Buildings Guide
Upgrade to ultra-low-energy buildings

bigEE

Strategic Approach

The Strategic Approach to improving energy efficiency in buildings

New residential buildings – (nearly) Zero and Plus-Energy Buildings

Authors
Dietmar Schüwer
Johanna Klostermann
Christopher Moore
Stefan Thomas

Printed 12/2012

The (nearly) Zero-Energy Building and the Plus-Energy Building concepts are based on the Low-Energy or preferably the Ultra-Low-Energy Building concept described in the Strategic Approach. This building standard includes on-site renewable energy technologies and/or combined heat and power (CHP) for generating power and also meeting cooling and heating requirements of the building at the same time. As on-site generation is normally more expensive than reducing energy consumption, the best possible energy efficiency should be achieved first by minimizing the energy needs. If the amount of on-site energy produced (converted in primary energy equivalent) is roughly equal to the annual primary energy consumption, the building can be described as a (nearly) Zero-Energy Building. If the production exceeds the consumption, the term Plus-Energy Building will be used. However, as on-site generation is normally more expensive, the first step in achieving energy efficiency is to minimize the energy consumption to the extent possible.

In the medium term, nearly all new residential buildings should achieve a (nearly) Zero or Plus-Energy Building standard. This will nearly eliminate the carbon footprint during use and, if possible, convert the building premises from an energy consumer to a net energy producer.

In principle, such a standard can be achieved by a surplus of on-site generated electricity, heating and cooling. Nevertheless, it is rare to be able to feed on-site generated solar thermal energy surplus into a local heating network. It is more common to feed surplus on-site electricity produced, by distributed CH(C)P units or by renewable electricity generation with photovoltaics or with micro wind or micro hydro turbines, into the electric grid. In both cases, the environmental footprint of the replaced electricity is crucial for the assessment of the on-site generation system.

Building integrated power generation

Distributed CHP

A combustion engine, stirling engine or, in the future, a fuel cell can simultaneously produce electricity, heating and – via absorption chiller – cooling that a building or group of buildings needs. This distributed cogeneration of heat and power (CHP) or heat, cold and power (CHCP) is very energy-efficient. Cost-effectiveness of distributed CHP improves with the size of the building and the plant.

Distributed CHP units can be considered to be highly efficient heat or cold generators with electric power as a waste product. The primary energy bonus for the by-product “electricity” can be estimated based on the chosen allocation method and the reference systems. CHP is generally a highly energy-efficient technology but there are two limitations in the context of high performance buildings. Firstly, the heating and cooling loads in high performance buildings are extremely low. A CHP unit cannot usually be operated economically for these loads in smaller buildings or apartments (compare the increase of specific investment costs for lower output in Figure 1). As a result, CHP is best suited to larger buildings, e.g. multiple dwelling units, high-rise buildings or clustered buildings supplied via a central CHP unit with a local heat or cold network. Secondly, small CHP units - especially so called micro-CHP systems with an electric output lower than 10 Kilowatt – currently have lower electric efficiencies and lower power indices (electricity to heat ratios)[1]. This means that the primary energy bonus for electricity will not be able to fully compensate the building’s energy consumption unless renewable fuels like biogas or wood pellets are used. This issue could be addressed by a successful market introduction of small-scale fuel cells with high electric efficiency[2].

1 Example of a typical mature micro-CHP unit (internal combustion engine): 12.5 kWth / 5.5 kWel / 27% electric and 88% total efficiency / power index: 0.44 (SeH 2011)
2 Example of a commercially available micro-CHP fuel cell: 1.0 kWth / 2.0 kWel / 60% electric and 90% total efficiency / power index: 2.0 (SeH 2011)

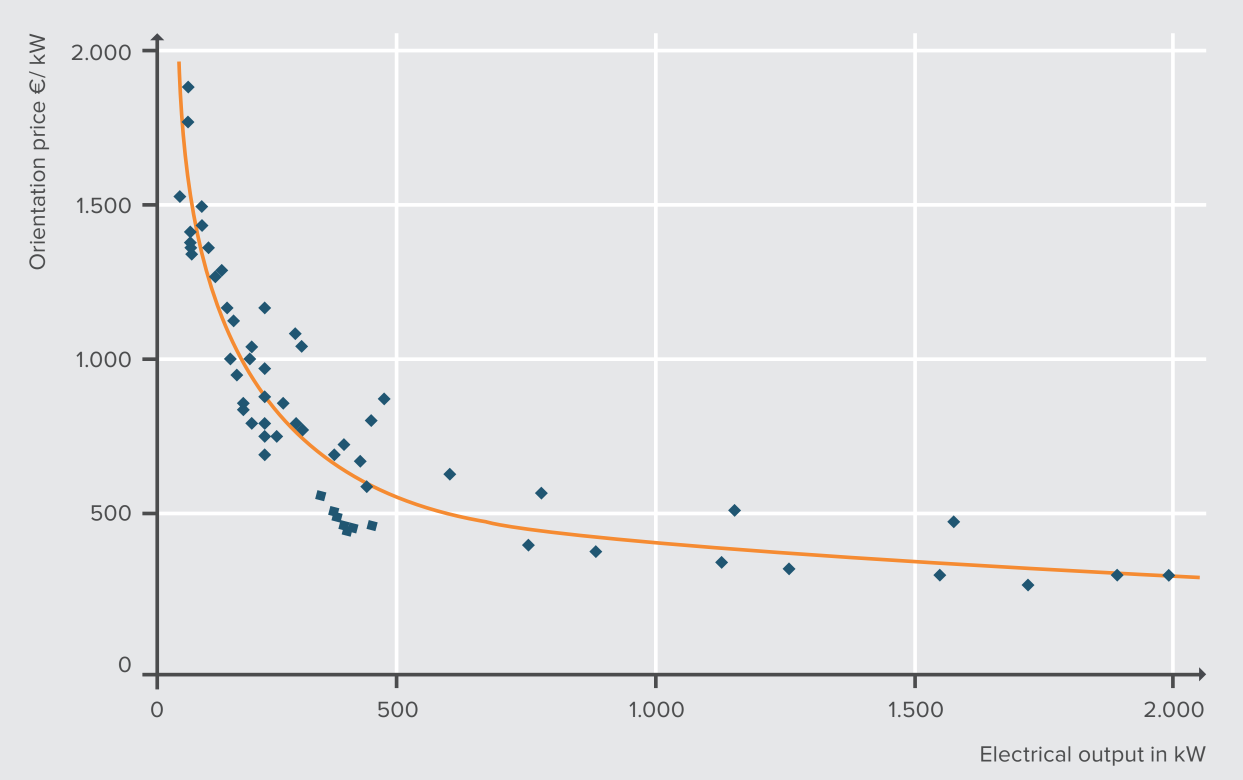

Figure 1: Cost curve as a function of electric output for natural gas fired combustion engine CHP plants (Analysis of 87 offers, including sound absorption, catalytic converter, lubrication, switchboard, ventilation, transport, mounting and commissioning)
Source: Wuppertal Institute, adapted from ASUE (2011)

Owing to the current limitations of CHP it is much more viable to achieve a (nearly) Zero or Plus-Energy Building by generating electricity from local renewable energy sources, especially solar photovoltaic systems.

Photovoltaics for on-site power generation

Photovoltaics (PV) is a semiconductor technology for converting sunlight directly into electricity. PV installed on the roof and walls can net meet the total electricity consumption of a single family house built to Ultra-Low-Energy Building (ULEB) standards in most climate zones. The cost of electricity produced by PV currently varies between €0.09/kWh$_{el}$ in sunny regions closer to the equator and €0.17/kWh$_{el}$ in Northern Europe.

The single solar PV cells are made of amorphous, poly- or mono-crystalline silicon, cadmium telluride or copper indium selenide / sulphide. They are interconnected to solar panels producing a few hundred Watts. PV arrays are very well suited for use in buildings because they are maintenance-free and emit neither noise nor pollution. Moreover, if they are mounted on or integrated into the building's roof or facade they will require no additional land use. PV systems are ideally positioned where they are unshaded throughout the year and with an orientation towards the equator. The optimum tilt or inclination angle depends on the latitude and varies e.g. between 48° for a northern city like Oslo / Norway (59°55' North, 10°45' East, Elevation: 25 m a.s.l.) and 2° for a location close to the equator like Nairobi / Kenya (1°17' South, 36°49' East, Elevation: 1680 m a.s.l.). Small deviations from the ideal positioning, e.g. orientation towards south-west or south-east[3], only have a small impact on the energy harvest (see Figure 2).

3 Orientation reversed to north-west and north-east for the southern hemisphere.

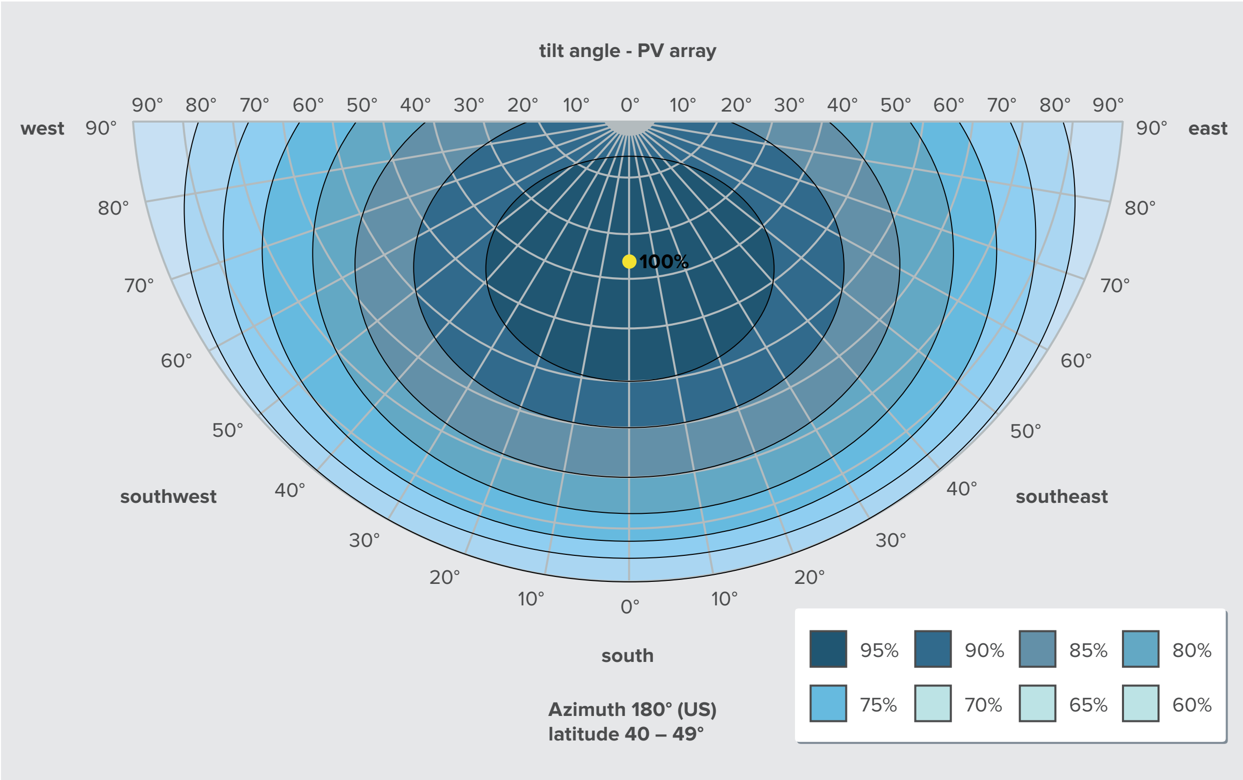

Figure 2: Deviations from the optimum solar energy yield (100%) depending on the array's orientation (exemplary for Central Europe). The orientation is defined by the azimuth (deviation from south) and the tilt or inclination angle against the horizontal line.
Source: Wuppertal Institute, adapted from REC (2012)

The solar energy potential depends primarily on the latitude and local climatic conditions like cloudiness and, secondly, on air temperature. Simulations with the Photovoltaic Geographical Information System (PVGIS)[4] for the cities mentioned above show that the average sum of global irradiation[5] per square meter received by optimally orientated modules lies between 1000 kWh/m^2/year for Oslo and 2190 kWh/m^2/year for Nairobi. In hot and arid climate zones even higher irradiation occurs, e.g. 2550 kWh/m^2/year for an optimum slope angle of 18° in Khartoum / Sudan (15°33' North, 32°32' East, Elevation: 383 m a.s.l.).

With this insolation power, a free standing crystalline silicon system with an installed peak power[6] of 1 kWp will harvest electricity in a range of 780 kWh_{el}/year (Oslo) to 1580 kWh_{el}/year (Nairobi) and 1780 kWhel/year in the extreme example (Khartoum). Assuming an average primary energy ratio of 2.5 this would result in a primary energy bonus in the range of ca. 1950 to 4450 kWh_{PE}/year, corresponding to 16 to 37 kWh_{PE}/m^2 TFA/year for a single-family building of 120 m^2 treated floor area.

4 PVGIS: The "Photovoltaic Geographical Information System" is an online-tool with interactive maps for PV performance calculations, powered by the European Commission. (REC 2012)
5 The global irradiation is the sum of direct and indirect (diffuse) solar radiation. PV cells are able to convert both energy shares into electricity.
6 The scale unit "Kilowatt peak" (kWp) describes a PV module's nominal power output of one Kilowatt at standard test conditions of 1000 W/m^2 irradiation at 25°C module temperature. To achieve one Kilowatt peak a module area of about 8 to 10 square metres is required, depending on the cell technology and efficiency. For the PVGIS simulations, a default value of estimated system losses of 14% has been adopted.

Such a building with e.g. a 4 kWp $_P$V system on a roof area of about 35 m^2 produces a primary energy equivalent of about 64 to 148 kWh$_{PE}$/m$_{TFA}$ ^{2}/year. This will be enough to fulfil the primary energy consumption of the building, if it is built according to bigEE's recommended ULEB standard . Depending on the climate zone this building will then be a nearly Zero or even a Plus Energy Building.

These calculations are valid for unshaded locations. PV modules are very sensitive to shading e.g. from trees or other buildings. Furthermore, high module temperatures diminish the energy yield[7].

Fixed PV modules are commercially available in free-standing (rack-mounted on the roof or on the ground nearby the building) as well as in building-integrated (BIPV) systems. Because there is no rear ventilation the latter are approximately 5% less efficient[8]. But as they can replace conventional building materials in parts of the building envelope such as the roof, skylights, or facades, BIPV can reduce the initial construction cost. Special forms are available on the market, such as semi-transparent shading elements or windows with integrated PV cells or solar roof tiles, which are also suitable for historic buildings.

Figure 3: Semi transparent solar PV roof at the main station of Berlin/Germany
Source: Schüwer (2011)

Due to economies of scale, costs for PV systems have fallen significantly in recent years. For example in Germany, one of the fastest growing PV markets world-wide, the Kilowatt peak price for a fully installed roof mounted system has fallen by more than 50% in four years (between end of 2008 and end of 2012) to around **€**1700 per kWp (see Figure 4).

7 These thermal induced losses are already factored in for the yield calculations above by using local ambient temperature data. The losses are estimated in a range of 6.8% for Oslo (cool climate zone) and up to 16.5% for Khartoum (hot and arid climate zone).
8 Calculations with PVGIS result in losses due to higher module temperatures of 37 kWh$_{el}$/year for Oslo and 100 kWh$_{el}$/year for Nairobi for a 1 kW$_p$ module.

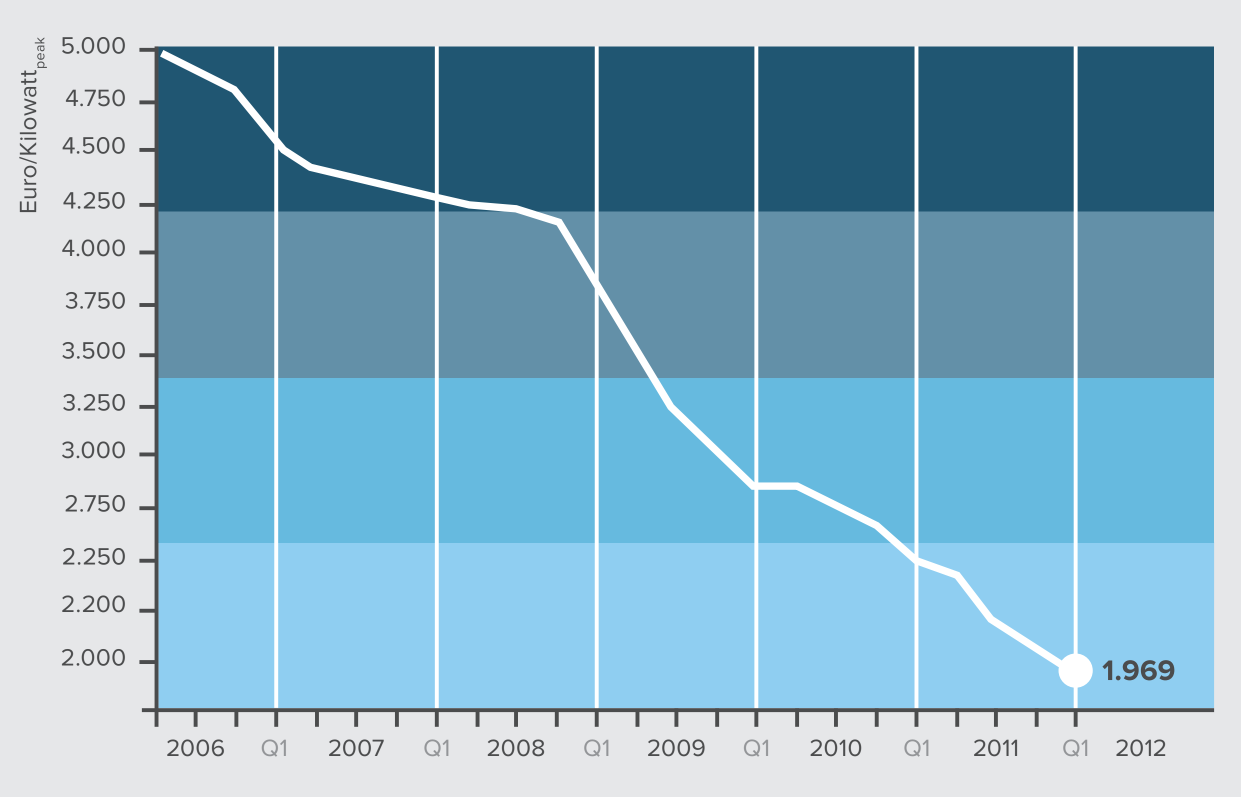

Figure 4: Development of the average end consumer price for a complete installed PV system for roof mounting (up to 100 kWpeak, without VAT)
Source: Wuppertal Institute, adapted from BSW Solar (2012)

However, in many instances they are not yet economically viable without financial incentives such as guaranteed feed-in tariffs or investment subsidies. The reason is that the sun's radiation and the electricity produced from it by the PV system does not normally match the electricity consumption of the house. There will be times, during which there is more solar electricity generated than needed, and it needs to be fed into the public network or stored in a battery. The latter option will cause additional costs. Feeding into the network will only be cost-effective if there are guaranteed feed-in priority regulations and tariffs at an attractive level. Nevertheless, given that module prices continue to fall and electricity prices or tariffs for end consumers are still increasing, in more and more countries the electricity generation costs of the PV system is equal to or lower than the electricity price or tariff for the final consumer. This means, the so-called grid parity is reached. Taking the example of Oslo with an annual yield of ca. 780 kWh_{el}/kW_p PV systems can deliver electricity in a cost range of 0.18/kWh_{el} today (€1700/kW_p) to €0.10/kWh_{el} in the future (€1000/kW_p, see Figure 5). In locations with double solar yield like Nairobi (roughly 1600kWh_{el}/kW_p) costs halve to €0.09/kWh_{el} (today) to €0.05/ kWh_{el} (future[9]). (Nitsch et al. 2012)

9 State for today: November 2012. The future system price of €1000/kW_p is expected to be reached around the year 2030 (Nitsch et al. 2012, S. 1).

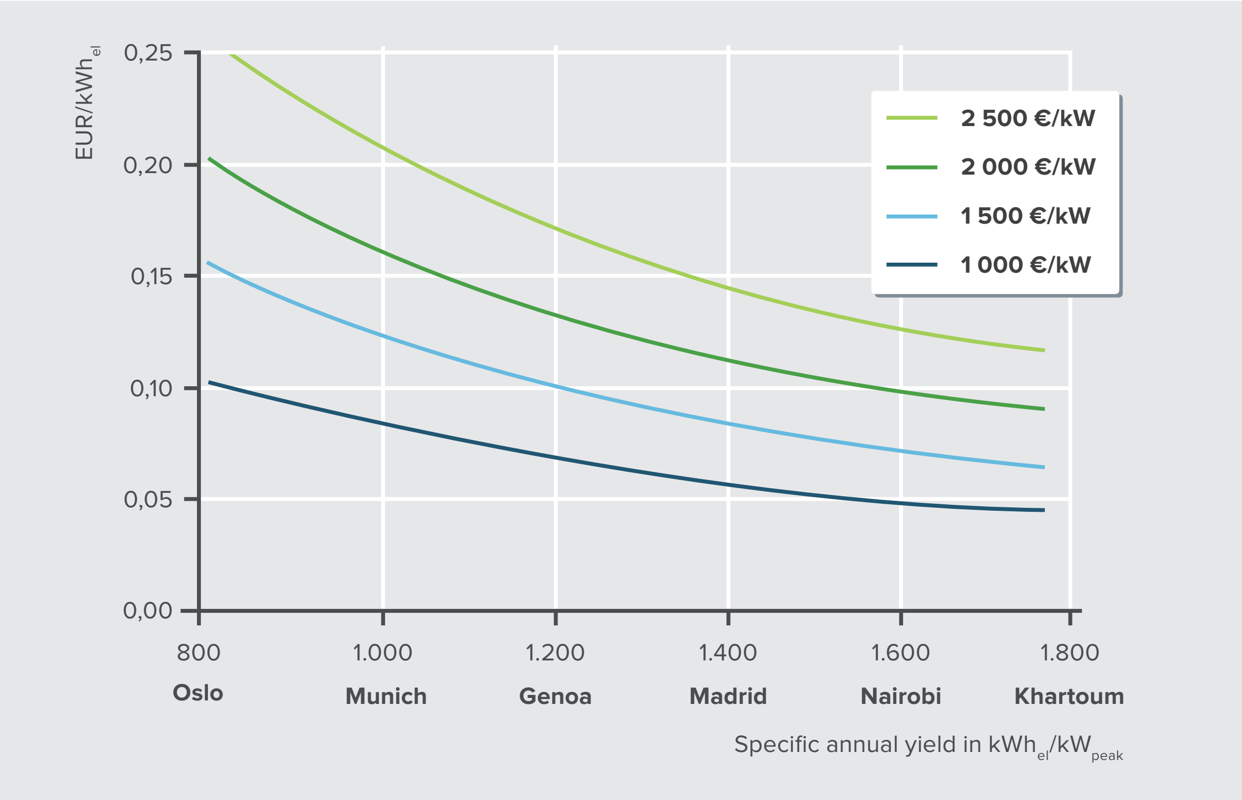

Figure 5: Power production costs for photovoltaic electricity in Euros per kilowatt-hour depending on specific system prices and specific annual yield (interest rate: 3.0% / life of plant: 20 years / O&M: 1.5% per year of initial investment)
Source: Calculations by Wuppertal Institute / Yield calculations for cities by REC (2012)

Other on-site renewable sources: Micro wind turbines and micro hydro

Depending on the availability of local resources, other renewable energy sources like wind or water power can be used in some cases.

Integrating small scale wind turbines is much more limited than the use of solar PV modules due to restrictions such as noise, vibration, wind turbulence, maintenance requirements or aesthetics. Information about small scale wind turbines can be obtained at e.g. http://www.bigee.net/s/2vawvr (Wind Energy Market 2012). Micro hydro turbines can only be used by buildings located close to creeks, streams or rivers. Generally, both installations are more suitable for rural areas and need appropriate dimensioning on site. In special cases, wind turbines with an output of a few kilowatts can be installed on the roof or facade of free standing or highrise buildings in cities (see Figure 6).

Figure 6: Examples of a small scaled urban wind turbines with vertical or horizontal axis
Sources:
a) Bahrain World Trade Center, Asian Pictures (2008):
b) Ökostation Bauen und Technik, Wuppertal, Schüwer (2012b)

References

Arbeitsgemeinschaft für sparsamen und umweltfreundlichen Energieverbrauch e.V. (ASUE). (2011):
BHKW-Kenndaten 2011 - Module, Anbieter, Kosten.
http://www.bigee.net/s/xhjqfc

Asian Pictures (2008):
Bahrain World Trade Center.
http://www.bigee.net/s/tq7wmb

Bundesverband Solarwirtschaft, Das Netzwerk der Solarbranche (BSW Solar) (2012):
Preisindex Photovoltaik.
http://www.bigee.net/s/npv56k

Joint Research Centre Institute for Energy and Transport (JRC) (2012):
http://www.bigee.net/s/xng1k7

Nitsch, J., Pregger, T., Scholz, Y., & Naegler, T. (2012):
Datenanhang II zum Schlussbericht „Langfristszenarien und Strategien für den Ausbau der erneuerbaren Energien in Deutschland bei Berücksichtigung der Entwicklung in Europa und global“ (No. BMU - FKZ 03MAP146) (S. 331). Berlin: Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU).
http://www.bigee.net/s/6s1cmw

Renewable Energy Concepts (REC) (2012):
Tilt angle - PV array
http://www.bigee.net/s/3e83p6

Schüwer, Dietmar (2011):
Semi transparent solar PV roof at the main station of Berlin/Germany. Wuppertal Institute for Climate, Environment and Energy GmbH. Wuppertal
Schüwer, Dietmar (2012):
Ökostation Bauen und Technik, Wuppertal. Wuppertal Institute for Climate, Environment and Energy GmbH. Wuppertal

Strom erzeugende Heizung (SeH) (2012):
Geräteübersicht der Strom erzeugenden Heizungen.
http://www.bigee.net/s/94ixhn

Wind Energy Market (2012):
http://www.bigee.net/s/2vawvr

Your guide to energy efficiency in buildings.

bigee.net

bigEE is an international initiative of research institutes for technical and policy advice and public agencies in the field of energy and climate, co-ordinated by the Wuppertal Institute (Germany). Its aim is to develop the international web-based knowledge platform bigee.net for energy efficiency in buildings, building-related technologies, and appliances in the world's main climatic zones.

The bigee.net platform informs users about energy efficiency options and savings potentials, net benefits and how policy can support achieving those savings. Targeted information is paired with recommendations and examples of good practice.

Co-ordinated by

Wuppertal Institute for Climate, Environment and Energy

Partners to date

Financial support

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

Dr. Stefan Thomas • bigee@wupperinst.org

Wuppertal Institute for Climate, Environment and Energy • Doeppersberg 19 • 42103 Wuppertal • Germany • Phone: +49 (0)202 2492-129