system
- Mechanical ventilation design

Monitoring has ended

Burghausen Schlagmann/BayWa
Living space: 176 m² *Water-to-water heat pump, seasonal storage 48,000 litres, PV = 10.5 kW$_{Peak}$ Solar thermal energy 51 m², Battery 10.8 kWh*

Final energy surplus (kWh/a):	
Forecast:	5,961
1st year of monitoring:	2,239
2nd year of monitoring:	1,727

Unterkirnach Haus Neininger
Living space: 282 m²
Brine-to-water heat pump, PV = 26.2 kW$_{Peak}$ Battery 24.0 kWh

Final energy surplus (kWh/a):	
Forecast:	11,003
1st year of monitoring:	7,574
2nd year of monitoring:	9,666

Bad Homburg Pro Klimahaus
Living space: 169 m²
Air-to-water heat pump PV = 9.4 kW$_{Peak}$

Final energy surplus (kWh/a):	
Forecast:	2,066
1st year of monitoring:	-9,508
2nd year of monitoring:	-664

Kassel Haus Barba/Griesel
Living space: 280 m²
Brine-to-water heat pump, PV = 15.8 kW$_{Peak}$ Battery 6.3 kWh

Final energy surplus (kWh/a):	
Forecast:	3,118
1st year of monitoring:	2,366
2nd year of monitoring:	2,470

Frankfurt am Main Cordierstraße
Living space: 1.170 m², Number of units: 17
CHP, PV = 49.7 kW$_{Peak}$ Solar thermal energy 40.0 m²*

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

Tübingen Licht + Luft
Wohnfläche: 891 m², Number of units: 9
District heat, PV = 36.0 kW$_{Peak}$

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

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

Legend for technologies:

- Heat pump
- Photovoltaics
- Solar thermal energy
- Ventilation system with heat recovery
- Battery charging station for electric vehicles
- Ice storage system
- Battery storage
- Long-term storage
- Cogeneration heating plant/partly district-related
- Local/district heat

Monitoring has started

Bremen Haus Büscher
Living space: 166 m²
Brine-to-water heat pump, PV = 10.8 kW_{Peak}
Solar thermal energy 10.0 kWh

Final energy surplus (kWh/a):	
Forecast:	938
1st year of monitoring:	-201
2nd year of monitoring:	–

Buchen-Hollerbach Haus Böhrer
Living space: 230 m²
Brine-to-water heat pump
PV = 12.4 kW_{Peak}

Final energy surplus (kWh/a):	
Forecast:	1,463
1st year of monitoring:	4,411
2nd year of monitoring:	–

Deggendorf Haus Bachl
Living space: 171 m²
Buffer storage 9,200 litres, PV = 7.8 kW_{Peak}
Solar thermal energy 49.0 m², Battery 8.0 kWh

Final energy surplus (kWh/a):	
Forecast:	1,807
1st year of monitoring:	2,820
2nd year of monitoring:	–

Poing/Grub Baufritz "Alpenchic"
Living space: 225 m²
PV = 12.6 kW_{Peak}
Battery 3.7 kWh, fuel cell

Final energy surplus (kWh/a):	
Forecast:	26
1st year of monitoring:	–
2nd year of monitoring:	–

Riedstadt-Crumstadt Haus Bernhardt
Living space: 165 m²
Brine-to-water heat pump
PV = 12.0 kW_{Peak}

Final energy surplus (kWh/a):	
Forecast:	1,170
1st year of monitoring:	7,418
2nd year of monitoring:	–

Stuttgart Aktivhaus B10
Living space: 82 m²
Water-to-water heat pump, PV = 10.4 kW_{Peak}
Battery 11.0 kWh

Final energy surplus (kWh/a):	
Forecast:	–
1st year of monitoring:	1,408
2nd year of monitoring:	–

Legend for technologies:

Heat pump
Photovoltaics
Solar thermal energy
Ventilation system with heat recovery
Battery charging station for electric vehicles
Ice storage system
Battery storage
Fuel cell
Wind wheel

Monitoring has started

Neu-Ulm Pfuhler Straße 4 and 6
Living space: 656 m², Number of units: 10
Brine-to-water heat pump, PV = 45.8 kW$_{Peak}$

Final energy surplus (kWh/a):

Forecast:	8,824
1st year of monitoring:	–
2nd year of monitoring:	–

Neu-Ulm Pfuhler Straße 12 and 14
Living space: 596 m², Number of units: 8
Brine-to-water heat pump, PV = 31.2 kW$_{Peak}$

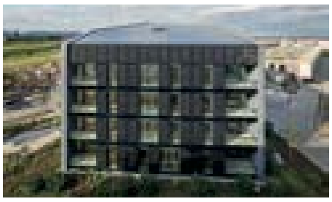
Final energy surplus (kWh/a):

Forecast:	2,022
1st year of monitoring:	–
2nd year of monitoring:	–

Berlin LaVidaVerde
Living space: 1,207 m², Number of units: 18
Air-to-water heat pump, PV = 78.1 kW$_{Peak}$

Final energy surplus (kWh/a):

Forecast:	4,390
1st year of monitoring:	5,647
2nd year of monitoring:	–



Frankfurt am Main Riedberg
Living space: 1,599 m², Number of units: 17
Brine-to-water hp, PV = 95.2 kW$_{Peak}$, Battery 60.0 kWh*

Final energy surplus (kWh/a):

Forecast:	24,524
1st year of monitoring:	–
2nd year of monitoring:	–

Geisenheim Internatsschule Hansenberg
Living space: 319 m², Number of units: 4
Air-to-water heat pump, PV = 18.9 kW$_{Peak}$

Final energy surplus (kWh/a):

Forecast:	no data
1st year of monitoring:	–
2nd year of monitoring:	–

Frankfurt am Main Aktiv-Stadthaus
Wohnfläche: 6.480 m², Number of units: 74
Water-to-water hp, PV = 370.0 kW$_{Peak}$*
Battery 250.0 kWh

Final energy surplus (kWh/a):

Forecast:	43,622
1st year of monitoring:	–
2nd year of monitoring:	–

** hp = heat pump*

Legend for technologies:

- Heat pump
- Photovoltaics
- Solar thermal energy
- Ventilation system with heat recovery
- Battery charging station for electric vehicles
- Ice storage system
- Battery storage
- Pellet boiler

Results from the network

The Fraunhofer Institute for Building Physics (IBP) cross-evaluates substantial measured data from all model projects in its leading accompanying research. Selected results are presented below.

Monitoring

An extensive measured programme is used not only to present the building's energy yield and consumption but also to evaluate the efficiency of the system technology. Inhabitants and designers will thus receive insightful feedback on the usage. The measuring configuration for a building includes fitting heat and electricity meters along with temperature sensors and volumetric flow sensors. The air temperature, relative air humidity and CO_2 concentration are also measured in selected rooms. The measured data is used to continually record how much energy from the photovoltaic system and the public grid is used, along with the consumption of all electrical appliances and building services equipment. The data for the individual buildings is analysed and published each month at: *www.forschungsinitiative.de/effizienzhaus-plus*

Structural heat insulation

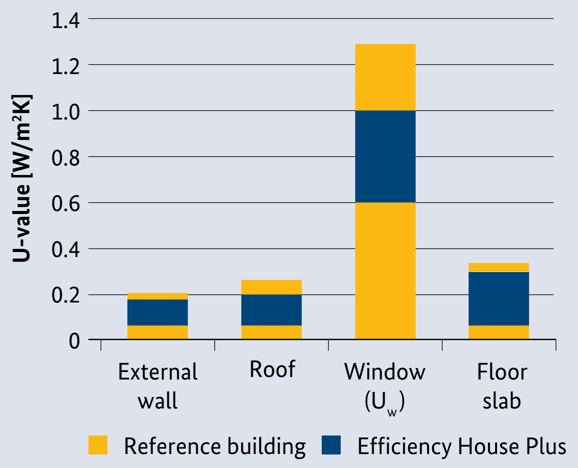
All model projects are predominantly compact in terms of structure and optimised for energy production. Comparatively, their heat insulation is significantly better than that required by the Energy Saving Ordinance (EnEV). However it is often not as high as that in passive houses. The transmission heat loss relative to the thermal envelope area for single to dual family homes is between 0.13 and 0.33 watt per square meter per kelvin (W/m²·K) and thus falls short by 18 to 62 percent of the permissible maximum value of the current EnEV (average 48 percent). The average energy performance of the model projects is mainly focused on the KfW Efficiency House 55.

Measurement results displayed via the building automation system

Heat supply

Most of the model projects use heat pumps in conjunction with surface heating. 41 percent are used as geothermal heat pumps, 37 percent as air-to-water heat pumps and 22 percent heat is generated either by a combination of water-to-water or an air-to-air heat pump. Different combinations of external air, brine fluid, 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 detached houses and 7 and 120 kilowatt for apartment blocks.

Figure 24: Thermal transmittance



Source: Fraunhofer Institute for Building Physics

Tip

Innovative building services systems should be equipped with a monitoring system so that their efficiency can be continually analysed and the appropriate improvements can be initiated. Appropriate small monitoring systems are already available on the market. 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.

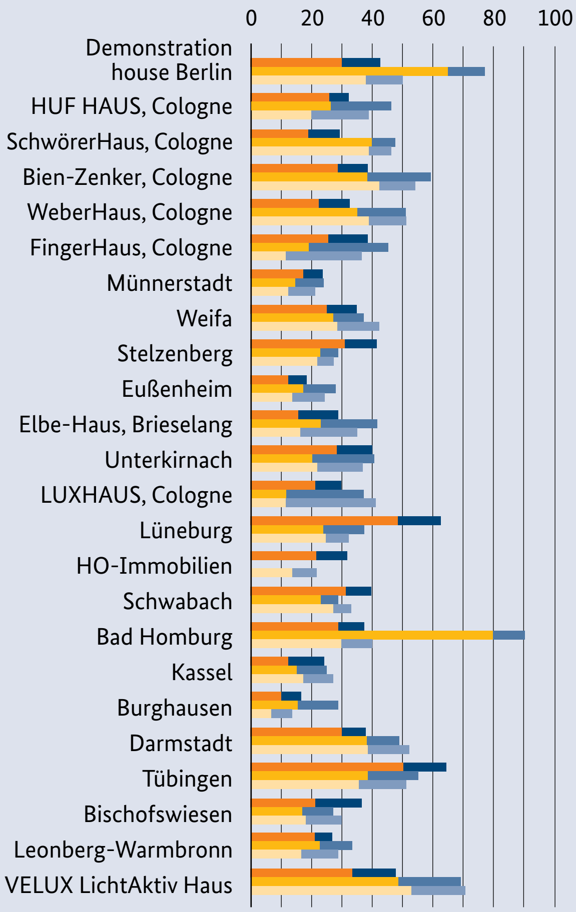
Delivered energy consumption

The energy consumption in relation to heating, domestic hot water, auxiliary energy as well as lighting, household appliance, household processes and other things are measured. In comparison to the measured data and design data, the required parameters for heating, domestic hot water, ventilation and other auxiliary energy are taken from the EnEV calculations in accordance with DIN V 18599. The projected values for lighting and residential electricity are based on the provisions of the Efficiency House Plus standard.

Figure 25: Delivered energy demand and consumption for the demonstration projects in first and second year of monitoring

Calculation / Measurement

Delivered energy demand and consumption [kWh/m^2a]



Heating, domestic hot water and auxiliary energy

- Calculation in accordance with DIN V 18599
- first year of monitoring
- second year of monitoring

Lighting and residential electricity

- Calculation for Efficiency House Plus standard
- first year of monitoring
- second year of monitoring

Source: Fraunhofer Institute for Building Physics

Almost all buildings use more delivered energy in the first years of operation than predicted. In the first year of measurement the average consumption was on ten percent and could be reduced by optimizing the second measurement year to less than one percent. Both the building services and the residential electricity created deviations. 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. Moreover, the building automation and control technology sometimes had an unexpectedly high electricity demand.

Residential electricity

Residential electricity is measured separately for lighting as well as for household appliances and processes in accordance with the Efficiency House Plus standard. An overall value of 20 kilowatt hours per square meter in a year, however, not exceeding a maximum of 2,500 kilowatt hours per square meter per year per housing unit was cited in the pre-calculation. A value of three kilowatt hours per square meter per living space is specified for lighting and for household appliances and processes, a value of 17 kilowatt hours per square meter in a year per living space. 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 three kilowatt hours per square meter per year. By contrast, the delivered energy demand for household appliances, processes and other consumers were met, in practice and, in fact, even remained below the values.

However, the predefined maximum limit values in relation to the housing unit exceeded the delivered residential electricity consumption of 2,125 kilowatt hours per square meter per year in both measurement years on an average of eight percent of most buildings.

! Tip

It is recommended that the dimensions of the photovoltaic system are greater by 10 to 20 percent to offset a less than optimal building performance in order to reliably generate a “plus-energy house”.

Solar power generation

Photovoltaic areas

To date, highly efficient houses have concentrated primarily 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.

The analysis of the model projects shows that on average 0.47 square meters of photovoltaic area per square meter of living space was installed. Based on the lower roof areas in relation to the living space, the photovoltaic area for apartment blocks is on average 0.32 square meters of photovoltaic area per square meter of living space. The installed capacity of the photovoltaic systems is between 8.5 and 26.2 kilowatt peak and averages around 14 kilowatt peak for detached houses.

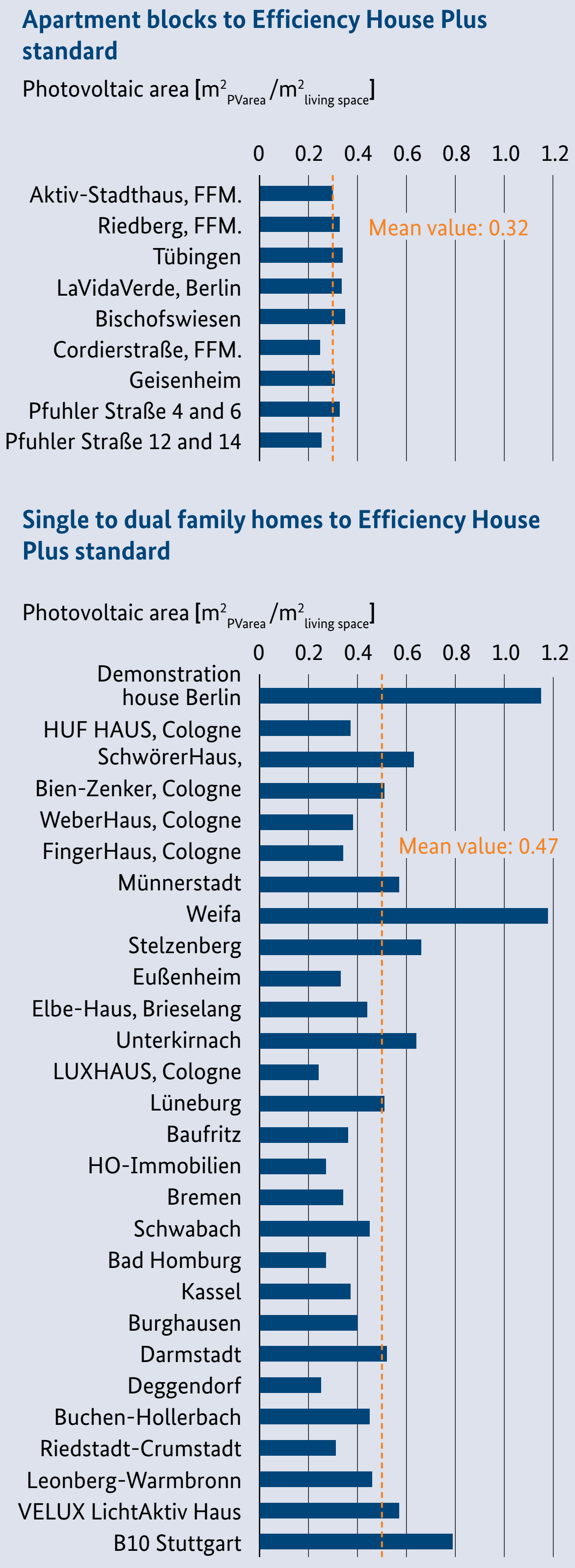
Pre-calculation versus measurement

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 meet the targets and their economic viability depend crucially on this. The measured results of model projects show a very high degree of agreement between the calculations made in advance and the results measured. Any deviations are usually below ten percent and can be explained by particular local weather conditions or shading factors. 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 meter of photovoltaic area per square meter of living space in order to be retrofitted to Efficiency House Plus standard.

Figure 26: Ratio of photovoltaic area to living space



Source: Fraunhofer Institute for Building Physics

Degree of self-sufficiency

The degree of self-sufficiency representing the solar fraction of the building's delivered energy demand by self-generated photovoltaic electricity, achieves 30 to 90 percent for projects with electricity storage. In buildings with no electrical storage, the degree of self-sufficiency is from 20 to a maximum of 39 percent. Battery storage can therefore significantly increase the rate of self-sufficiency.

Degree of self-use

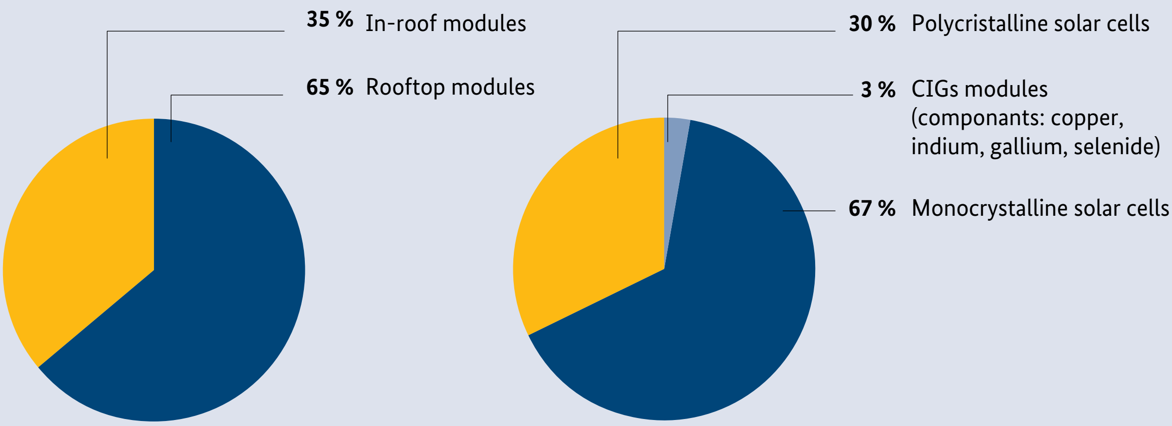
The degree of self-use can be determined by dividing the photovoltaic yields into the share of self-generated electricity used by the house itself and the share fed into the public power grid. It is vital to aim for a higher level of self-use as far as possible. In 2014, the degree of self-use of the model projects with an electricity storage of fluctuated between 16 and 60 percent and for the model projects without batteries between 11 and 40 percent. The degree of self-use in the model 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 however essentially low.

Roof with monocrystalline photovoltaic modules

! Tip

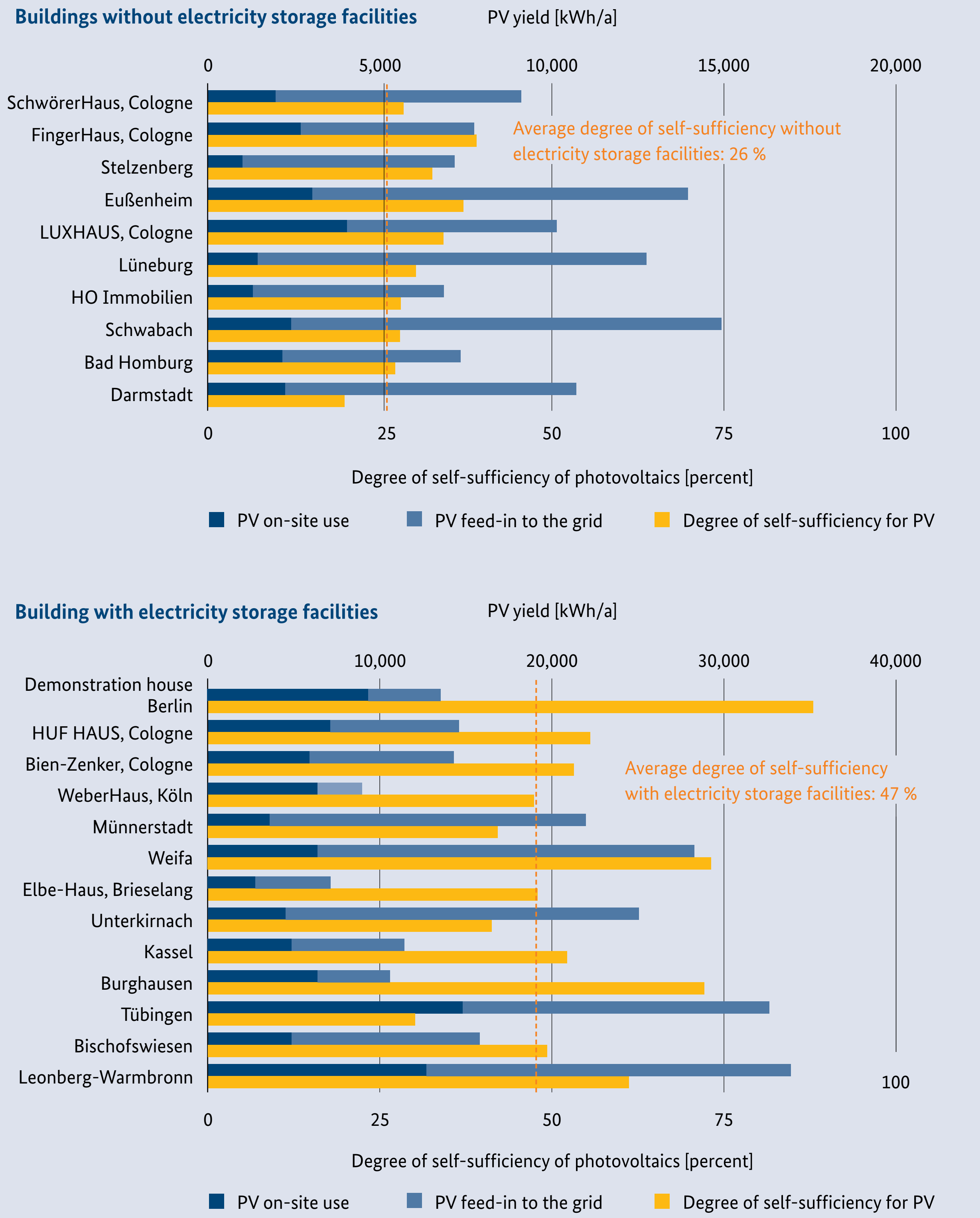
A one kilowatt-peak photovoltaic system (with a surface between eight and ten square meter) can produce between 700 to 1,100 kilowatt hours of electricity per year.

Figure 27: Type, distribution and performance of the photovoltaic modules of the demonstration projects to Efficiency House Plus standard



Source: Fraunhofer Institute for Building Physics

Figure 28: Personal use, feed-in and rate of self-sufficiency of the photovoltaic power in the second year of monitoring for projects with and without electrical storage



Source: Fraunhofer Institute for Building Physics

Electrical storage system

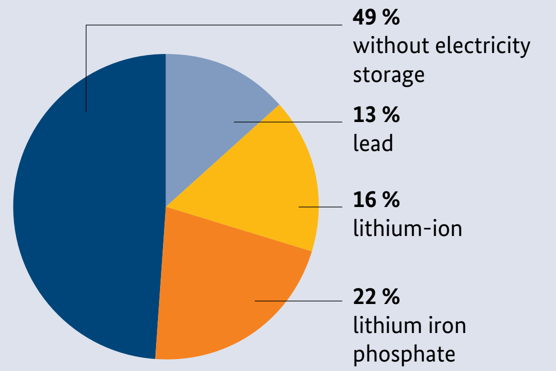
As a result of changes to the feed-in tariffs, Efficiency House Plus building planners are responding with designs which significantly increase the percentage of solar electricity that the building could use itself. Whereas in the past it was virtually impossible (without incorporating batteries) for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

Tip

Using an electrical storage system (usable capacity between around eight to ten kilowatt hours) can easily double the rate of self-sufficiency (the percentage of renewable electricity generated by the house itself) in a detached house.

51 percent of the model projects have an electrochemical storage system (see figure 29). The gross storage capacity is between 3.5 and 40 kilowatt hours in detached houses and up to 250 kilowatt hours for an apartment block.

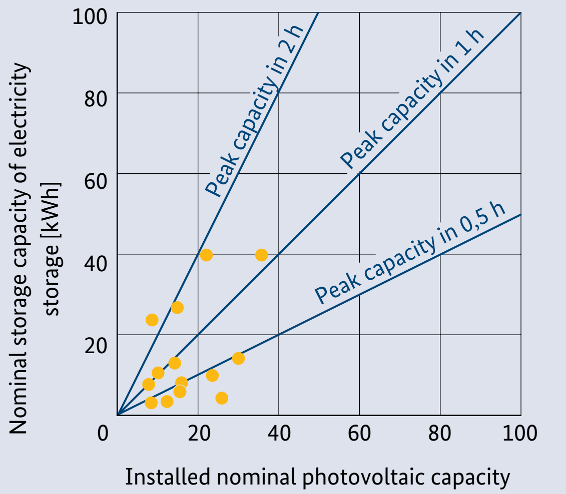
Figure 29: Type and distribution of electrochemical storage in the model projects of Efficiency House Plus standard



Source: Fraunhofer Institute for Building Physics

The dimensions of the photovoltaic storage systems can be aligned with the installed power of the photovoltaic system or the power-based delivered 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. This means that a system with a peak performance of 20 kilowatt has 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. Properties that have a charging capacity of two hours have the largest capacities.

Figure 30: Storage capacity



Source: Fraunhofer Institute for Building Physics

New battery storage, 13.2 kilowatt hour

Costs

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

In the projects invoiced to date, gross costs for cost groups 300 (building design) and 400 (technical systems) amount to between 800 and 8,100 euros per square meter usable area. The overwhelming percentage (more than 75 percent) of all buildings incurred costs of between 1,000 and 2,000 euros per square meter of usable floor area.

It seems to make more sense to present a lower or additional cost consideration compared to the same building constructed to standard energy performance quality.

Highly energy-efficient building envelope

The Efficiency Houses Plus that have been built to date usually have a building envelope that is a 40 percent improvement on the requirements of the Energy Saving Ordinance. This incurs extra costs of between 50 and 80 euros per square meter of usable floor area.

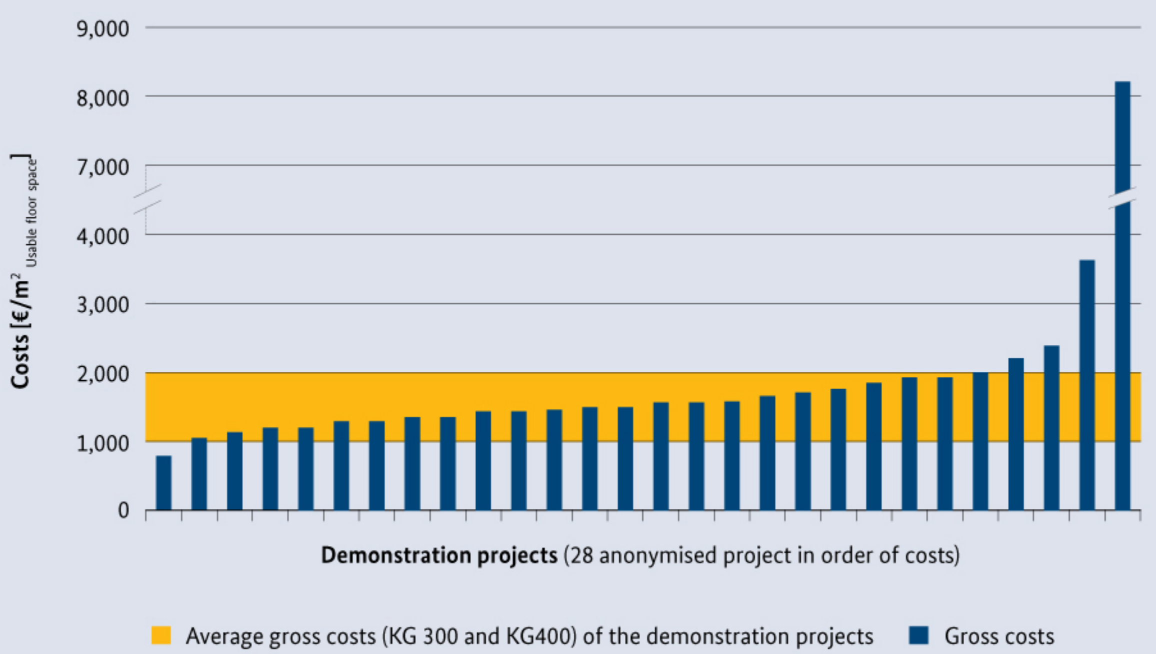
Highly efficient ventilation systems for living spaces

It is essential to have a good ventilation scheme in new builds. Ventilation has 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 and has heat recovery rates of more than 80 percent adds 30 to 50 euros per square meter of usable floor area to the cost of a new build.

Heat pump systems with buffer storage tanks

In recent years, electric heat pumps have become increasingly popular in the new build market. The additional costs for heat pump systems in Efficiency Houses Plus are between 35 and 50 euros per square meter of usable floor area by comparison with a standard

Figure 31: **Gross costs for cost groups KG 300 and KG 400 of the demonstration projects to Efficiency House Plus standard**



Source: Fraunhofer Institute for Building Physics

heating supply using a condensing boiler and hot water tank.

Highly efficient household appliances

Using highly efficient household appliances can lower the electricity consumption in an average household by about 1,000 watt per square meter per kelvin ($W/m^2 \cdot K$). This reduces the photovoltaic capacity that needs to be installed by one 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 the last three years. This is largely due to mass production in Asia. Further price drops are expected soon. Currently, the investment costs for ready-assembled medium-sized rooftop installations are for single-family homes 1,500 to 1,700 euros per kilowatt-peak. For the grid connection costs the equivalent of 500 to 1,000 euros.

For an installed capacity of 45 wattpeak per square meter of usable floor area, which was the average for buildings to date, the average installation costs are between 70 and 80 euros per square meter of usable floor area.

Electrical battery system

Electric batteries are not absolutely essential for an Efficiency House Plus. However, they do lower operating costs. Standard (lead acid) house batteries (approximately eight kilowatt hours) cost about 500 euros per kilowatt hours of capacity; more efficient lithium ion batteries cost more than double that figure.

Overall additional investment

As the analysis of the individual elements shows, an Efficiency House Plus requires an average additional investment of between 185 euros and 260 euros per square meter of usable floor area. Installing extra photovoltaic areas to support electric mobility will increase the level of investment accordingly.

Lower operating costs

The operating costs for an average detached house of EnEV 2016 standard can be estimated at around eight euros per square meter of usable floor area for heating and around ten euros per square meter for electricity – in other words a total of 18 euros per square meter. This operating cost potential can be best exploited in an Efficiency House Plus.

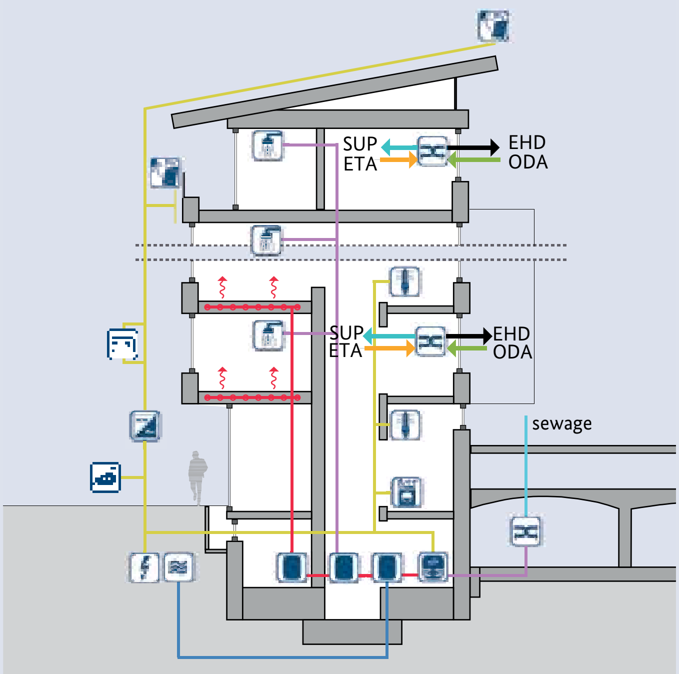
Even four years ago, it was still possible to reduce the operating costs of an Efficiency House Plus to less than zero euros per square meter per year. Today, this is in practice no longer possible for houses that produce only slightly more solar electricity than they need, unless they incorporate batteries into the system. This is because of degressive feed-in tariffs and the fact that payment for the electricity generated but 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 two and three euros per per square meter per year of usable floor area. Today, only a photovoltaic system that is about 35 percent “too large” produces operating costs below zero euros.

! Note

Field results to date show that the additional capital costs for an Efficiency House Plus are reasonable by comparison with the achievable operating costs. Since the feed-in tariffs are continually being revised, any consideration of the economic aspects must always take account of the latest regulatory framework. Generalisations are not possible here.

Efficiency House Plus for apartment buildings

Figure 32: Technology concept from the building "Active City House" in Frankfurt am Main



Electric devices
Lamps
Heat
Ventilation heat recovery
Photovoltaic plants
Storage
Energy grid
Potable water
Heat pump
Domestic hot water
Inverted Rectifier
Charging station for electric
Battery

SUP Supply air
ETA Extract air
EHD Exhaust air
ODA Outdoor air

Source: Fraunhofer Institute for Building Physics

The "active-town house" in Frankfurt am Main is the largest multi-storey residential building in Efficiency House Plus Standard. 74 residential units are located above a commercial basement on seven floors. The aligned south-facing shed roof is almost completely covered with photovoltaic modules. A folded front slightly rises from the ground floor façade. The folding breaks the length of the building creating the necessary ground depth for the development of residential floor plans with a low building depth. For the provision of heat, a heat pump comes with a thermal capacity of 120 kilowatt hours. As a heat source serves the waste water of a nearby dirt water channel that is extracted the required heat on a total length of about 50 metres via a heat exchanger.

Frankfurt am Main
Speicherstraße

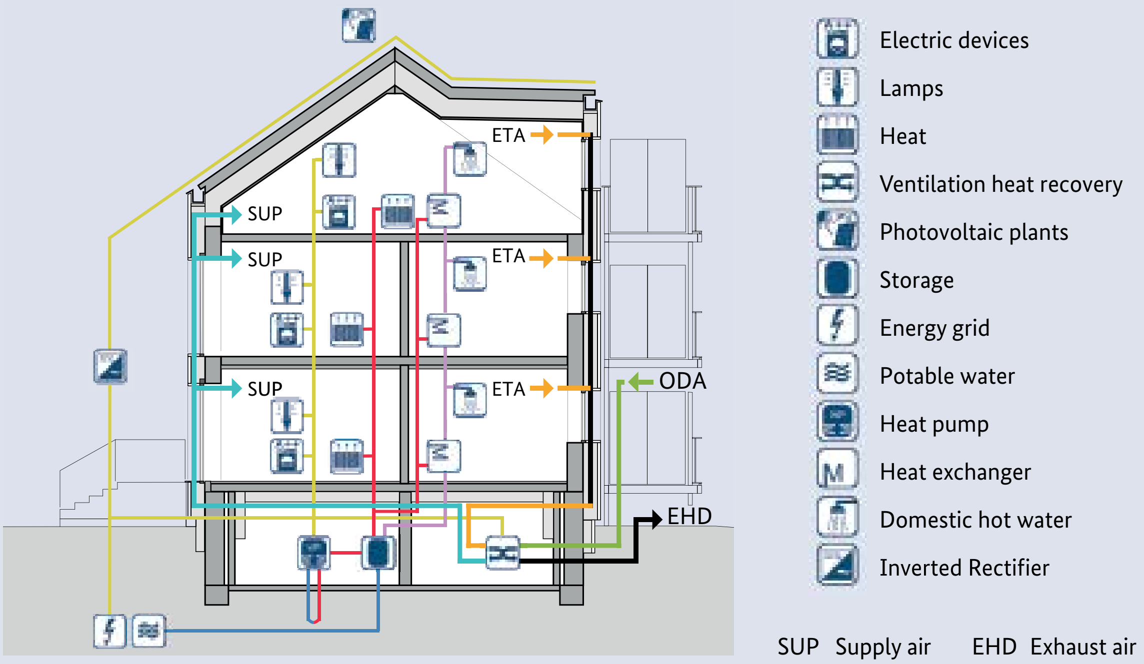
Architect:	HHS Planer + Architekten AG
Builder:	ABG Frankfurt Holding GmbH
Living Space:	6,480 m²
Battery:	250 kWh
Rated output roof:	250 kW_{Peak}

Legend for technologies:

Heat pump
Photovoltaic plants
Charging station for electric vehicles
Battery
Ventilation system with heat recovery

Efficiency House Plus in old buildings

Figure 33: Technology concept in building from Pfuhler Straße 4 and 6



Source: Fraunhofer Institute for Building Physics

In Neu-Ulm the first Efficiency House Plus Projects in Old Buildings were inaugurated in May 2016th. The model concept by the urban housing company NU-WOG, gave Efficiency House Plus Standard the start in the renovation of multi-storey apartment buildings. The row houses built in 1938 in the Pfuhler Street got quite old and in need of renovation.

A huge financial excess were especially the energy costs of 500 kilowatt hours per square meter and year that were required to operate the premises. In 2012, the Federal Building Ministry cooperated with NUWOG due to a planning competition for universities in cooperation with consultants. The conditions were a restructuring plan for an Efficient House Plus in the old building. Both winning concepts of TU Darmstadt and University Ruhr West implement the extra energy caused by building-integrated photovoltaics solving at the same time the high standards of architecture and comfort.

The existing buildings were given new, barrier-free bathrooms and enlarged, floor to ceiling windows. Shading elements prevent from overheating of the rooms during summer months. The floor plan offers spacious, use neutral spaces and therefore a long-term flexibility. The previously used only as storage lofts were transformed into quality housing. The residents use highly efficient appliances and LED lighting.

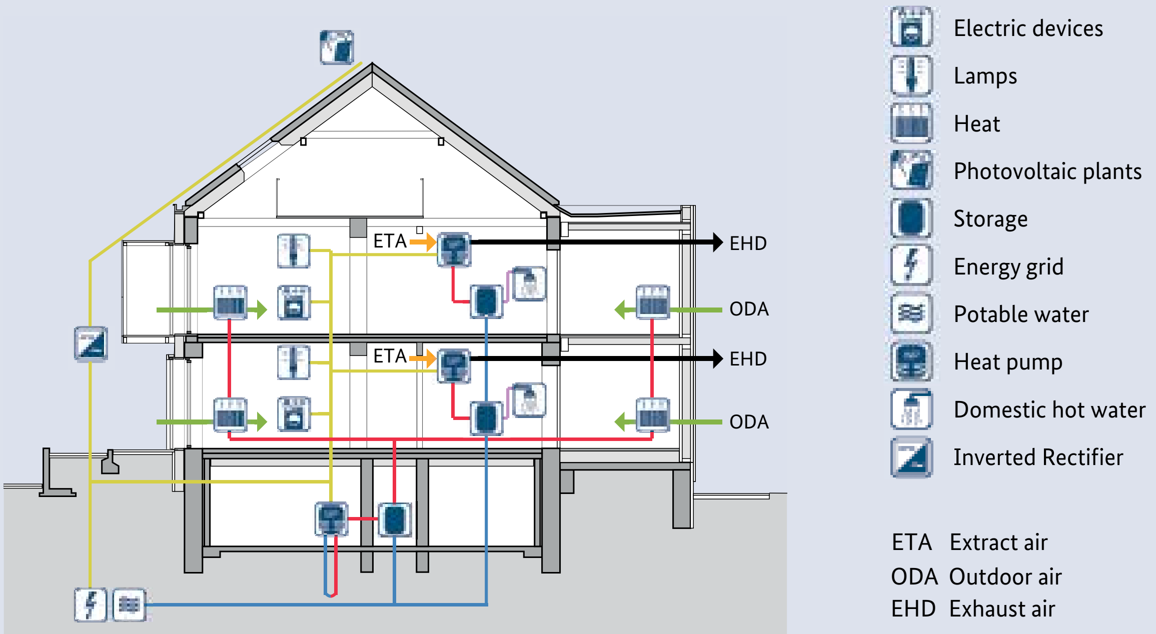
The Neu-Ulm model projects show that through proper planning and construction measures,

Neu-Ulm
Pfuhler Straße 4 and 6

General contractor:	werner sobek design, Stuttgart
Heated net floor area:	656 m²
Projected electricity surplus:	8,824 kWh/a
PV surfaces:	214 m²
Rated output:	33.5 kW_{Peak}

Legend for technologies: Heat pump | Photovoltaic | Ventilation system with heat recovery

Figure 34: Technology concept in building from Pfuhler Straße 12 and 14



Source: Fraunhofer Institute for Building Physics

Efficiency House Plus Standards can be implemented in combination with a high level of comfort. Expected are now new research findings and outcrop in a two-year monitoring for future development of existing properties.

Pfuhler Straße 4 and 6, Neu-Ulm

The Stuttgart architect Werner Sobek integrated as a planning main element partially prefabricated wall and roof elements that surround the building. The stock roof was completely removed and replaced with the new elements. The highly insulated facade system in timber was then mounted on the existing exterior wall including the ventilation ducts.

Pfuhler Straße 12 and 14, Neu-Ulm

According to the plans by o5 architects from Frankfurt, spacious maisonettes were created upstairs under the gabled roof by spatial expansion. The heat is won by central brines – water heat pumps. The water is heated by decentralised air water heat pumps.

Neu-Ulm
Pfuhler Straße 12 and 14

Architect:	o5 architekten BDA, Frankfurt am Main
Heated net floor area:	596 m²
Projected electricity surplus:	2,022 kWh/a
PV surfaces:	162 m²
Rated output:	24.93 kW_{Peak}

Legend for technologies: Heat pump · Photovoltaic · Ventilation system with heat recovery

Efficiency House Plus in educational facilities

The Efficiency House Plus approach is not solely limited to the construction of detached houses and apartment buildings. Though currently, private households represent the largest group with around a quarter of the total annual energy consumption in the building sector, also other use areas provide considerable savings.

chools and other educational facilities are highly suitable buildings for the implementation of the Efficiency House Plus Standard: the day times at which most of the energy is used in such buildings and in which the photovoltaic systems produce electricity are congruent. Furthermore, educational buildings are predestined to sensitize future generations for resource-saving and future-oriented building. And, being part of a campus, Educational Facilities excellently serve as testing new energy management solutions on quarter levels.

Especially in the area of public buildings there is a great need for renovation. In Germany, their share of the total of all non-residential buildings is about 25 percent[4]. Only through the rehabilitation of existing schoolhouses in Germany four terawatt hours per year could be theoretically saved in energy[5]. However, in the field of educational buildings stand there are also many municipalities building new facilities besides renovating others. Thus, for the coming years a significant increase in new construction of day-care facilities is expected. Also rising student numbers and the unbroken influx into the metropolitan areas are factors that require more investment in educational buildings.

To promote the construction or renovation of educational buildings in Efficiency House Plus Standard, there is a new funding guideline of BMUB since 2015. The aim of promotion is to establish through research

Upon completion the Luise-Otto-Peters-School in the town of Hockenheim will achieve an energy surplus nearby 15,000 kilowatt hour per year.

4 See: Erhorn, Erhorn-Kluttig and Reiß, IBP report WB 167/2012, Studies on standard funding of innovations in the construction sector and for monitoring educational buildings of Effizienzhaus Plus standard in Germany, Stuttgart 2012, Page 4

5 See: B. Niesing, energy-producing building, in: Weiter.vorn 4.11, Munich 2011, Page 11.

and development the Efficiency House Plus Standard and thus continuing to establish the positive energy thoughts in non-residential construction. Educational Facilities within the meaning of the funding guidelines are buildings related to education and training, research and teaching. Thus, the funding covers a maximum bandwidth of day care to universities, from community colleges to laboratory buildings. Eligible are both, new buildings under planning as well as renovations and expansions of existing buildings that meet the Efficiency House Plus Standard. The application relates to Germany and German property abroad. The facilities can be operated both by public and by private organisations. The promotion is open to planning, material, and technology.

The core of the promotion is the scientific monitoring and evaluation of projects. So for some projects, novel systems for energy-saving and comfortable space conditioning will be tested. Simulations are used in advance in order to describe the thermal behaviour of the building during the planning. Thus, on the one hand the interaction of the individual components can be optimized, while on the other hand an excessive mechanization of the buildings can be counteracted this way by specifically integrating potentials such as storage masses into the energy concept. All completed Educational Facilities in funding are subject to a two-year monitoring. Likewise, as in the support programme for Efficiency Houses Plus Residential Building, the measurement results shall be evaluated in the future by an accompanying research team and published continuously.

Other elements of the programme are the promotion of the use of innovative, not yet commercially available components and quality assurance. This includes the certification of buildings according to the “Rating System Sustainable Building” of the Federation (BNB).

The Wustrow Nursery School already fulfils the Efficiency House Plus standards.

The primary school in Hohen Neuendorf was constructed as an energy-plus building.

Renovations of educational buildings are on the agenda in many communities. The Uhlandschule in Stuttgart is being converted into a plus energy school.

Efficiency House Plus in the quarter

How can solutions be found for an economically optimal storage concept in order to maximize their own consumption of locally generated renewable energies in Efficiency House Plus buildings and to relieve the electricity grids? For this purpose the Federal Building Ministry promotes scientific investigations for a quarter central storage solution as a possible economic future solution: In the Living Lab of the prefab world "FertighausWelt" in Wuppertal, 19 Efficiency Houses Plus are centrally networked in a settlement among themselves. A reception building is supplied "sisterly" from the other houses with renewable electricity. The settlement is equipped with an electric central storage, which currently has a usable capacity of 40 kilowatt hours and can be upgraded up to 100 kilowatt hours.

The detailed measurement programmes demonstrated that the average residents' profile is comparable to a typical German two-person household. Therefore, the results obtained in an exhibition settlement can be transferred to "normal" inhabited settlements with the same type of house. The advantage of the exhibition settlement is that unlike "normal" inhabited settlements, changes in energy supply and energy management can be easily implemented during operation, because all homeowners participate in the trial. So, a real "Living Lab" can be implemented.

In a two-year monitoring till September 2017 profitability statements are developed to storage approaches. At a later date also solutions for data protection, land issues, storage access rights, and operator forms can be found besides the currently technical issues for a model of an economically optimal storage concept.

The results will help to reduce the cost of energy concepts of Efficiency Houses Plus to reduce electricity costs by a higher proportion intrinsically generated current and thereby bringing the practice approaches more economically into the market while relieving the electricity grids.

Figure 35: Map of the "FertighausWelt" Wuppertal: Heated net floor area and projected electricity surplus of the single buildings

		Heated net floor area:	Forecast of the final energy surplus (kWh/a):
1	*Reception building*	–	–
2	**Schwörer Haus**	261 m²	3,645
3	**Finger Haus**	172 m²	1,808
4	**Fingerhut Haus**	195 m²	89
5	**WeberHaus**	217 m²	1,064
6	**PartnerHaus**	171 m²	3,374
7	**HUFHAUS**	218 m²	no Data
8	**Büdenbender**	184 m²	512
9	**KAMPA**	204 m²	16
10	**ProHaus**	165 m²	1,827
11	**Rensch-Haus**	168 m²	56
12	**Bien-Zenker**	397 m²	5,677
13	**Holz&Raum**	142 m²	2,906
14	**Hanse Haus**	238 m²	2,326
15	**allkauf Haus**	191 m²	307
16	**OKAL**	343 m²	477
17	**Nordhaus**	164 m²	no Data
18	**Schwabenhaus**	200 m²	59
19	**Gussek Haus**	206 m²	595
20	**Danhaus**	153 m²	573
21	*central storage*	–	–

Source: According to FertighausWelt Wuppertal

The unanimous opinion of the network partners is: the technology is mature. The Efficiency House Plus works in practice and can contribute a lot to the energy transition in the building sector. Nationwide, the first pilot projects funded by the Federal Building Ministry are promoting the Efficiency House Plus for more Efficiency House Plus residential buildings. The Association of the Prefabricated Housing Industry has been reporting that its market share of Efficiency House Plus residential building is already at five percent

Figure 36: Projects in detail and their used technologies


allkauf Haus


Bien-Zenker


Büdenbender


Danhaus


Finger Haus


Fingerhut Haus


Gussek Haus


Hanse Haus


Holz&Raum


HUFHAUS


KAMPA


Nordhaus


OKAL


PartnerHaus


ProHaus


Rensch-Haus


Schwabenhaus


Schwörer Haus


WeberHaus

Technologies in all objects: Heat pump · Photovoltaic · Ventilation system with heat recovery

Source: According to FertighausWelt Wuppertal

What else needs to be taken into account?

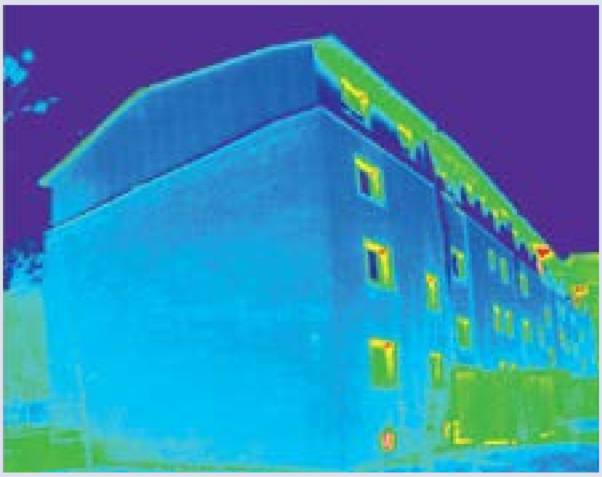
Higher specifications have to be met when designing and building an Efficiency House Plus. The following checklist can help to systematically address the challenges in the different phases.

Urban design

- → Site 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 face the sun.
- → Use planting to provide shade in summer and influence the microclimate.

Scheme design

- → Make the building as compact as possible. 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, if rooms are arranged on both sides of the circulation route, windows should be evenly distributed across the east and west façades. This lowers costs and saves energy.
- → 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 a useful tool for carrying out a visual check for consistency of workmanship.

- → 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 needs to be paid.
- → 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 daylighting.
- → Optimal orientation and pitch of surfaces to allow passive and active use of solar energy.
- → Zone the building according to the different temperature of the rooms.
- → Place internal building components that have storage capacity to take account of the sun's path.

Structural heat insulation

- → Avoid thermal bridges at structural connections (floor supports, roller shutter boxes, roof flashings).
- → Make sure all connection details that could 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 design

- 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, volumetric 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 fit out is completed.
- Monitoring construction work: Thermal imaging can detect manufacturing defects in roof and wall insulation.

Transfer to the user

- 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 this 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 easy-to-use building services 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 also be monitored.

Key links for research and funding

- Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
  www.bmub.bund.de
- Federal Office for Building and Regional Planning
  www.bbr.bund.de
- "Zukunft Bau" research initiative
  www.forschungsinitiative.de
- Fraunhofer Institute for Building Physics (IBP), department Energy Efficiency and Indoor Climate (EER)
  www.ibp.fraunhofer.de/en/Expertise/energy-efficiency-and-indoor-climate.html
- KfW Bankengruppe
  www.kfw.de
- Deutsche Energie-Agentur GmbH (dena)
  www.dena.de
- Effizienzhaus Plus Rechner
  www.effizienzhaus-plus-rechner.de
- Effizienzhaus Plus network
  www.forschungsinitiative.de/effizienzhaus-plus/

List of abbreviations

BBSR	Federal Institute for Research on Building, Urban Affairs and Spatial Development within the Federal Office for Building and Regional Planning
BHKW	Cogeneration heating plant (CHP)
BMUB	Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
BNB	Assessment System for Sustainable Building
CHP	Combined Heat and Power
CIGS	(Copper, indium, gallium, selenide)
DEH	Direct electrical heating
EEG	Renewable Energy Resources Act
EEWärmeG	Act on the Promotion of Renewable Energies in the Heat Sector
EFH	Detached house
EH	Efficiency House
EnEG	Energy Conservation Act
EnEV	Energy Saving Ordinance
EnVKV	Energy Labelling Directive
EU-RL	EU guidelines
IBP	Fraunhofer Institute for Building Physics
KfW	German Reconstruction Loan Corporation
kW	kilowatt
kW_{peak}	kilowatt peak
kWh/a	kilowatt hour per year
KWK	Combined heat and power generation (CHP)
l	Litre
LED	Light Emitting Diode
m	millimeter
m^2	square meters
MFH	Apartment block
OSB panels	Oriented strand board
PP/PE	Polypropylene/polyethylene
PV	Photovoltaics
S/V ratio	Surface-to-volume ratio
TU	Technische Universität
Qh	Heating energy demand
Qtw	Domestic hot water
U-value	Thermal transmittance
W/mK	Watt per meter kelvin
$W/m^2{\cdot}K$	Watt per square meter kelvin
W_p	Watt peak

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