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ENERGYbase office building:

A reality check by seven years of monitored energy system performance

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Abstract

The architectural design and the energy system concept of the ENERGYbase office building in Vienna / Austria fulfils the requirements of the *'Passivhaus'* standard. The use of ecological construction materials, high insulation and air-tightness of building envelope, advanced and energy efficient technologies - like solar-assisted air-conditioning, heat pump technology, photovoltaics - as well as innovative systems in terms of high quality of indoor comfort reduces the energy consumption. Since August 2008 the ENERGYbase office building is in operation and a monitoring campaign was carried out. This publication reports on seven years energy building performance based on measurement data from 2009 till 2015. Key findings are drawn and finally the ENERGYbase office building exceeds its ambitious targets related to energy and high indoor comfort in reality.

Keywords: *Nearly zero energy office building, local renewable energy use, energy monitoring, reality check*

1. Introduction

According the recast of the EU-Directive [1], future buildings are 'Nearly Zero Energy Buildings' and technically a bright variety of future building concepts exists. Two essential measures lead to such high energy performing buildings: high energy efficiency for both a) the building envelope and the energy systems and b) the use of renewable energy sources on-site. In Europe 'Nearly Zero Energy Buildings' have to be built in 2021, thus there is a need of successful pilot-projects demonstrating the feasibility of such future building concepts. The ENERGYbase [2] office building, owned by the Vienna Business Agency and located in the 21st district of Vienna, was built to show up cutting-edge office designs, energy efficient technologies and the use of renewable energy gained from on-site resources with the goal of stimulating further use and development of these techniques. The contracted planning team achieved these ambitious energy targets by complying the energy requirements of the '*Passivhaus*' standard [3]. For designing the ENERGYbase technical solution further measures had high priority; the use of a) environmentally friendly materials, b) high quality insulation, c) a well-sealed building envelope and d) innovative energy technologies (e.g., photovoltaics, solar-assisted air-conditioning, and advanced heat pump technology) as well as e) the development of an innovative control strategy to provide a high quality indoor air and comfort. The architectural design and the applied technology mix lead to a significantly reduction of the energy demand for heating, cooling and artificial lighting in comparison to the existing building standard. The ENERGYbase building and its energy features where already presented on the EUROSUN 2008 -1st International Conference on Solar Heating and Cooling in Buildings eight years ago [4].

Building facts are listed in Table 1. Figure 1 shows two photos of the ENERGYbase, one shows the south and west façade and the other one north and east façade. The geographical position of the ENERGYbase

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location and some selected weather parameter are presented in Table 2.

2006 during the planning phase of the ENERGYbase building project the energy demand values were calculated by applying the method of the Austrian energy performance certificate. Based on this data and simulation results experts indicated a total electricity demand for heating, cooling, air treatment and artificial lighting of one year ENERGYbase operation of 25 kWh_{el} per useful area and year. With the current Austrian conversion factors [5] for primary energy (PE, nonrenewable part) and CO_2-Emissions the ENERGYbase consumes 33 $kWh_{PE,nr}$ primary energy per useful area and year and emits 69 kg_{CO2} per useful area and year.

Figure 1: Photo of ENERGYbase showing left) south and west facade and right) north and east façade (Source: Hurnaus)

Table 1: Building facts of ENERGYbase

Type of building	Office
Location	1210 Vienna / Austria
In operation since	2008
System operated by	Siemens Facility Management
Area (Gross/ Useful/ Air-conditioned)	9,430 m²/ 7,544 m² / 5,000 m²
Use of solar energy	Photovoltaics 48.2 kW_p (peak) power
Use of shallow geothermal energy	Ground water coupled heat pump
Other innovation	Green ventilation (i.e., biological supply air treatment in wintertime for pre-humidification and filtering)
	Costume-made south façade oriented to the South and 7° to West
	Thermal mass activation for sensible heating & cooling

Table 2: Climate

Located	48°12' N/ 16°22' E
Tmean (Tmax / Tmin hourly)	9.5°C (28.9 / -14.6°C)
Global radiation on horizontal	1,122 kWh/m² year
Global diffuse on horizontal	627 kWh/m² year
Global direct on horizontal	495 kWh/m² year

2. Heating, Cooling and Ventilation System

The ENERGYbase office building is fulfils the requirements of the 'Passivhaus' standard. The heating, cooling and ventilation system is designed to use both a) water and b) an air based energy distribution systems. The air temperature of the office rooms in the ENERGYbase is controlled by thermally activated building construction elements. The concrete core activation (CCA) covers the sensible load for heating and cooling; due to the controlling of the water inlet temperature into CCA and the different air temperature levels in the office rooms heat is extracted from or delivered to the building construction mass. For controlling the indoor air humidity and for supplying fresh air, a solar heat driven Desiccant Evaporative Cooling (DEC) system is put into operation, which is an air-conditioning system without using conventional vapor compression chiller for cooling and dehumidification purposes. The assessment of the energy performance of the solar heat driven DEC system is already published [6].

Geothermal energy is exploited by means of ground water in the ENERGYbase building. Two heat pumps coupled to the ground water temperature levels raises the water temperature up to 45 degree Celsius in winter and the hot water is supplied on one hand to the CCA and on the other the hand to several heating coils of the air treatment system. In summer the ENERGYbase is cooled by extracting heat from CCA with the help of water circulated through the building construction. Finally a water to water heat exchanger transfers the extracted heat to the ground water. The ground water temperature in summer time is approx. 14 degree Celsius and is raised by around 4 Kelvin. In summer high ambient air temperature and humidity values are treated by the DEC system using solar heat. The collector area is around 285 m² and mounted on the upper part of the south façade – see scheme in Table 8. First of all the solar heat is used for the regeneration process of the loaded sorption material used in the DEC system and additionally for covering partly the heating demand of the CCA and the heating coils. Table 3, Table 4 and Table 5 list technical design data of the heating, cooling and air treatment system of ENERGYbase.

Table 3: Ventilation and air treatment system

Technology	Desiccant and evaporative cooling
N° of DEC systems	2 DEC system (twins)
Nominal volumetric flow rate	2 x 8,240 m³ per hr
Nominal capacity	~ 40 kW_{th} per DEC system
Brand of cooling units	robatherm
Cooling load subsystem	Central AHU
Dehumidification	Sorption wheel (Klingenburg SECO 1770)
Regeneration power	80 kW_{th} per DEC system

Technology	Air treatment system
N° systems / components	1 system, 1 heating & 1 cooling coil, 2 speed controlled fans, 1 heat recovery wheel
Nominal volumetric flow rate	6,000 m³ per hr
Set supply temperature	22°C (Winter & Summer)
Heat recovery efficiency	~ 0,66
Brand of cooling units	robatherm
Nominal motor el power for fan	4 kW_{el}
Dehumidification/ Humidification	No humidity treatment

Table 4: Heat generation

Heat pump system

Technology	Heat pump
Brand / Type	Climaveneta
Nominal heating capacity	2 x 160 kWth
Evaporator circuit temperatures	10/6°C
Evaporator circuit volume flow	36 m³ per hr
Condenser circuit temperatures	40/35°C
Condenser circuit volume flow	27.4 m³ per hr
Nominal electric power	38.1 kW_{el}

Solar collector system

Collector type	Flat-plate collectors
Brand of collector	Sonnenkraft /MEA DESIGN
Collector area	285 m² aperture area
Tilt angle/ orientation	32° / South and 7° to West
Collector fluid	Water/propylene-glycol (70/30)
Typical operation temperature	80°C
Mass flow operation mode	Low flow
Integration	Roof top mounted
Storage technology	Solar hot water tank
Storage volume	15,000 l

Table 5: Ground water / water heat exchanger design data

Nominal heat transfer capacity	270 kW_{th}
Primary circuit - Ground water	
Delta T	6 Kelvin
Nominal mass flow	38,700 kg per hr
Secondary circuit	
Delta T	4 Kelvin
Nominal mass flow	68,500 kg per hr
Ground water data	
Ground water temperature (min/max)	9°C / 14°C
Max volume flow	20 l per sec
Limited temperatures of fed in water (min/ max)	5°C / 18°C

3. Energy Performance Assessment

3.1 Annual Overall Energy System Performance

Since August 2008 the ENERGYbase office building is in operation and a monitoring campaign was permanently carried out. This publication reports on seven years energy building performance based on measurement data from 2009 till 2015. Table 6 lists selected annual amounts of energy of consumed and delivered electricity and heat generated and extracted from the building. Line I of Table 6 displays the percentage of rented office areas in the observation period. The displayed data are essentially registered by the facility management and cross checked by Austrian Institute of Technology. Monthly accumulated energy fluxes are regularly taken from different kinds of sources; a) building automation system, b) energy meters implemented in systems devices like inverters, heat meters etc., and c) energy data registered by meters of the energy supplying company. In most cases the figured monthly energy data are adjusted in consequence of different time intervals. The annual total electricity consumption indicated in Table 6 – see line A - represents annual consumed electricity for operating all technical devices for heating, cooling, ventilation, artificial lighting of general areas and all other building equipment, like permanent emergency lighting. The electricity consumed by the office usage of tenants is not included.

Table 6: Annual energy performance data from 2009 till 2015 (Source: FM Siemens)

			2009	2010	2011	2012	2013	2014	2015
	Consumed electricity								
A	**Total electricity**	**kWh**	158,259	164,959	151,566	141,086	166,734	147,092	160,068
B	**Electricity from grid**	**kWh**	131,621	135,520	118,160	108,699	136,382	116,940	128,904
C	**Air handling unit**	**kWh**	43,547	44,631	40,174	34,871	44,149	51,265	62,026
D	**Heat pump**	**kWh**	40,467	40,106	33,028	33,274	45,730	27,949	31,529
E	**Ground water pumps**	**kWh**	13,763	12,056	8,560	6,905	6,838	4,570	5,071
F	**Artificial lighting**	**kWh**	6,799	3,503	6,149	4,122	4,754	4,501	3,592
G	**Others**	**kWh**	53,683	64,663	63,655	61,914	65,263	58,808	57,849
	Selected key performance indicators								
H	**Spec. total electricity**	**kWh/m²**	21.0	21.9	20.1	18.7	22.1	19.5	21.5
I	**Ratio of rented area**	**%**	32%	48%	72%	87%	87%	87%	90%
J	**Ratio C/A**	**%**	28%	27%	27%	25%	26%	35%	39%
K	**Ratio D/A**	**%**	26%	24%	22%	24%	27%	19%	20%
L	**Ratio E/A**	**%**	9%	7%	6%	5%	4%	3%	3%
M	**Ratio F/A**	**%**	4%	2%	4%	3%	3%	3%	2%
N	**Ratio G/A**	**%**	34%	39%	42%	44%	39%	40%	36%
	Photovoltaics (PV) electricity								
O	**PV_{el} delivered**	**kWh**	36,038	38,015	47,430	45,859	44,208	40,544	42,878
P	**PV_{el} self-consumed**	**kWh**	26,638	29,439	33,406	32,387	30,352	30,152	32,982
Q	**PV_{el} fed into the grid**	**kWh**	9,400	8,576	14,024	13,472	13,856	10,392	9,896
R	**PV_{el} Yield**	**kWh/kWp**	748	789	984	951	917	841	890
S	**Ratio O/A**	**-**	0.23	0.23	0.31	0.33	0.27	0.28	0.26
T	**Ratio P/A**	**-**	0.17	0.18	0.22	0.23	0.18	0.20	0.20

U	**Ratio P/O**	-	0.74	0.77	0.70	0.71	0.69	0.74	0.77
	Heating (heat pump HP, solar collector)								
V	**Heat delivered by HP**	**kWh**	124,049	148,840	119,960	121,534	168,684	102,299	121,438
W	**$SEER_{HP}$ L/C**	-	3.07	3.71	3.63	3.65	3.69	3.66	3.77
X	**Solar heat delivered**	**kWh**	58,335	55,964	61,023	54,247	29,983	50,844	73,980
	Cooling								
Y	**Heat from CCA**	**kWh**	100,105	107,916	143,620	146,527	147,865	165,793	177,935
Z	**El. cold water pumps**	**kWh**	9,263	7,049	6,167	5,570	5,037	4,866	6,093
AA	**Ratio Y/Z**	-	10.81	15.31	23.29	26.31	29.35	34.07	29.21
	Weather[1]								
AB	**Glob. radiation, hor**	**kWh/m² y**	1,199	1,144	1,248	1,226	1,174	1,133	1,227
AC	**Mean $T_{Ambient}$**	**°C**	11.0	9.9	11.0	11.3	10.9	12.0	12.1

Due to the fact the ENERGYbase is only externally powered by the electric grid, i.e. there is no connection to district heat or gas network, the assessment of the consumed electricity is key. In the observation period of seven years the ENERGYbase was operated by electricity in a range from 141 MWh_{el} till 166.7 MWh_{el} per year, this corresponds to specific values from 18.7 kWh_{el} till 22.1 kWh_{el} per useful area and year. High ratio of the electricity consumption are achieved by the operation of the air handling unit, heat pump system and all other electric driven devices - see line J till N of Table 6. The south façade attached photovoltaic system delivers 23% up to 33% of the total consumed electricity for operating the heating, cooling, ventilation systems and all other general building service devices.

3.2 Monthly Energy System Performance in 2015

Figure 2 shows an energy flow chart displaying annual heat and electricity fluxes of the ENERGYbase without users' electricity consumption in 2015. The annual heat delivered to both the CCA and as well to the numerous heating coils (excl. the heat transferred to the regeneration coils of the air treatment system) is calculated to value of 19.7 kWh_{th} per useful area and year. In cooling mode the heat is extracted from CCA and transferred to the ground water, here the specific heat extracted from the building is 23.6 kWh_{th} per useful area and year. In 2015 the heat pump system delivered around 121.4 MWh heat per year with an electricity input of 32.2 MWh_{el} per year including the consumers a) control system, b) compressors and c) the pumps of the water circuits of condenser and evaporator part. This quantified energy fluxes result into a seasonal energy efficiency ratio $SEER_{HP}$ of the heat pump system of 3.77, which is calculated according to the formula expressed in Equation 1. The ratio of the used solar heat generated by the collector in relation to the cumulated heat transferred to the CCA, heating and regeneration coils of the air treatment system is around 38% und the formula of the solar fraction is expressed in Equation 2.

[1] Data source; Zentralanstalt für Meteorologie und Geodynamik, weather station ‚Hohe Warte' in Vienna

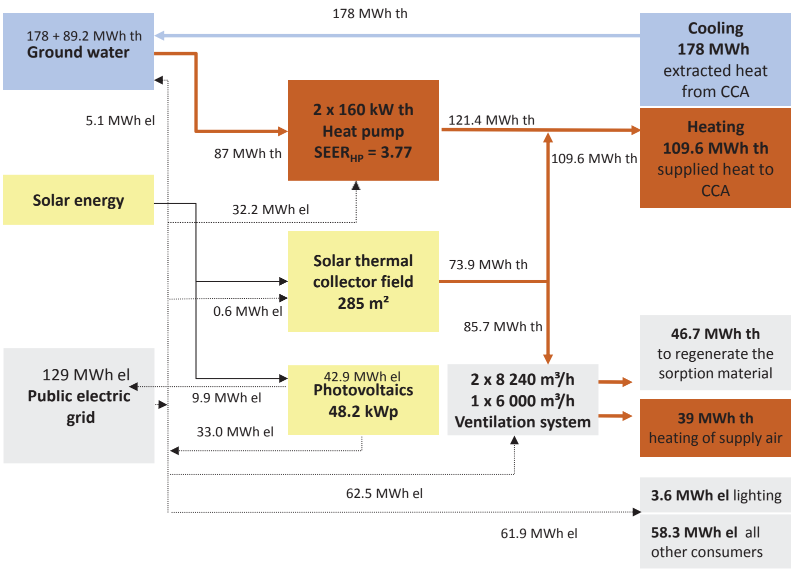


Figure 2: Annual energy fluxes (heat and electricity) of ENERGYbase in 2015 (Source: AIT)

Table 7 contains monthly values of electricity consumed by different energy systems. Furthermore the monthly values of heat transferred by circulated water to a) the CCA, b) the heating coils of the air treatment system and c) regeneration heating coil of the DEC system – see lines g, i and h of Table 7. As mentioned above the ENERGYbase is equipped with two heat pumps and one solar thermal collector field delivering hot water to heat distribution system described above. In 2015 the monthly calculated energy efficiency ratio $SEER_{HP}$ of the heat pump system operation is in range from 2.67 up to 3.87 – see line k of Table 7. The share of the solar heat used in the ENERGYbase can be calculated according to Equation 1. From May till September 2015 the solar heat covers fully the demand for the regeneration process of the sorption material in the DEC system, i.e. the solar fraction is accounted to 100%. Due to the lower availability of solar radiation in winter monthly values of the solar fraction decrease dramatically – see line m in Table 7.

$$SEER_{HP} = \frac{Q_{HP,\,Heat}}{E_{el,\,HP}} \left[\frac{kWh_{th}}{kWh_{el}}\right] \quad \text{(eq. 1)}$$

Where:

$SEER_{HP}$	Seasonal energy efficiency ratio of the heat pump system [kWh_{th}/kWh_{el}]
$Q_{HP,\,Heat}$	Heat generated by the heat pump condenser, water cycle [kWh_{th}] – see line j in Table 7
$E_{el,\,HP}$	Electricity consumed by the heat pump components, i.e. motor for compressor and pumps of both circuits and the control unit [kWh_{el}] – see line j in Table 7

$$SF_{solarheat} = 1 - \frac{Q_{Heat\ Pump}}{Q_{CCA} + Q_{Heating\ Coil} + Q_{Reg.,Coil}} \left[\frac{kWh_{th}}{kWh_{th}}\right] \quad \text{(eq. 2)}$$

Where:

$SF_{solar\ heat}$	solar heat fraction [-]
$Q_{Heat\ Pump}$	heat delivered by heat pump [kWh_{th}] – see line j in Table 7
Q_{CCA}	heat delivered to concrete core activation for heating purposes [kWh_{th}]
$Q_{Heating\ Coils}$	heat delivered to heating coils of the air treatment system [kWh_{th}]
$Q_{Reg.,\ Coil}$	heat delivered to heat coil of DEC system for regeneration purposes [kWh_{th}]

In 2015 the cooling season of the ENERGYbase started from April and ended in September. Monthly amounts of heat that has been extracted from the CCA are in the range from 14.92 MWh_{th} up to 43.64 MWh_{th} per month. The seasonal energy efficiency ratio $SEER_{Cool,\ Sys}$ of the water based cooling system can be expressed by eq. 3. According to line p in Table 7 the ENERGYbase ground water cooling system operates energy efficient and $SEER_{Cool,\ Sys}$ values are higher than 30.

$$SEER_{Cool,\,Sys} = \frac{Q_{Heat\,extr\,by\,\,CCA}}{E_{el,\,cold\,water\,pumps}} \left[\frac{kWh_{th}}{kWh_{el}} \right] \qquad \textbf{(eq. 3)}$$

Where:

$SEER_{Cool,\,Sys}$	Seasonal energy efficiency ratio for the cooling system [kWh_{th}/kWh_{el}]
$Q_{Heat\,extr\,by\,CCA}$	Heat extracted by the water cycle of CCA [kWh_{th}] – see line j in Table 7
$E_{el,\,cold\,water\,pumps}$	Electricity consumed by all cold water pumps [kWh_{el}] see line o in Table 7

Table 7: Monthly energy fluxes and key performance indicators for operating the air treatment system, heating and cooling system of ENERGYbase in 2015 (Source: FM Siemens)

	2015		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Consumed electricity by the energy system													
a	**Total**	**MWh**	18.34	15.11	16.20	10.31	11.51	10.27	10.35	10.85	12.38	13.32	17.07	16.17
b	**AHU**	**MWh**	4.52	3.79	6.52	4.95	5.88	5.92	3.59	6.17	7.22	5.03	4.98	4.01
c	**HP**	**MWh**	7.58	5.35	3.61	0.70	0.01	0.08	0.01	0.01	0.06	2.36	6.30	6.14
d	**GWP**	**MWh**	0.24	0.22	0.29	0.34	0.51	0.58	0.90	0.87	0.51	0.17	0.27	0.25
e	**AL**	**MWh**	0.31	0.25	0.24	0.32	0.27	0.29	0.38	0.39	0.34	0.31	0.29	0.23
f	**Others**	**MWh**	5.70	5.50	5.55	4.00	4.84	3.40	5.47	3.41	4.27	5.44	5.23	5.55
	Heat transferred to													
g	**Heat to SDEC**	**MWh**	-	0.00	0.04	0.10	4.11	6.48	8.16	19.05	8.00	0.81	-	-
h	**Heat to HC**	**MWh**	8.75	7.12	8.10	1.30	0.47	0.29	-	0.02	0.12	0.51	7.39	4.94
i	**Heat to CCA**	**MWh**	21.21	17.69	13.23	5.04	0.74	0.23	-	-	0.66	11.49	19.72	19.62
	Heat delivered													
j	**Heat from HP**	**MWh**	29.28	20.29	13.38	1.99	-	0.22	-	-	-	8.49	24.36	23.42
k	**SEER $_{HP}$ j/c**	**kWh/kWh**	3.86	3.80	3.71	2.85	-	2.67	-	-	-	3.60	3.87	3.82
l	**SH**	**MWh**	0.69	4.52	8.00	4.45	5.31	6.79	8.16	19.07	8.79	4.32	2.74	1.15
m	**SF = 1–j/(g+h+i)**	**%**	2%	18%	37%	69%	100%	97%	100%	100%	100%	34%	10%	5%
	Heat extracted from building (cooling)													
n	**Heat from CCA**	**MWh**	0.09	0.18	0.63	14.92	21.64	32.05	43.64	40.30	17.73	3.07	1.98	1.71
o	**El. CWP**	**MWh**	0.01	0.04	0.19	0.43	0.71	0.92	1.41	1.35	0.81	0.10	0.06	0.05
p	**$SEER_{Cool,Sys}$ n/o**	**kWh/kWh**	10.33	4.03	3.39	34.39	30.56	34.65	30.94	29.86	21.87	29.85	31.88	33.69
	Specific heat transferred per useful area													
q	**Sp. heat to sys**	**kWh/m²**	3.97	3.29	2.83	0.85	0.70	0.93	1.08	2.53	1.16	1.70	3.59	3.26
r	**Sp. heat extr.**	**kWh/m²**	0.01	0.02	0.08	1.98	2.87	4.25	5.78	5.34	2.35	0.41	0.26	0.23

Where:

a – Total: Overall electricity consumed by the technical equipment of the heating, cooling, ventilation system, lighting and other services

b - AHU: Electricity consumed by the fans, control unit and other devices of the Air Handling Units

c - HP: Electricity consumed by the heat pump by means of the a) control system, b) compressors and c) the pumps of the water circuits of condenser and evaporator part.

d - GWP: Electricity consumed by a) motors for ground water and cold water distribution pumps

e - AL: Electricity consumed by artificial lighting for general area

f – Others: All other electricity consuming devices

g – Heat to SDEC: Heat transferred to the two regeneration heating coils implement in the return air stream of the DEC system in dehumidification mode

h – Heat to HC: Heat transferred to all heating coils implemented in the air treatment system

i – Heat to CCA: Heat transferred to concrete core activation in order to lift the indoor air temperature

j – Heat from HP: Heat delivered by the heat pump systems, i.e. condenser water circuit

k – SEER $_{HP}$: Seasonal energy efficiency ratio of the heat pump according to eq. 1

l – SH: Used solar heat taken from the hot water storage

m – SF: Solar fraction expressed according eq. 2

n - Heat from CCA: Heat extracted from concrete core activation for lowering the indoor air temperature

o - El. CWP: Electricity consumed by motors of all required cold water pumps

p - SEER $_{Cool,Sys}$: Seasonal energy efficiency ratio of the cooling system according to eq. 3

q – Sp. heat to sys: Heat transferred to the energy system divided by useful office area (7.544 m²)

r – Sp. heat extr.: Heat extracted from concrete core activation divided by useful office area (7.544 m²)

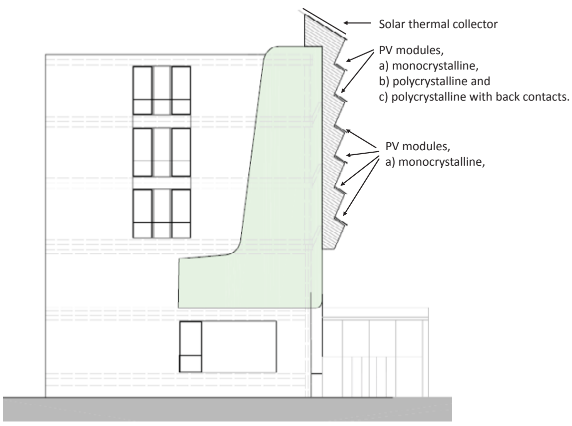
3.3 Energy Performance of the Photovoltaics (PV)

The photovoltaic system with a nominal capacity of 48.2 kW_p is attached to a custom-made stepped south façade. Six module lines with three different kinds of cell and module technologies are attached to the façade. In order to maximize the solar electricity yield the modules are naturally ventilated by ambient air and tilted with an angle of 31.5 degree – see scheme in Table 8.

In addition the façade added photovoltaic systems was designed and planned as well for research purposes and a scientific monitoring system is implemented beside other measurement equipment of the inverter. The upper two PV module lines are designed and installed for research activities and three different kinds of cell technologies are integrated; namely a) monocrystalline, b) polycrystalline and c) polycrystalline with back contacts. These different modules can be investigated with regard to their different long-term performance. The other four modules strings configured only with modules using polycrystalline cells and investigation of the inverter performances are foreseen. The technical data of the photovoltaic system are listed in Table 8. Since February 2009 the PV system is in operation. Annual energy performance indicators like a) delivered electricity from the all 366 PV modules, b) self-consumed electricity from PV system and c) PV electricity fed to the public grid are quantified in Table 9.

Table 8: Technical data of the PV system (Source: ATB-Becker 2008)

Type of	Attached to façade/ natural
Orientation / tilt	South and 7° to West / 30°
Total nominal	48.2 kW_p
Total PV module	400 m²
Module type 1	Solarwatt M135-55 GEG LK
Cell type	monocrystalline
number of pieces	286
Nominal power	134 W_p
Module type 2	Solarwatt P 125-55 GEG
Cell type	polycrystalline
number of pieces	40
Nominal power	122 W_p
Module type 3	Solarwatt M135-55 GEG
Cell type	polycrystalline
number of pieces	40
Nominal power	127 W_p
Inverter	10 x Sunways, 2 x SMA



During the observation period from January 2009 till December 2015 the annual electricity delivered by the PV system is in the range from 36,038 kWh per year (2009) to 47,430 kWh per year (2011), this corresponds to specific solar electricity yields from 748 and 984 kWh per kW installed peak capacity. In the beginning of the building operation some outages of the inverters occurred. The ratio of the PV electricity used in house and the total annual electricity consumed by the operation of the ENERGYbase energy systems is in range from 0.17 up to 0.22. In 2011 the PV system fed 14,024 kWh into the public grid and 33,406 kWh were directly used to operate the office building, this corresponds to approx. 70% of direct used solar electricity on site.

Table 9 lists monthly energy fluxes and key performance indicators from January till December 2015. Due to the specific shape of the solar façade the PV system achieved maximal yields in March with 112 kWh per kW installed peak capacity and in July with 126.4 kWh per kW installed peak capacity. Based on this measured data the predicted high yields for May, June and July cannot be confirmed. Demonstrably there is shading effect from the upper cell string on at least one of the lower module line occurring in June. Figure 3 illustrates monthly solar electricity a) delivered by the PV system, b) used in house and c) fed to the public grid from January till December 2015.

Table 9: Monthly energy fluxes and key performance indicators of the PV system in 2015 (Source: FM Siemens)

			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Consumed electricity by the energy system													
A	**Total**	**MWh**	18,34	15,11	16,20	10,31	11,51	10,27	10,34	10,85	12,38	13,31	17,07	16,16
	Delivered electricity													
B	**PV el delivered**	**kWh**	745	3,410	5,399	4,639	4,691	2,768	6,092	3,828	4,058	3,924	1,657	1,668
C	**PV el self**	**kWh**	505	2,386	4,135	3,487	3,707	2,408	4,460	3,164	3,314	2,780	1,321	1,316
D	**PV el fed to grid**	**kWh**	240	1,024	1,264	1,152	984	360	1,632	664	744	1,144	336	352
	Key performance indicators													
	Ratio B/A	-	0.04	0.23	0.33	0.45	0.41	0.27	0.59	0.35	0.33	0.29	0.10	0.10
	Ratio C/A	-	0.03	0.16	0.26	0.34	0.32	0.23	0.43	0.29	0.27	0.21	0.08	0.08
	Ratio C/B	-	0.68	0.70	0.77	0.75	0.79	0.87	0.73	0.83	0.82	0.71	0.80	0.79
	Specific yield	**kWh/kWp**	15.5	70.7	112.0	96.2	97.3	57.4	126.4	79.4	84.2	81.4	34.4	34.6
	Specific yield	**kWh/m²**	1.9	8.5	13.5	11.6	11.7	6.9	15.2	9.6	10.1	9.8	4.1	4.2

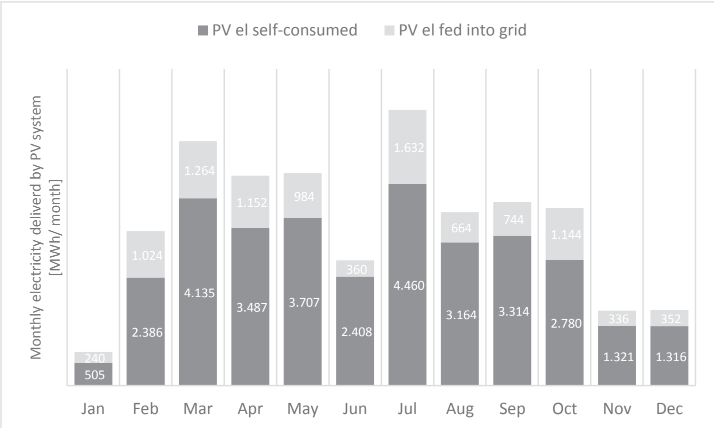


Figure 3: PV system energy performance in 2015

4. Key findings

Since August 2008 the ENERGYbase office building is in operation and a monitoring campaign was carried out. With this paper numerous annual energy fluxes and key performance indicators are presented from 2009 till 2015. Monthly energy system performance data are presented for 2015. The long-term observation allows an energy system performance assessment over seven years of the ENERGYbase office building operation. The electricity consumed by the office usage of the tenants, like using computers etc., is not part of this investigation. By analyzing the energy and key performance indicators following key findings are drawn:

- The ambitious energy targets stated in the initial ENERGYbase project phase were exceeded by the acquired energy data of seven years. From 2009 till 2015 the total electricity consumption for heating, cooling, air treatment, artificial lighting and other devices of the ENERGYbase is quantified from 141.1 MWh_{el} (2012) up to 166.7 MWh_{el} (2013), this corresponds to a range of specific values from 18.7 kWh_{el} up to 22.1 kWh_{el} per useful area and year. The allows the conclusion that the architectural design, the applied ‘Passivhaus’ standard and the implemented technology mix with a significant use of local renewable energy sources lead to a robust, reliable and predictable building energy performance.
- The convincing energy efficient performance is a result of a fruitful cooperation between the facility management and researchers on-site. The facility manager has carried out and investigated numerous measures achieving improvements in terms of energy efficiency, for instance permanently running pumps and fans have been operated in part load when motors are driven by frequency converters. AIT researcher performed several research projects focusing the optimization of subsystems of the ENERGYbase energy system. These activities are always a tradeoff between lowering the energy input and keeping the required high indoor comfort.

- The façade attached photovoltaic system delivered solar electricity in the range from 36 MWh_{el} up to 47.4 MWh_{el} per year. 69% up to 77% of the delivered solar electricity was self-consumed by the building operation and 17% up to 23% of the total electricity consumed was provided by PV system. Unfortunately self-shading effects of the shaped south façade result into relevant losses of solar electricity generation of the PV system when the solar altitude angle of the sun is near to its local maximum of $\alpha S \approx 65°$.

5. References

[1] EU-Directive 2010/31: The Energy Performance of Buildings Directive (2010/31/EU) recast Oct 2010

[2] https://viennabusinessagency.at/property/project-development/energybase/ Access: October 1st, 2016

[3] Wolfgang Feist, Passivhaus Institut (Hrsg.): PHPP 2007: Passivhaus Projektierungs-Paket 2007. 7. Auflage. Darmstadt 2007

[4] ENERGYbase - Sunny Office Future"; oral presentation: EUROSUN 2008 - 1st International Conference on Solar Heating, Cooling and Buildings, Lisbon, Portugal; 07.10.2008 - 11.10.2008; in: "EUROSUN 2008 - 1st International Conference on Solar Heating, Cooling and Buildings", SPES - Sociedade Portuguesa de Energia Solar, (2008), ISBN: 978-972-95854-7-0; Paper-N°. 357.

[5] http://www.oib.or.at/sites/default/files/richtlinie_6_26.03.15.pdf Access: October 1st, 2016

[6] T. Selke, A. Frein, M. Muscherà, S. Sethuvenkatraman, S. Handls, S. White: "SHC Task 48 B2 - Three GOOD Practice examples of solar heat driven desiccant evaporative cooling systems"; oral presentation: SHC 2015, International Conference on Solar Heating and Cooling for Buildings and Industry, Istanbul, Turkey; 01.12.2015 - 04.12.2015. SHC 2015, published in Energy Procedia, Volume 91, June 2016, Pages 832–843