
GOAL: ZERO ENERGY BUILDING

Exemplary Experience Based on the Solar Estate *Solarsiedlung Freiburg am Schlierberg, Germany*

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INTRODUCTION

Zero energy consumption. The goal sounds simple and is presented excessively in variations all over the world. Energy and environmental politics demand zero consumption as a long-term goal, marketing has discovered the concept and first buildings and settlements aiming at balanced energy or emission budgets have been constructed.

As an example, the German Federal Government specifies in its fifth energy research programme (2005): For new buildings, the goal is to reduce the primary energy demand, i.e. the energy demand for heating, domestic hot water, ventilation, air-conditioning, lighting and auxiliary energy, again by half compared to the current state of the art. The long-term goal is zero-emission buildings. England and the USA aim for zero carbon developments and net-zero energy buildings (DOE, 2009) in political programmes.

The Vatican accepted the offer of climatic “indulgence”—and thus became the first country in the world to completely compensate its carbon emission (Spiegel online, 2007).

Megaprojects in the growth regions of the Arabian Gulf and China advertise with a CO₂-neutral balance. A Zero Carbon Community is to be created in Masdar, Abu Dhabi (Foster, 2007), and the first Chinese carbon-neutral ecocity was planned for Dongtan, Shanghai (Pearce, 2009).

Not only to aid international communication, but also to further the processes required to solve energy-related problems, it is essential that key words, central concepts, their usage and their relationships be clarified. This article intends to contribute to this clarification based on the monitored example of a solar estate.

Net zero energy building, equilibrium building, carbon neutral city—the accounting method varies, depending on motivation and point of view. If the focus is on finite and scarce resources, energy is the currency; CO₂-equivalent emissions are considered if global warming and public health is the issue; the cost of energy is what concerns a tenant paying for heating and electricity. A balance in one set of units can be converted to another, but the conversion factors often also shift the balance point. Energy will be used as the reference quantity in the following article, which prevents confusion with non-energy measures (e.g. carbon credits for forestry) and avoids the nuclear power debate, in which nuclear power is partly calculated as being CO₂ neutral.

The diversity of concepts is an indicator that a scientifically based methodology is still lacking, though initial publications focus hereon (Pless et al. 2009). Since October 2008, a group of experts in the International Energy Agency has been addressing this issue under the heading, Towards Net Zero Energy Solar Buildings (Riley et al. 2008). The goal is to document and analyse outstanding examples that are close to being net zero-energy buildings, and while doing so, to develop the methodology and tools for working with such buildings. The Chair of Technical Building Services, University of Wuppertal, is co-ordinating the methodological work.

The zero-energy approach—still under construction—will here be presented using a solar estate as an illustration.

KEY WORDS

net zero energy, zero emission, solar estate, solarsiedlung freiburg am schlierberg, monitoring

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FIGURE 1. The solar estate, “*Solarsiedlung Freiburg am Schlierberg.*” 59 plus-energy terrace houses, nine of them on the flat roof of an office block. Source: Büro Disch.



PLANNING AND REALISATION OF THE SOLAR ESTATE, SOLARSIEDLUNG FREIBURG

The architect Rolf Disch is a pioneer of building with the sun. From 1999 to 2006, he built his solar estate of *plus-energy houses*[®] on the Schlierberg hill in Freiburg.

The city of Freiburg in the South-West of Germany is one of the sunniest places of the country—

lat. 48°, longitude 7,5°, annual total irradiation about 1.100 kWh/m², average temperature 10°C.

The estate is located three kilometres south of the historic centre, bordering directly on the suburb called *Vauban*. This former barracks area has been a test ground for sustainable, ecological construction since the 1990s. On the ex-sports grounds of the barracks area Disch planned a holistic, sustainable estate with plus-energy houses being one of the major components in a set of measures including advanced water management and mobility concepts. Due to financial circumstances, the initial planning had to be reduced and only the Northern half of the planned settlement was realised.

By now about 170 residents live in the 59 terrace houses, nine of them are placed on the roof of the *sun ship*, a commercial block of offices and shops acting as a noise barrier to the nearby main road. The terrace houses are of different widths and extend over two or occasionally three storeys, so that the living areas vary from 75 to 200 m². In accordance with classic solar building principles, the living/dining rooms and bedrooms are to the south, access is in the centre and the service zones on the northern side include kitchens, bathrooms and building services.

ENERGY MONITORING

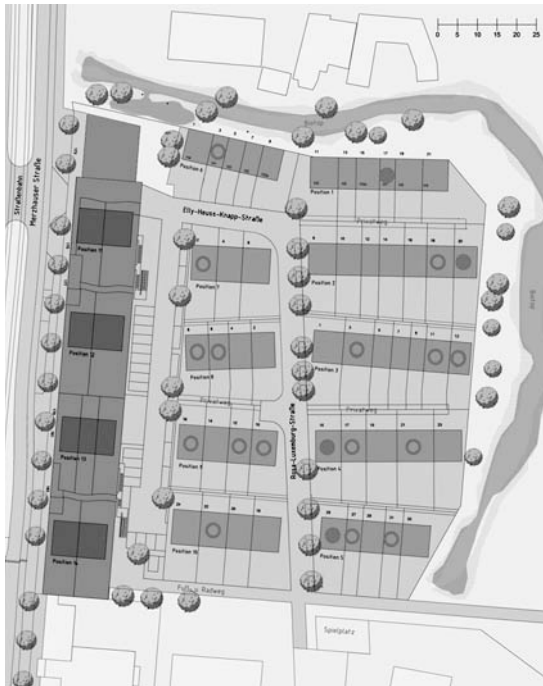
Goal of the monitoring is a full balance for the consumption of the 50 ground-based terrace houses, with heating and electricity on the demand side and solar electricity generation on the generation side (*energy credits*). This is possible with conventionally

TABLE 1. Basic Construction Data.

∅ building envelope	U value 0.28 W/(m ² K)	
Windows (triple, low-e)	U _g value 0.70 W/(m ² K)	g value glass >55%
external walls	U value 0.12 W/(m ² K)	
floors	U value 0.16 W/(m ² K)	
roofs	U value 0.11 W/(m ² K),	
Photovoltaics	total 3,150 m ²	about 400 kW _p
Ventilation: decentral mechanical ventilation with heat recovery per room		
Heat supply: local heating network with a combined heat and power plant driven by woodchip and gas		

Source: Büro Disch

FIGURE 2. Site plan of the *Solarsiedlung Freiburg*. The marked terrace houses are those included in the energy analysis. The balance of the estate in total is based on averaging of the results of these houses. Extra measurement equipment for transient data collection was installed in the four houses marked with a solid circle. *Source:* Büro Disch + Uni Wuppertal.



installed metering equipment. With the agreement of the residents, the data have been obtained from the utility in the same way as for the new so called *building energy passport*, resulting from the 2002 EC directive on Energy Performance in Buildings. State-of-the-art meters do save the monthly or daily values for several years for detailed analysis.

All residents were approached and asked for permission to collect their data. 24 households agreed; of these, sufficient data were acquired from 20 houses—at least annual consumption figures covering the same period for heating including domestic hot water, electricity consumption including that for appliances and lighting, and electricity generation by the PV generators. These 20 houses describe the *monitored estate*. For some individual houses, monthly or even daily values of energy consumption and generation are available. Additional measurements of the indoor climate and the energy consumption for domestic hot water are made in four of the houses.

INTEGRATED URBAN PLANNING

The orientation and housing density on the estate were designed to take account of living quality, unobstructed solar radiation on the photovoltaic roofs throughout the year, summer shade and winter sun on the southern façades on the one hand, and expensive land on the other. An example of suitable tools for this planning phase is illustrated by Fig. 3, taken from a study made during the course on

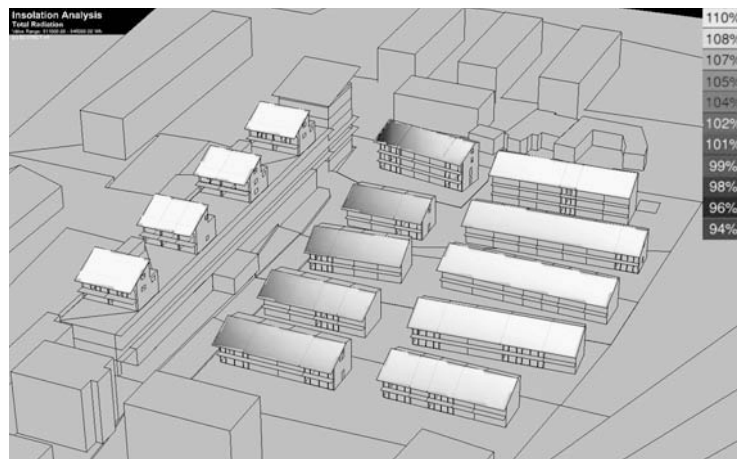


FIGURE 3. Simulation of the solar radiation potential of the roof areas. A solar yield of 105–110% is possible over almost the entire area. A value of 100% is the value for an unshaded, horizontal plane in Freiburg, namely global radiation of app. 1050 kWh/m²a. *Source:* Research Master’s Course on Environmental Building Design 2008, Tool: Ecotect.

Environmental Building Design within the Master's Programme in Architecture at Wuppertal. Students simulated solar radiation availability—qualitative and quantitative—with the programmes *Sketchup*, *Ecotect*, and *Gosol* and compared results with model studies under the artificial sun. They focused on annual solar radiation potential of roofs and seasonal solar radiation of facades (radiation in winter, shading in summer) in comparison with total potential and on shading masks of open spaces (terraces and playgrounds) for a differentiated view on periods of use. Radiation and shading are well represented in all programmes.¹

A whole article could be devoted solely to the subject of orientation of ultra low-energy houses. Deviations from a southern orientation by up to 45° do not reduce the winter solar gains from southern façades significantly. As will be demonstrated later, other effects predominate.

THE PATH TOWARDS NET ZERO ENERGY

Designed as ultra low energy houses (so-called *passive houses*), the houses consume very little energy. Only this small remaining amount of energy can be balanced by the photovoltaic yields from the roofs. This high energy-efficiency on site reduces the consumption of renewable energy and the requirements on transport and storage of energy in grids (low mismatch factor).

The low consumption results from a whole group of measures: The compact houses were built in compliance with the passive house standard. The high insulation standard—the average U-value for the building envelope is 0.28 W/(m²K)—together with efficient ventilation heat recovery are first keys to low consumption. Electricity-saving appliances and appropriate user behaviour reduced the domestic power consumption. Water-saving tap fittings were installed. Finally, all of the houses on the estate are connected to a local heating network supplied by cogeneration from a combined heat and power plant operating with woodchips and natural gas.

Compared to heat, electricity is a high-quality form of energy (100% exergy). Taking the different exergy potential into account balances with electricity and heat are thus regarded at the primary energy

level, with the consumed end energy being weighted with the relevant primary energy factor. As an example, German standards weight wood with a factor of 0.2, heating oil and gas with a factor of 1.1 and electricity with a factor of 2.7² thereby considering the non-renewable part of the primary energy only. The primary energy factor for electricity reflects the regional or national power system with its energy sources and efficiency.

The *average house* was defined from the data for the monitored estate (Table 2):

- 2.9 inhabitants,
- 138 m² heated living area,
- 50 m² photovoltaic system with 6.4 kW_P rated power, i.e. 0.36 m² photovoltaic area with 46 W_P rated power per m² heated living area.

The *average house* of the *Solarsiedlung Freiburg* has a primary energy balance of +36 kWh/(m²a).³

Fig. 4 explains the path from a house built according to the current building code towards zero energy based on the data obtained for the average house.

- a. The *average house* of the *Solarsiedlung Freiburg*, if planned in accordance with the current German Building Code, (would consume 185 kWh/m²y) of primary energy incl. appliances,⁴
- b. This house, if operating as an electricity-saving household like the average household of the *Solarsiedlung Freiburg*, would consume 165 kWh/m²y.
- c. The house as designed, complying with the passive house standard, still consumes 98 kWh/(m²a).
- d. If the heat is obtained from the local heating network with its share of wood as the fuel, the consumption decreases to 79 kWh/(m²a)⁵ compared to 100% gas fired heating.
- e. This low consumption is then to be compensated with a credit of 79 kWh/(m²a) primary energy for photovoltaically generated electricity, the remainder is the positive primary energy balance of 36 kWh/m²a on average. To compensate the consumption of the *average house* according to the current German standard, twice as much electricity would have to be generated. The roof area of the existing terrace houses would be too small to install the necessary photovoltaic modules.

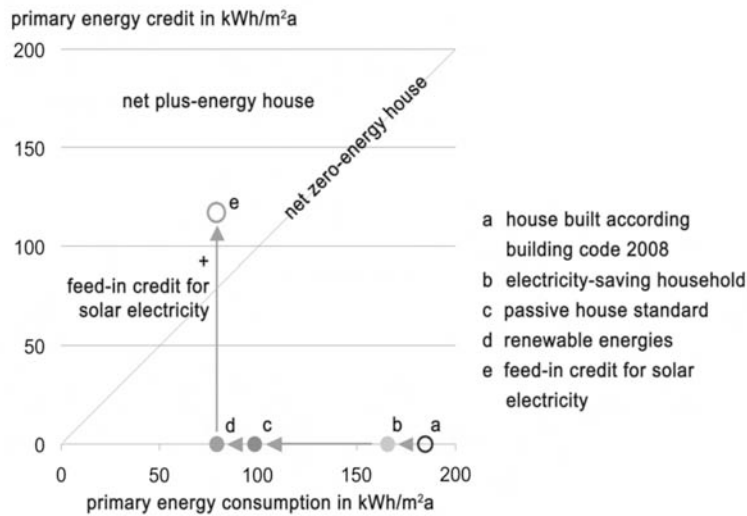


FIGURE 4. Derivation of the positive balance. The graph shows the route to the plus-energy house based on the data acquired for the *average house* from the 20 buildings monitored. The decisive steps are the passive-house construction and the photovoltaic systems. Primary energy factors applied: 0.9 for the heating network, 2.7 for grid electricity.

In scenarios with a wider scope, compensation is also achieved by feeding heat into heating networks or with credits from CO₂ emissions trading. In this case, the proposal is to take the building to define the system boundary for the balance.

DIFFERENCES AND LIMITATIONS

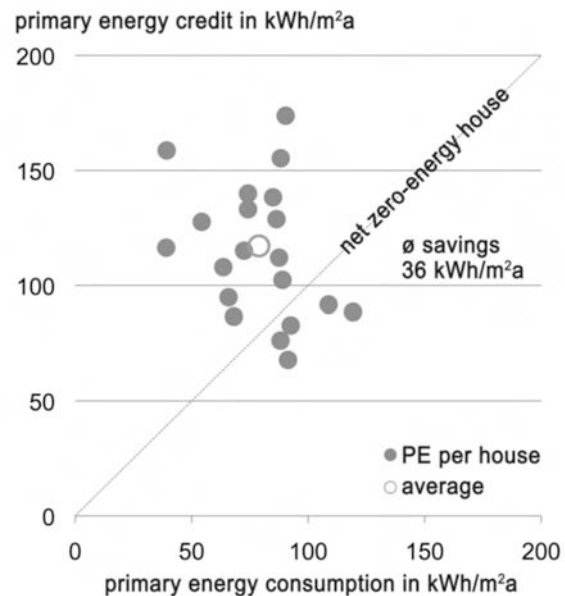
The balance for the *average house* of the estate is positive, but individual houses deviate from this positive average balance (Figure 5, Table 2). In some cases, the ratio of living area to photovoltaic area is unfavourable, as there are a few three-storey houses, which have relatively less roof area for the photovoltaic system (0.22 m² instead of the average of 0.36 m² PV/heated living area). Some terrace houses are at the end of a row and thus consume more heating energy. The lower ratio of roof area to living area with higher buildings already indicates that there are limits to the energy concept that underlies the *Solarsiedlung Freiburg*. Other solutions will be required for such buildings.

Furthermore, the user behaviour is decisive for the energy balance of optimised buildings. This influence is averaged out in an estate with similar types of houses.

THE SIGNIFICANCE OF USER BEHAVIOUR

Typical for lowest-energy houses: In the *Solarsiedlung Freiburg*, only less than 30% of the primary energy is consumed for heating and hot water, but

FIGURE 5. Primary energy balances for the houses of the monitored estate. Primary energy factors applied: 0.9 for heating network, 2.7 for electricity.



about 70% for electricity. This indicates the potential for energy-saving appliances (class A++) and appropriate user behaviour. The determined electricity consumption on the estate is somewhat lower than the German average. However, there is still considerable potential for reducing it further.

TABLE 2. Monitored Consumption and Generation Data.

house	inhabitants	heated living area	size pv		heat consumption ^x in endenergy	heat consumption ^x in primary energy	electricity consumption in endenergy	electricity consumption in primary energy	electricity generated in endenergy	electricity generated in primary energy	in total
#		m ²	m ²	kW _p	/m ² a	/m ² a	/m ² a	/m ² a	/m ² a	/m ² a	PE /m ² a
1	2	107	23	2,9	20	18	27	73	25	68	-23
2	2	148	46	5,9	33	30	23	62	31	83	-10
3	3	121	62	7,8	35	32	16	43	52	140	66
4	2	133	62	7,8	39	35	20	53	58	155	67
5	4	132	62	7,8	13	12	10	27	59	159	119
6	3	197	77	9,8	23	20	20	54	49	133	59
7	2	134	51	6,3	24	22	24	65	41	112	25
8	1	81	30	3,8	16	14	18	49	40	108	44
9	1	94	30	3,8	22	20	18	49	32	87	18
10		147	51	6,0	24	22	19	51	43	115	43
11		162	82	9,6	18	16	34	92	34	92	-17
12	2	119	46	6,2	17	16	38	104	33	89	-31
13	office	147	46	6,2	23	20	24	64	51	138	53
14	5	133	62	7,5	29	26	24	64	64	174	83
15	4	133	46	6,2	9	8	12	31	43	116	77
16	4	147	31	4,2	28	25	11	29	47	128	73
17	5	162	46	6,2	28	25	23	62	48	129	42
18		147	46	6,2	40	36	19	52	28	76	-12
19	4	162	46	6,2	19	17	26	72	38	102	13
20		147	46,3	6,2	26	23	16	43	35	95	29
∅	2,9	138	50	6,4	24	22	21	57	43	115	36

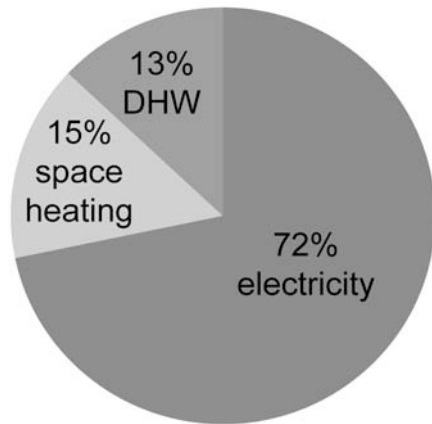
Sources: Badenova, Disch, ews Schönau, inhabitants, Stahl +Weiss, 2001–2007

NET ZERO ENERGY AND THE GRID

In contrast to energy-autonomous buildings, which supply sufficient energy to meet their own consumption at any given time, only an annual average balance of zero is intended for zero-energy houses. Zero-energy houses are not energy-autonomous, they feed energy—photovoltaically generated electricity in this case—into the grid and draw electricity from the grid for in-house consumption.⁷ The

problem of storing energy within the house, particularly on a seasonal scale, is transferred to the grid. On the one hand, this makes the concepts feasible, but on the other hand they can become non-credible, if a very large imbalance has to be compensated to the detriment of the grid (mismatch). The concept that has been introduced in Germany by the electricity feed-in law for crediting photovoltaically generated electricity favours feeding in all of the

FIGURE 6. Distribution of the consumed primary energy for electricity, space heating and domestic hot water for the *average house*. The electricity consumption dominates the balance. The share of the total heat consumption that is allocated to domestic hot water was calculated according to the German VDI standard 3807. The hot water consumption is now being measured.



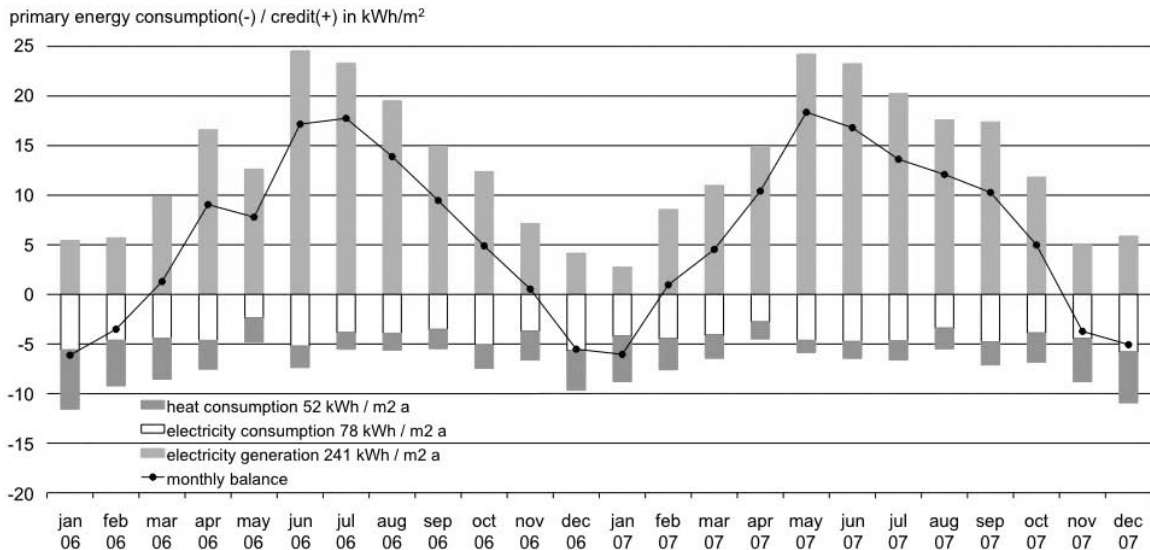
generated electricity over meeting the household demand locally first.

QUESTIONS REMAINING

National and international agreement on the methodology for determining zero energy balances has not yet been achieved. At present, the system boundaries and scope are defined differently, depending on standards, calculation tools, funding programmes or available meters. In order to determine consumption rather than demand balances, we favour complete acquisition of information on the consumer side, including the consumption for appliances and lighting.

The effect of the political framework on balances can be illustrated by the evaluation of wood as a fuel, which can be regarded as renewable only under certain conditions. As it is not unconditionally sustainably available, its weighting with the favourable primary energy factor of 0.2 is questionable on the long term. The same applies for electricity bonuses, which are determined according to the current national electricity scenario. If the trend toward a higher proportion of grid electricity from renewable

FIGURE 7. Time-dependent profiles for consumption and generation, taking one house as an example. Consumption data are plotted as negative values, generation data as positive values. The common measure is the primary energy. The seasonal imbalance is evident when monthly averages are considered.^{vi}



sources continues or even accelerates, the bonus per fed-in kWh will fall.

Nevertheless, the balance presented here for the *Solarsiedlung Freiburg* proves in practice that the zero-energy goal is already feasible today.

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APPENDIX

1. www.sketchup.google.com, www.ecotect.com, www.gosol.de (6/2009). www.lernnetz-bauphysik.de is a virtual platform publishing amongst others detailed experiences of Wuppertal University with the programmes Gosol and Ecotect and descriptions and experiences of software used at German Universities when teaching light, energy and indoor climate.
2. DIN 18599, part 10
3. These data have not been corrected for meteorological variation, as measured values for the domestic hot water consumption are not yet available.
4. Average German energy consumption without electrical hot water generation of the same household size as the “average house” was added to the primary energy result of the building code calculation.
5. The Primary Energy Factor was calculated using consumption data per energy of the combined heat and power plant 2007.
6. These projects depend on the commitment of their inhabitants. In Freiburg, selected inhabitants monitor most of the solar generation devices in behalf of the ownership—and detected i.e. breakdowns of inverters. Two households noted daily and weekly consumption and generation data of their homes over a period of up to six years. The examples here shown of 2006 and 2007 are not corrected for meteorological variation, as measured values for the domestic hot water consumption are not yet available.
7. As photovoltaically generated electricity is subsidized by the Federal Government in Germany, it is financially attractive to feed in all electricity generated by the photovoltaic system, not only the excess remaining after in-house consumption.
8. www.arch.uni-wuppertal.de/Lehrende/Wissenschaftliche_und_technische_Mitarbeiterinnen/Heinze_Mira, (June 2009).