REPORT
PUBLIC

D6.9 Report on potential of on-site usage of RES by following district or battery storage approach

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OUTPHIT – DEEP RETROFITS MADE FASTER, CHEAPER AND MORE RELIABLE
outPHit pairs such approaches with the rigour of Passive House principles to make deep retrofits cost-effective, faster and more reliable. On the basis of case studies across Europe and in collaboration with a wide variety of stakeholders, outPHit is addressing barriers to the uptake of high quality deep retrofits while facilitating the development of high performance renovation systems, tools for decision making and quality assurance safeguards. **outphit.eu**

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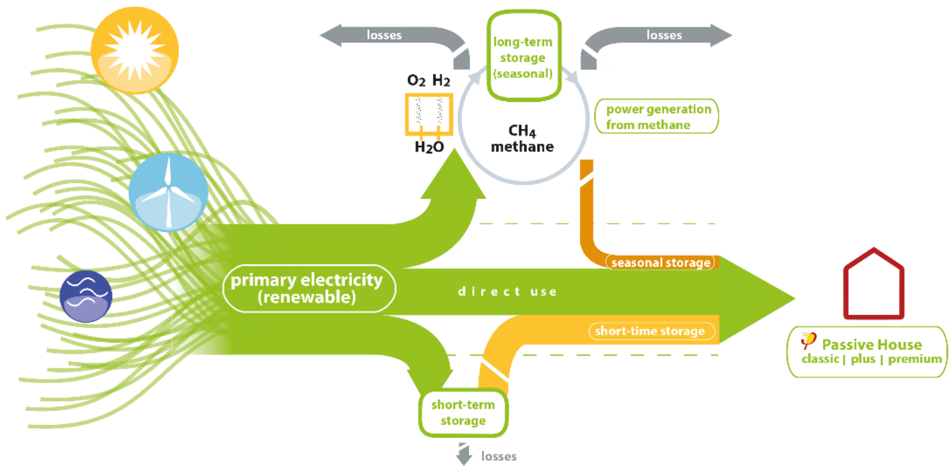
RES POTENTIAL IN CASE STUDY PROJECTS

Case study projects for which appropriate data is available are presented with their RES potential as per PHPP calculation. Where possible a comparison is made with measured data. The ***PER*** rating system is used in addition to the final energy values. For implications of this method please refer to ***D.6.8 Adequate net zero rating approach chosen for case study projects.*** It concluded that, for a reliable and robust assessment of building concepts with regard to carbon emissions and the transition to renewable energy sources, the various fuzzy "net zero" concepts are not very helpful and even misleading for two main reasons:

For one, the energy use is not necessarily capped, meaning, that energy efficiency is not directly stipulated. It may or may not come into play indirectly but the annual turnover is effectively unlimited. This neglects the fact that the renewable energy (RE) potential is indeed constrained by natural limitations in available land. Since the energy transition is desired for the entire society and economy energy efficiency targets are indispensable to achieve the energy transition within the natural boundaries and economic constraints.

The other weakness relates to the two-fold temporal mismatch of abundant RE availability in the summer and reduced availability in the winter, due to reduced PV yield in this period. It is met by an increased energy demand in the winter due to space heating, particularly for inefficient buildings. The simple annual balance of e.g. PV yield and annual electricity usage is misleading as long as energy losses that are incurred in the processes involved to transfer electrical energy from the summer to the winter are not taken into account.

In order to establish a robust approach to guide design choices the Passive House Institute has developed the Primary Energy Renewable (***PER***) system. This system assumes the energy transition as accomplished and can thereby rate a building's performance within a 100 % RES scenario by way of weighting factors for energy use sectors. It makes the central assumption that electrical energy is the main primary energy available from RES in the future. The factors consider the temporal correlation of RES availability and usage patterns. They are derived from the proportions of immediate electricity use, required short-term storage (and its associated losses) as well as long-term, seasonal storage requirements (and its associated losses) as they can be expected for typical energy uses such as domestic hot water preparation, household electricity, space heating or space cooling. More information on ***PER*** can be found ***here***.



PER rating system: Sankey diagram of a future electrical power system based on all-renewable input from various sources, with short-term and long-term storage processes and associated losses

In combination with a focus on energy efficiency such as is inherent to the Passive House / EnerPHit schemes, a truly sustainable and robust solution can be identified, that will perform very well in today's energy system while being 100 % ready for the all-renewable future.

BULGARIA

OP33 Gabrovo

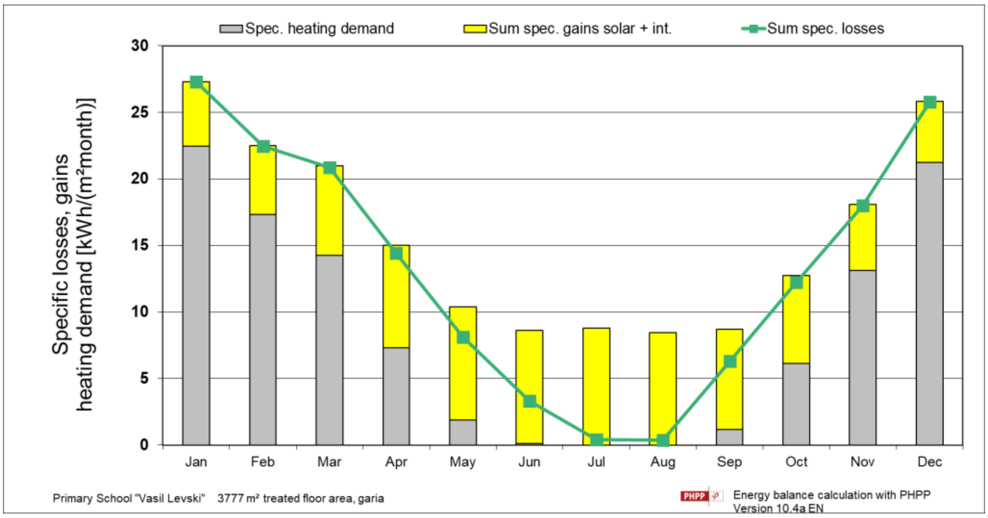
School building from 1962, underwent conventional retrofit with 120 mm insulation and fossil gas boilers in 2022, no RES system was installed yet.

Space heating demand as built is 105 kWh/(m^2a), much less than before retrofit, but still a missed opportunity as the comparison with the easily achievable alternative will highlight.

The alternative is presented as the combined potential of deep retrofit to the ***EnerPHit*** standard (~240 mm insulation, etc.), use of an electrical heat pump and a PV system on the roof areas.

Space heating demand of the ***EnerPHit*** variant is only 16 kWh/(m^2a), thanks to the availability of relatively much solar radiation in the winter at the location.

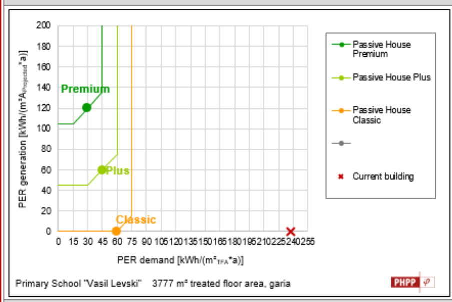
OP33, view into the lobby after refurbishment



OP33 as built PHPP calculation of area-specific space heating demand (grey bars). Note high energy demand

Total energy demand kWh/(m²$_{TFA}$ a)			PER:	237.7	PE:	194.5	CO_2:	148916	kg/a
Energy generation referred to projected building footprint	Final energy		PER		PE		CO_2		
	Final energy generation	Final energy generation	PER factor	PER generation	PE factor	PE generation	Emission factor (CO_2-eq)	Emissions generated	Emissions saved
	kWh/a	kWh/(m²A$_{Projected}$*a)	kWh/kWh	kWh/(m²A$_{Projected}$a)	kWh/kWh	kWh/(m²A$_{Projected}$a)	kg/kWh	kg/a	kg/a
PV electricity	0	0.0	1.00	0.0	0.00	0.0	0 I 0.363	0	0
Solar thermal system	0	0.0	-	0.0	0.00	0.0			
		0.0							
Total energy production kWh/(m²$_{Projected\ building\ footprint}$ a)			PER:	0.00	PE:	0.00	CO_2:	0	0

Verification Passive House/EnerPHit standard

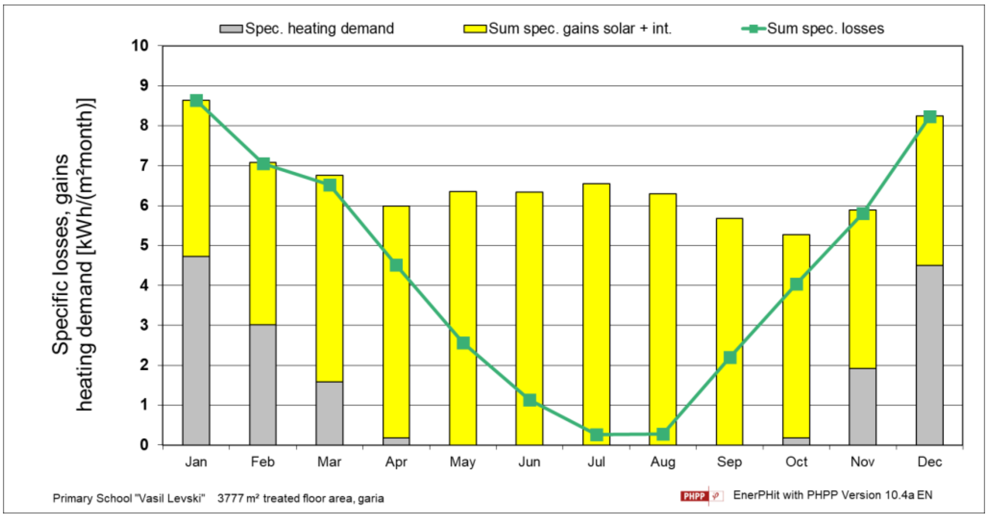


Classes in subdivisions:	Current value:			PHI Criteria Low Energy Building	Criteria Passive House: Classic	Plus	Premium	Achieved class
Heating demand referred to TFA	105	kWh/(m²a)	≤	30		15		PHI Low Energy Building
Heating load referred to TFA	53	W/m²	≤	-		10		
Cooling and dehumidification demand referred to TFA	-	kWh/(m²a)	≤	-		-		-
Airtightness n_{50}	3.0	1/h	≤	1		0.6		Not achieved
PER demand referred to TFA	238	kWh/(m²a)	≤	75	60	45	30	Not relevant
PER generation referred to projected building footprint	0	kWh/(m²a)	≥	-	0	60	120	
PE demand (non-renewable primary energy)	195	kWh/(m²a)	≤	120		120		Not achieved
Energy standard of the whole building				With the selected verification method PE (non-renewable) the following class can be reached:				Not achieved

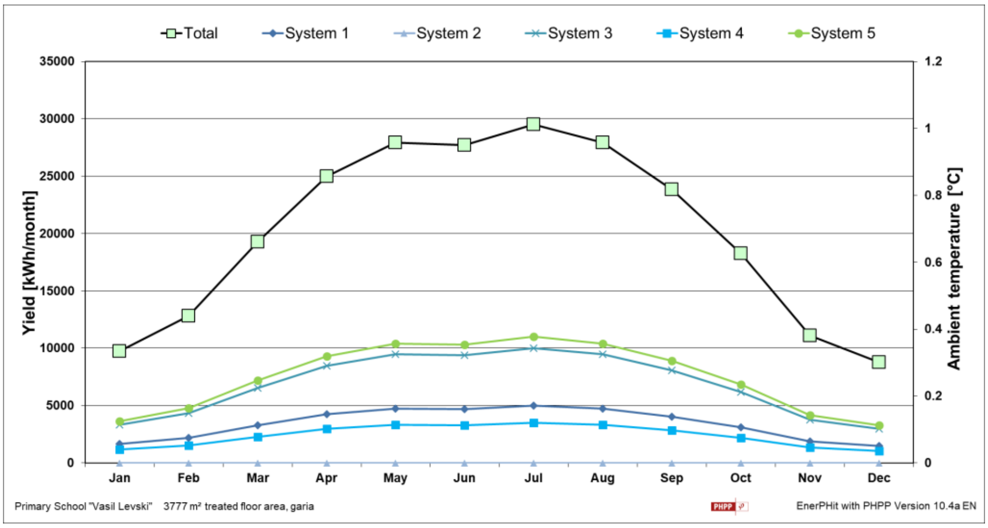
OP33 as built PHPP snippet of PER rating worksheet. Note high energy demand and no energy production (red mark)

The PHPP calculations for the as-built situation estimate an annual final energy demand of 560000 kWh. Factoring in storage and grid losses as are inevitable for year-round availability of power drive the ***PER*** demand up to 898000 kWh.

The optimised variant to ***EnerPHit*** standard improves at more or less marginal cost the thickness of the thermal insulation to 240 mm, uses better windows and airtightness measures. It further employs a mechanical ventilation system with heat recovery that also benefits indoor air quality standards. Further, the heating system is based on a relatively small (reduced demand!) electric air to water heat pump. The heating load is reduced by a factor of four, therefore the heat pump must deliver only ¼ the power of the gas boilers in the as-built condition. The small domestic hot water demand is served by electrical resistance heaters as before.



OP33 <u>EnerPHit</u> PHPP calculation of area-specific space heating demand (grey bars). Note greatly reduced energy demand



OP33 <u>EnerPHit</u> PHPP estimated PV yield per month. Large roof areas are available

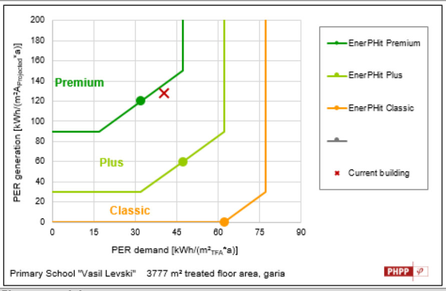
The PHPP calculations estimate a mean annual PV yield of 240000 kWh which significantly exceeds the estimated annual electricity demand of 123000 kWh. Factoring in storage and grid losses as are inevitable for year-round availability of power drive the ***PER*** demand up to 153000 kWh, which is still much less than on-site production potential.

Total energy demand kWh/(m²TFA a)	PER:	40.5	PE:	84.5	CO_2:	44571	kg/a

Energy generation referred to projected building footprint	Final energy		PER		PE		CO_2		
	Final energy generation	**Final energy generation**	PER factor	**PER generation**	PE factor	PE generation	Emission factor (CO_2-eq)	Emissions generated	Emissions saved
	kWh/a	kWh/(m²A Projected a)	kWh/kWh	kWh/(m²A Projected a)	kWh/kWh	kWh/(m²A Projected a)	kg/kWh	kg/a	kg/a
PV electricity	241817	127.7	1.00	127.7	0.00	0.0	0.13 I 0.363	31436	56343
Solar thermal system	0	0.0	-	0.0	0.00	0.0			
		0.0							

Total energy production kWh/(m²Projected building footprint a)	PER:	127.69	PE:	0.00	CO_2:	31436	56343

Verification Passive House/EnerPHit standard



Classes in subdivisions:	Current value:			PHI Criteria Low Energy Building	Criteria EnerPHit: Classic	Plus	Premium	Achieved class
Heating demand referred to TFA	**16**	kWh/(m²a)	≤	30		25		Premium
Heating load referred to TFA	**13**	W/m²	≤	-		-		
Cooling and dehumidification demand referred to TFA	-	kWh/(m²a)	≤	-		-		-
Airtightness n_{50}	**0.6**	1/h	≤	1		1.0		Premium
PER demand referred to TFA	**40**	kWh/(m²a)	≤	75	62	47	32	Plus
PER generation referred to projected building footprint	**128**	kWh/(m²a)	≥	-	0	60	120	
PE demand (non-renewable primary energy)	**85**	kWh/(m²a)	≤	120		121		Classic
Energy standard of the whole building							**With the selected verification method PER (renewable) the following class can be reached:**	**Plus**

OP33 EnerPHit PHPP snippet of PER rating worksheet. Note significantly reduced energy demand and high energy production (red mark)

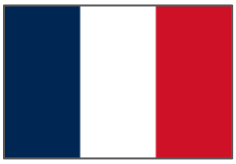
However, the adequate metric for RES yield in buildings is the built-up area, the building footprint.

With regard to the building footprint area the yield amounts to 128 kWh/(m²a) which means a full use of the available potential. This is reflected as a high score for energy production in the ***PER*** rating scheme. The building can achieve a very good ***EnerPHit plus*** rating (red mark in the plot). This is due to very low ***PER*** demand for heating, due to the use of a heat pump for space heating and the particularly low space heating demand.

In this case of a school building an actually positive balance in absolute ***PER*** terms is achieved. This can be attributed to the mild climate, low space heating energy demand and very efficient building services system.

For the hypothetical PV system no measured data is available.

FRANCE



CS 7 Bagnères-de-Bigorre

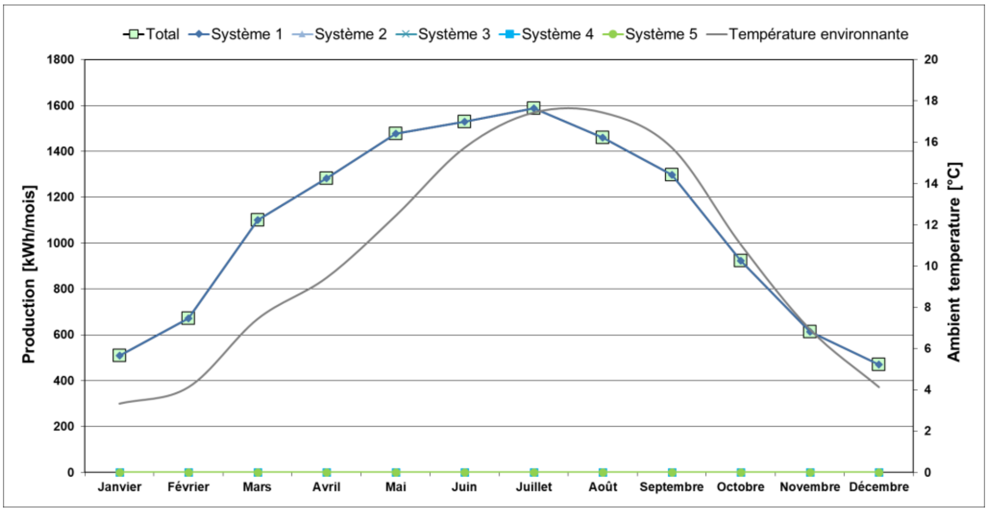
CS7 is a four storey multifamily/hotel building built in 1832 and retrofitted to EnerPHit standard in 2023. Interior insulation with vacuum insulation panels was used on the historic street façade while prefabricated wooden elements with straw insulation were used elsewhere.

Space heating demand after retrofit is 12 kWh/(m²a).

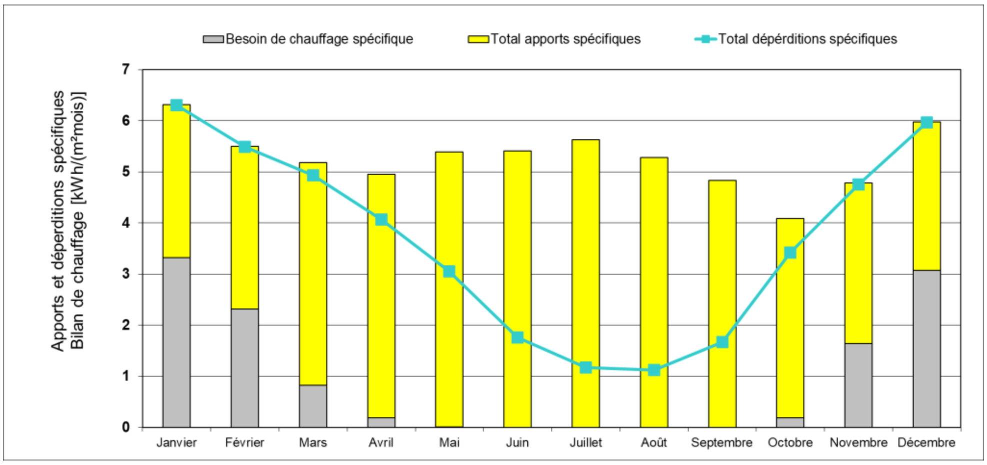
As yet the building was not equipped with a RES system. Therefore, the use of the available roof area for a PV array has been studied.

CS7 as seen from the street before refurbishment

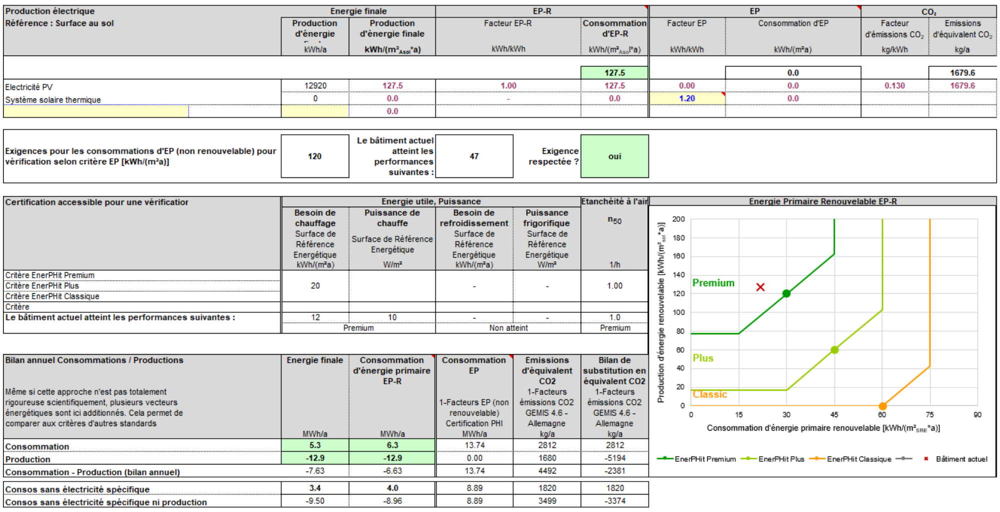
The PHPP calculations estimate a mean annual PV yield of 12900 kWh which significantly exceeds the estimated annual electricity demand of 5300 kWh. Factoring in storage and grid losses as are inevitable for year-round availability of power drive the ***PER*** demand up to 6300 kWh, which is still much less than on-site production.



CS7 PHPP estimated PV yield per month



CS7 PHPP calculation of area-specific space heating demand (grey bars)



Production électrique Référence : Surface au sol	Energie finale: Production d'énergie finale kWh/a	Energie finale: Production d'énergie finale kWh/(m²Asol*a)	EP-R: Facteur EP-R kWh/kWh	EP-R: Consommation d'EP-R kWh/(m²Asol*a)	EP: Facteur EP kWh/kWh	EP: Consommation d'EP kWh/(m²a)	CO₂: Facteur d'émissions CO_2 kg/kWh	CO₂: Emissions d'équivalent CO_2 kg/a
				127.5		0.0		1679.6
Electricité PV	12920	127.5	1.00	127.5	0.00	0.0	0.130	1679.6
Système solaire thermique	0	0.0	-	0.0	1.20	0.0		
		0.0						

Exigences pour les consommations d'EP (non renouvelable) pour vérification selon critère EP [kWh/(m²a)]	120	Le bâtiment actuel atteint les performances suivantes :	47	Exigence respectée ?	oui

Certification accessible pour une vérificatior	Energie utile, Puissance: Besoin de chauffage Surface de Référence Energétique kWh/(m²a)	Puissance de chauffe Surface de Référence Energétique W/m²	Besoin de refroidissement Surface de Référence Energétique kWh/(m²a)	Puissance frigorifique Surface de Référence Energétique W/m²	Etanchéité à l'air: n_{50} 1/h
Critère EnerPHit Premium Critère EnerPHit Plus Critère EnerPHit Classique	20		-	-	1.00
Critère					
Le bâtiment actuel atteint les performances suivantes :	12	10	-	-	1.0
	Premium		Non atteint		Premium

Bilan annuel Consommations / Productions Même si cette approche n'est pas totalement rigoureuse scientifiquement, plusieurs vecteurs énergétiques sont ici additionnés. Cela permet de comparer aux critères d'autres standards	Energie finale MWh/a	Consommation d'énergie primaire EP-R MWh/a	Consommation EP 1-Facteurs EP (non renouvelable) Certification PHI MWh/a	Emissions d'équivalent CO2 1-Facteurs émissions CO2 GEMIS 4.6 - Allemagne kg/a	Bilan de substitution en équivalent CO2 1-Facteurs émissions CO2 GEMIS 4.6 - Allemagne kg/a
Consommation	5.3	6.3	13.74	2812	2812
Production	-12.9	-12.9	0.00	1680	-5194
Consommation - Production (bilan annuel)	-7.63	-6.63	13.74	4492	-2381
Consos sans électricité spécifique	3.4	4.0	8.89	1820	1820
Consos sans électricité spécifique ni production	-9.50	-8.96	8.89	3499	-3374

CS7 PHPP snippet of PER rating worksheet

However, the adequate metric for RES yield in buildings is the built-up area, the building footprint.

With regard to the building footprint area the yield amounts to 128 kWh/(m²a) which means a full use of the available potential. This is reflected as high score for energy production in the ***PER*** rating scheme. The building can even achieve the ***EnerPHit premium*** rating (red mark in the plot). This is due to a very low ***PER*** demand for heating, due to the use of a heat pump for all space heating and the particularly low space heating demand.

In this case of a 4-storey building (that has a relatively small roof area with regard to the living area) an actually positive balance in absolute ***PER*** terms is achieved. This can be attributed to the mild climate, the row-house like attachment to neighbouring buildings reducing the heat transmitting area and the very efficient building services system.

At the time of writing this report no measured data of PV yield was available yet.

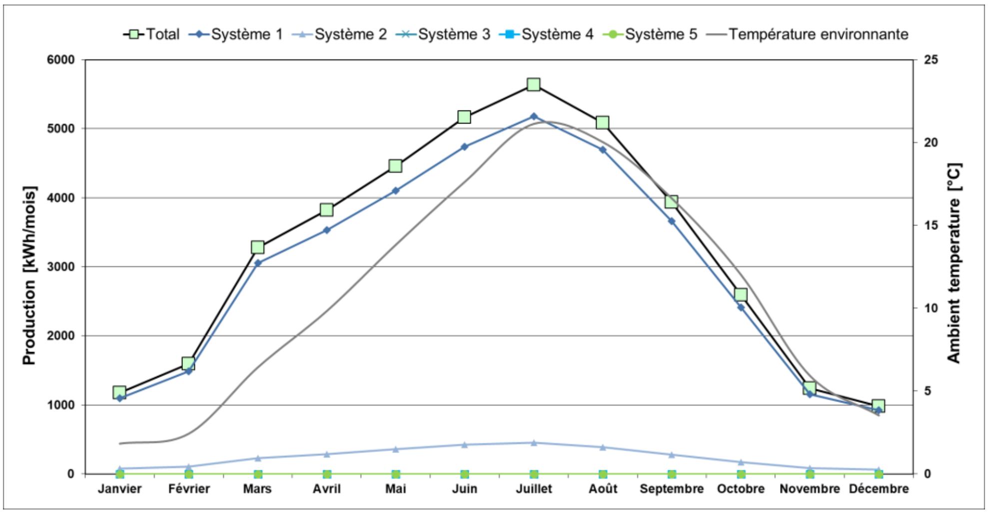
CS9 Lons-le-Saunier

CS9 is an office/training 1960s concrete non-residential building on the outskirts of Lons le Saunier, refurbished to EnerPhit standard in 2023. Internal Insulation had to be used on the “blind” north wall.

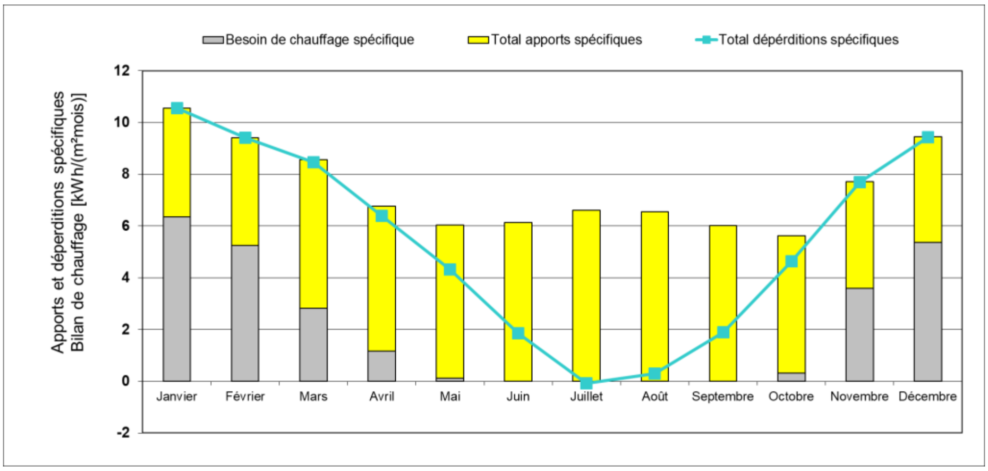
Space heating demand after retrofit is 25 kWh/(m²a).

CS9 as seen from the courtyard after refurbishment

The PHPP calculations estimate a mean annual PV yield of 38900 kWh which significantly exceeds the estimated annual electricity demand of 17600 kWh. However, factoring in the combined biomass and electric resistance heating as well as storage and grid losses as are inevitable for year-round availability of power drive the ***PER*** demand up to 23600 kWh, which is still less than on-site production.



CS9 PHPP estimated PV yield per month



CS9 PHPP calculation of area-specific space heating demand (grey bars)

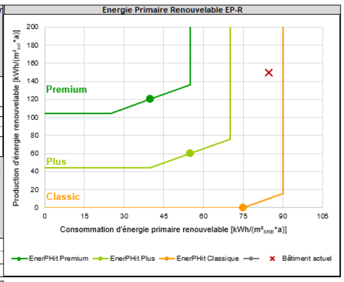
Production électrique Référence : Surface au sol	Energie finale Production d'énergie finale kWh/a	Energie finale Production d'énergie finale kWh/(m²$_{Asol}$*a)	EP-R Facteur EP-R kWh/kWh	EP-R Consommation d'EP-R kWh/(m²$_{Asol}$*a)	EP Facteur EP kWh/kWh	EP Consommation d'EP kWh/(m²a)	CO_2 Facteur d'émissions CO_2 kg/kWh	CO_2 Emissions d'équivalent CO_2 kg/a
				149.8		0.0		2650.0
Electricité PV	38959	149.8	1.00	149.8	0.00	0.0	0.068	2650.0
Système solaire thermique	0	0.0	-	0.0	1.20	0.0		
		0.0						

Exigences pour les consommations d'EP (non renouvelable) pour vérification selon critère EP [kWh/(m²a)]	131.9938118	Le bâtiment actuel atteint les performances suivantes :	116	Exigence respectée ?	oui

Certification accessible pour une vérification	Energie utile, Puissance Besoin de chauffage Surface de Référence Energétique kWh/(m²a)	Puissance de chauffe Surface de Référence Energétique W/m²	Besoin de refroidissement Surface de Référence Energétique kWh/(m²a)	Puissance frigorifique Surface de Référence Energétique W/m²	Etanchéité à l'air n_{50} 1/h
Critère EnerPHit Premium Critère EnerPHit Plus Critère EnerPHit Classique	25		-	-	1.00
Critère					
Le bâtiment actuel atteint les performances suivantes :	25	15	-	-	1.0
	Premium		Non atteint		Premium

Bilan annuel Consommations / Productions Même si cette approche n'est pas totalement rigoureuse scientifiquement, plusieurs vecteurs énergétiques sont ici additionnés. Cela permet de comparer aux critères d'autres standards	Energie finale MWh/a	Consommation d'énergie primaire EP-R MWh/a	Consommation EP 1-Facteurs EP (non renouvelable) Certification PHI MWh/a	Emissions d'équivalent CO2 1-Facteurs émissions CO2 GEMIS 4.6 - Allemagne kg/a	Bilan de substitution en équivalent CO2 1-Facteurs émissions CO2 GEMIS 4.6 - Allemagne kg/a
Consommation	**17.6**	**23.6**	32.35	6529	6529
Production	**-39.0**	**-39.0**	0.00	2650	-18076
Consommation - Production (bilan annuel)	-21.36	-15.41	32.35	9179	-11547
Consos sans électricité spécifique	**11.8**	**16.3**	17.28	3446	3446
Consos sans électricité spécifique ni production	-27.16	-22.65	17.28	6096	-14631

Energie Primaire Renouvelable EP-R



CS9 PHPP snippet of PER rating worksheet

However, the adequate metric for RES yield in buildings is the built-up area, the building footprint.

With regard to the building footprint area the yield amounts to 150 kWh/(m²a) which means a full use of the available potential. This is reflected as high score for energy production in the ***PER*** rating scheme. However, the building does not achieve the ***EnerPHit plus*** rating (cf. red mark in the plot). This is due to a high ***PER*** demand for heating, due to the use of electric resistance heaters and biomass. Use of a heat pump for all space heating could decrease the ***PER*** value by approximately 20 kWh/(m²a). Hence, if the plant is replaced by an electric heat pump at a later date the ***EnerPHit plus*** class will be safely achieved.

In this case of a two storey building (that has a large roof area with regard to the useful area) an actually positive balance in absolute ***PER*** terms is nevertheless achieved.

At the time of writing this report no measured data of PV yield was available yet.

GERMANY

OP 37 Darmstadt/Arheilgen

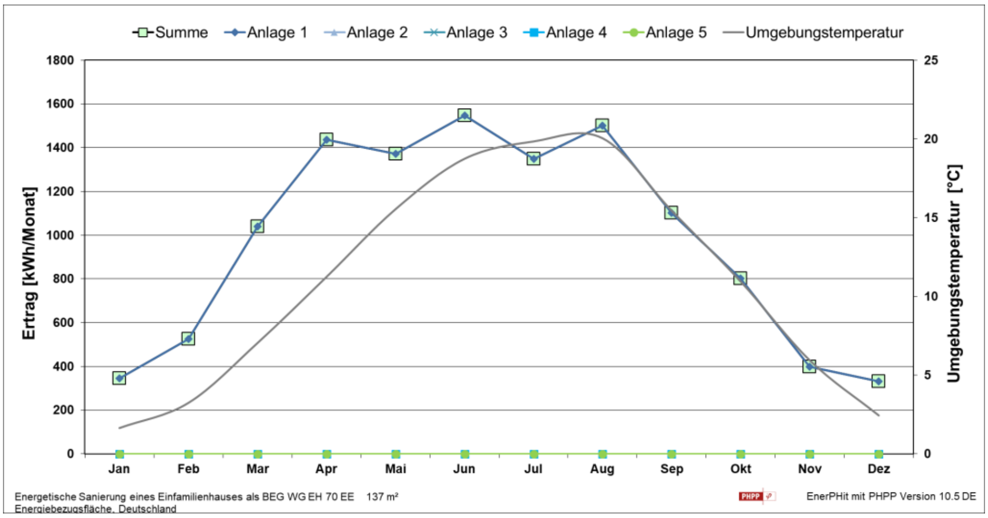
OP37 is a single family house built in 1928. It underwent deep retrofit to EnerPHit standard in 2023/24, when it was also equipped with a PV array covering the entire south side of the pitched roof.

Space heating demand after retrofit is 47 kWh/(m²a). This may appear much, but is actually a good result considering the relatively large impact of remaining thermal bridging of structural walls to the unheated basement.

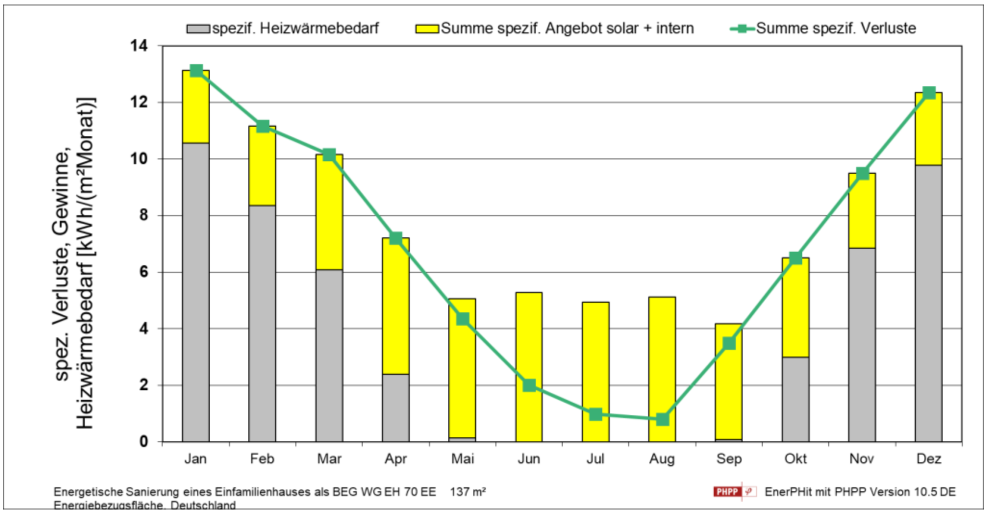
OP37 as seen from the street before refurbishment

The PHPP calculations estimate a mean annual PV yield of 11750 kWh which exceeds the estimated annual electricity demand of 8116 kWh. However, factoring in storage and grid losses as are inevitable for year-round availability of power drive the ***PER*** demand up to 11700 kWh, on par with on-site production.

This is mainly due to the anti-correlation of PV power availability in the summer and space heating demand in the winter.



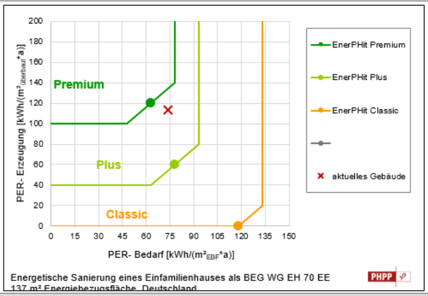
OP37 PHPP estimated PV yield per month



OP37 PHPP calculation of area-specific space heating demand (grey bars)

Summe Energieerzeugung kWh/(m²$_{\text{überbaute Fläche}}$ a)	PER:	113.33	PE:	0.00	CO_2:	1528	2738

Nachweis Passivhaus/EnerPhit Standard



Klassen in Teilbereichen: aktueller Wert:				Kriterien PHI-Energiesparhaus:	Kriterien EnerPHit : Classic	Plus	Premium	erreichte Klasse
Heizwärmebedarf bezogen auf EBF	47	kWh/(m²a)	≤	30		nach Bauteilverfahren		PHI-Energiesparhaus
Heizlast bezogen auf EBF	23	W/m²	≤	-		-		
Kühl- und Entfeuchtungsbedarf bezogen auf EBF	0	kWh/(m²a)	≤	30		nach Bauteilverfahren		Nicht erreicht
Luftdichtheit n_{50}	1.0	1/h	≤	1		1.0		Premium
PER-Bedarf bezogen auf EBF	74	kWh/(m²a)	≤	75	118	78	63	Plus
PER-Erzeugung bezogen auf überbaute Fläche	113	kWh/(m²a)	≥	-	0	60	120	
PE-Bedarf (nicht erneuerbare Primärenergie)	105	kWh/(m²a)	≤	95		134		nicht relevant

OP37 PHPP snippet of PER rating worksheet

However, the adequate metric for RES yield in buildings is the built-up area, the building footprint.

With regard to the building footprint area the yield amounts to 113 kWh/(m²a) which means a full use of the available potential. This is reflected as a very good score within the ***EnerPHit plus*** rating (red mark in the plot).

In this case of a single family building (that has a large roof area with regard to the living area) an actually neutral balance in absolute ***PER*** terms is achieved.

At the time of writing this report the PV system was not yet in operation and thus no measured data was available.

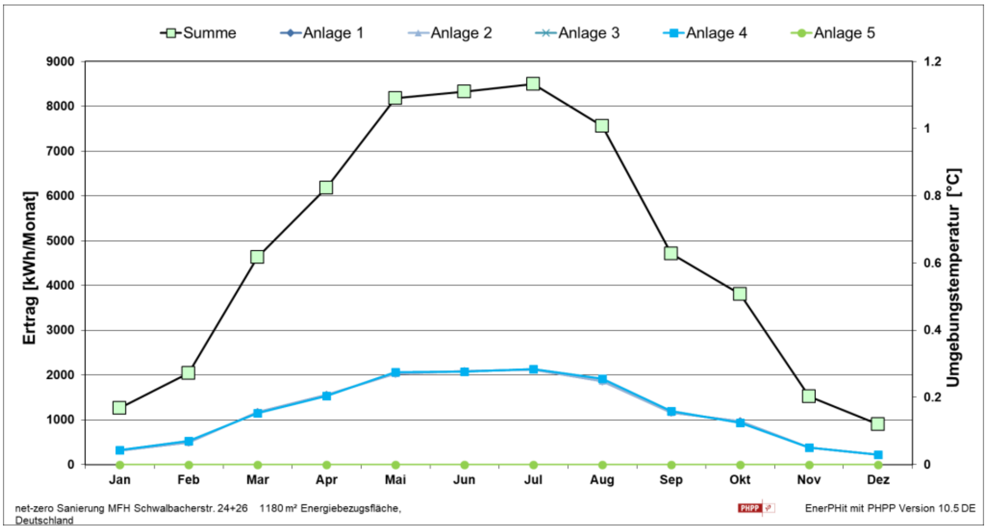
OP39 Köln

OP39 is a multifamily building built in 1961 and refurbished to EnerPHit standard with prefabricated large panels in 2023. It is equipped with a PV system in four sub-sections, oriented symmetrically east and west on the pitched roof.

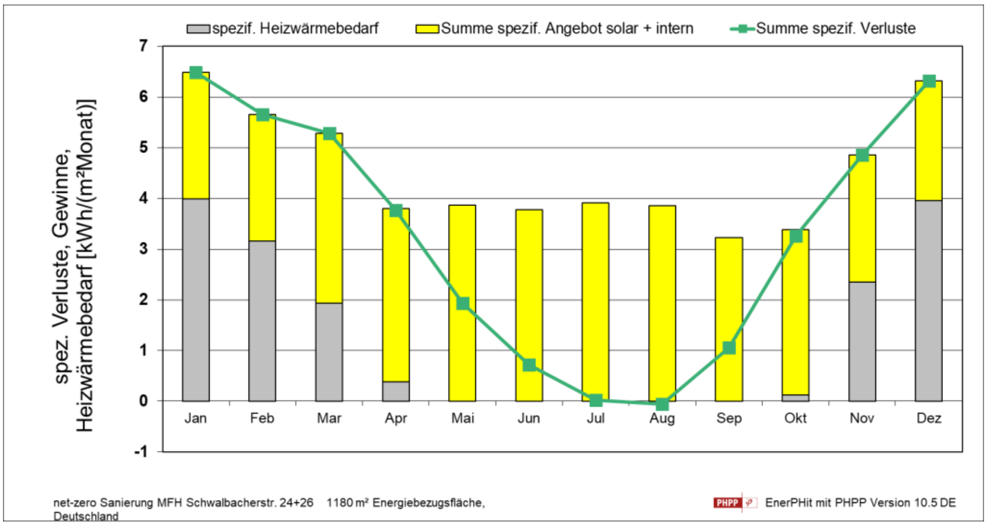
Space heating demand after retrofit is 16 kWh/(m²a).

OP39 as seen from a neighbouring building from ca. 165° (south-east)

The PHPP calculations estimate a mean annual PV yield of 57600 kWh which is about on par with the estimated annual electricity demand of 52145 kWh. However, factoring in storage and grid losses as are inevitable for year-round availability of power drive the ***PER*** demand up to 73645 kWh. This is mainly due to the anti-correlation of PV power availability in the summer and space heating demand in the winter.



OP39 PHPP estimated PV yield per month



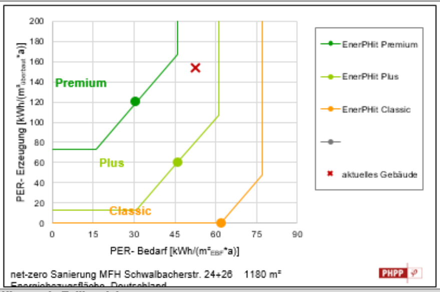
OP39 PHPP calculation of area-specific space heating demand (grey bars)

Summe Energiebedarf kWh/(m²EBF a)	PER:	52.7	PE:	75.7	CO_2:	18017	kg/a
		62114.75211					

Energieerzeugung bezogen auf die überbaute Fläche	Endenergie: Endenergie-erzeugung kWh/a	Endenergie: Endenergie-erzeugung kWh/(m²a)	PER: PER-Faktor kWh/kWh	PER: PER-Erzeugung kWh/(m²a)	PE: PE-Faktor kWh/kWh	PE: PE-Erzeugung kWh/(m²a)	CO_2: Emissionsfaktor (CO_2-eq) kg/kWh	CO_2: erzeugte Emissionen kg/a	CO_2: eingesparte Emissionen kg/a
PV-Strom	57601	154.1	1.00	154.1	0.00	0.0	0,13 I 0,363	7488	13421
Thermische Solaranlage	0	0.0	-	0.0	0.00	0.0			
		0.0							

Summe Energieerzeugung kWh/(m²überbaute Fläche a)	PER:	154.08	PE:	0.00	CO_2:	7488	13421

Nachweis Passivhaus/EnerPhit Standard



Klassen in Teilbereichen:	aktueller Wert			Kriterien PHI-Energiesparhaus	Kriterien EnerPHit: Classic	Kriterien EnerPHit: Plus	Kriterien EnerPHit: Premium	erreichte Klasse
Heizwärmebedarf bezogen auf EBF	**16**	kWh/(m²a)	≤	30		25		Premium
Heizlast bezogen auf EBF	**10**	W/m²	≤	-		-		
Kühl- und Entfeuchtungsbedarf bezogen auf EBF	-	kWh/(m²a)	≤	-		-		-
Luftdichtheit n_{50}	**0.6**	1/h	≤	1		1.0		Premium
PER-Bedarf bezogen auf EBF	**53**	kWh/(m²a)	≤	75	62	46	31	Plus
PER-Erzeugung bezogen auf überbaute Fläche	**154**	kWh/(m²a)	≥	-	0	60	120	
PE-Bedarf (nicht erneuerbare Primärenergie)	**76**	kWh/(m²a)	≤	95		96		Classic
Energiestandard für gesamtes Gebäude						**mit dem gewählten Nachweisverfahren PER (erneuerbar) wird folgende Klasse erreicht:**		**Plus**

OP39 PHPP snippet of PER rating worksheet

However, the adequate metric for RES yield in buildings is the built-up area, the building footprint.

With regard to the building footprint area the yield amounts to 154 kWh/(m²a) which means a full use of the available potential. This is reflected as a very good score within the ***EnerPHit plus*** rating (red mark in the plot).

OP39 thus fully meets the requirements for a future proof building with minimized space heating demand and maximized RES yield on the available area.

For the period 10/2022 until 09/2023 metered data are available courtesy Zeller-Kölmel Architects:

	PHPP calculation [kWh]	Metered ´22/´23 [kWh]
PV yield	57600	55042
Electricity consumption	52145	45441

OP39 calculated vs. metered electricity yield and consumption, courtesy ZK Architects

The PV yield is very close to the average annual expectation, while the consumption is somewhat lower than expected, probably due to milder winter conditions. The outPHit Verified Performance monitoring was not yet in place at that time but will shed some more light on the 2023/2024 season.

GREECE

CS2 Athens/Papagou

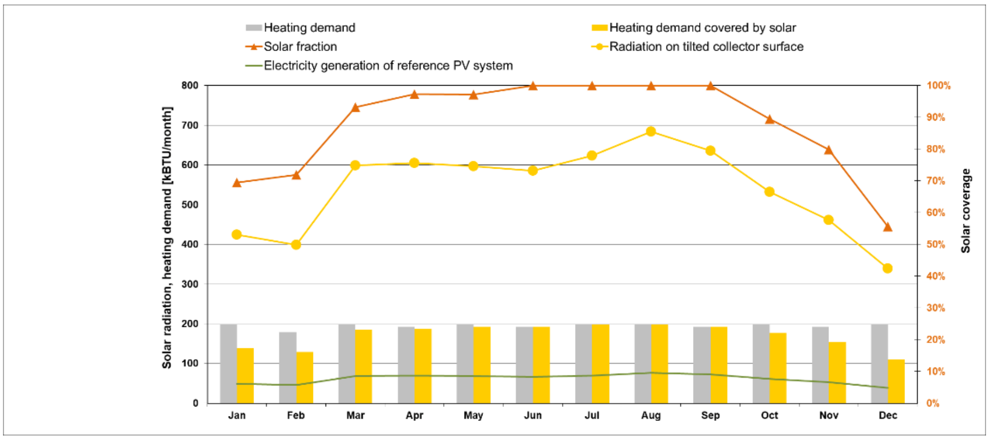
CS2 is a Single family house built 1970 and refurbished to EnerPHit standard in 2022, it was not yet equipped with a PV system, but a 4 m² solar thermal domestic hot water system is in place that covers 88 % of the DHW demand.

Space heating demand after retrofit is 35 kWh/(m²a). This may appear much, but is actually a good result considering the relatively large impact of remaining thermal bridging of structural walls to the unheated basement.

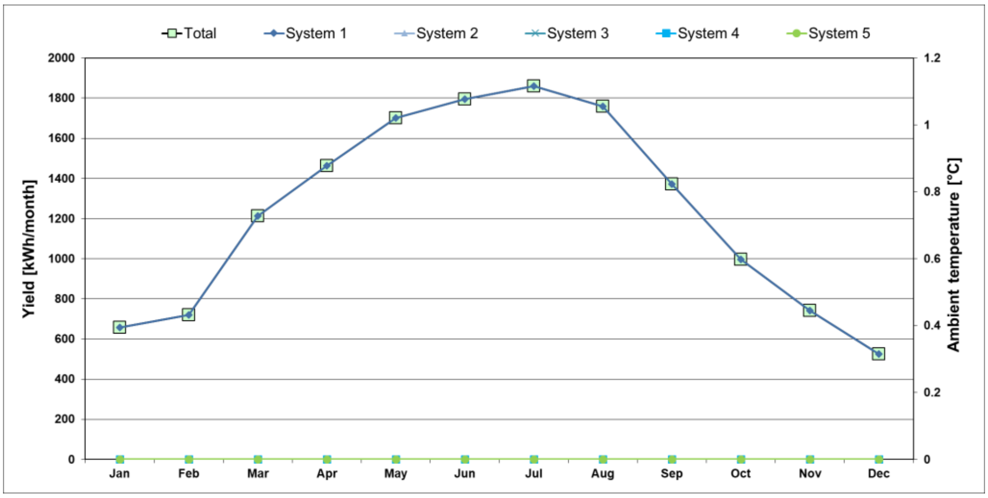
Therefore, the full RES potential was analyzed based on the available roof area, and a PV system assumed to use the remaining roof area.

CS2 as seen from a neighbouring building before refurbishment

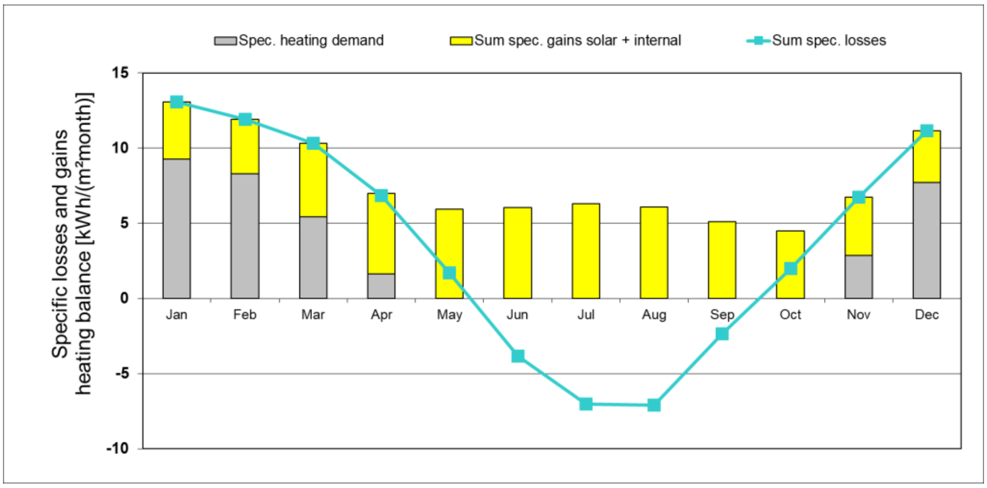
The PHPP calculations estimate a mean annual yield of 14800 kWh which greatly exceeds the estimated annual electricity demand of 7900 kWh, thanks to the sunny climate of Greece. However, factoring in storage and grid losses as are inevitable for year-round availability of power drive the ***PER*** demand up to 8400 kWh. This is mainly due to the anti-correlation of PV power availability in the summer and space heating demand in the winter.



CS2 PHPP estimated solar thermal yield per month



CS2 PHPP estimated PV yield per month

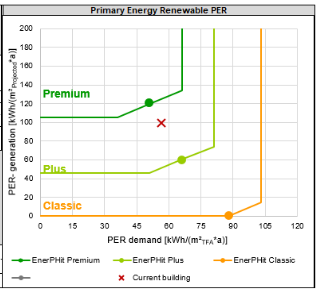


CS2 PHPP calculation of area-specific space heating demand (grey bars)

Energy generation Reference: Projected building footprint area	Final energy: Final energy generation kWh/a	Final energy: Final energy generation kWh/(m²A$_{Projected}$*a)	PER: PER factor kWh/kWh	PER: PER specific value kWh/(m²A$_{Projected}$a)	PE: PE factor kWh/kWh	PE: PE Value kWh/(m²a)	CO_2: Emission factor (CO_2-eq) kg/kWh	CO_2: CO_2eq emissions kg/a
				99.6		16.2		2017.1
PV electricity	14806	95.6	1.00	95.6	0.00	0.0	0.130	1924.7
Solar thermal system	2054	13.3	0.30	4.0	1.22	16.2	0.045	92.4
		0.0						

PE demand requirement in case of verification through PE (non-renewable) [kWh/(m²a)]	-	Current building reaches following class	103	Requirement met?	-

Achievable energy standard through the verification of renewable primary energy (assessment of individual aspects)	Useful energy, performance: Annual heat. dem Treated floor area kWh/(m²a)	Heating load Treated floor area W/m²	Useful cool. energy Treated floor area kWh/(m²a)	Cooling load Treated floor area W/m²	Airtightness n_{50} 1/h
Requirement EnerPHit Premium Requirement EnerPHit Plus Requirement EnerPHit Classic	-		0	-	1.00
Requirement					
Current building reaches following class for a:	35	21	18	15	1.0
	Premium		Unachieved		Premium



Summary Though, from the scientific point of view, not entirely correct, different energy carriers will be added together here. This is done to meet the criteria of other energy standards.	Final energy MWh/a	PER specific value MWh/a	PE value 1-PE factors (non-renewable) PHI Certification MWh/a	CO2eq emissions 1-CO2 factors GEMIS (Germany) kg/a	CO_2eq substitution balance 1-CO2 factors GEMIS (Germany) kg/a
Demand	7.9	8.4	15.30	3223	3223
Generation	-16.9	-15.4	-2.51	2017	-6379
Demand, cumulative generation (annual balance)	-8.92	-7.06	12.79	5240	-3156
Demand w/o household electricity	5.7	5.7	9.61	2059	2059
Demand w/o household electricity, cum. generation	-11.11	-9.68	7.10	4076	-4320

CS2 PHPP snippet of PER rating worksheet

However, the adequate metric for RES yield in buildings is the built-up area, the building footprint.

With regard to the building footprint area the yield amounts to 95.6 kWh/(m²a) which means a full use of the available potential. The solar thermal system adds another 4 kWh/(m²a) to make the sum 99.6 kWh/(m²a). This is reflected as a very good score within the ***EnerPHit plus*** rating (red mark in the plot).

CS2 thus fully meets the requirements for a future proof building with minimized space heating demand and maximized RES yield on the available area.

In this case of a single family building (that has a large roof area with regard to the living area) in a mild and sunny climate a positive balance in absolute ***PER*** terms is achieved, the production exceeding the demand by almost a factor of two.

For the hypothetical PV system no measured data is available.

CS3 Athens/Cholargos

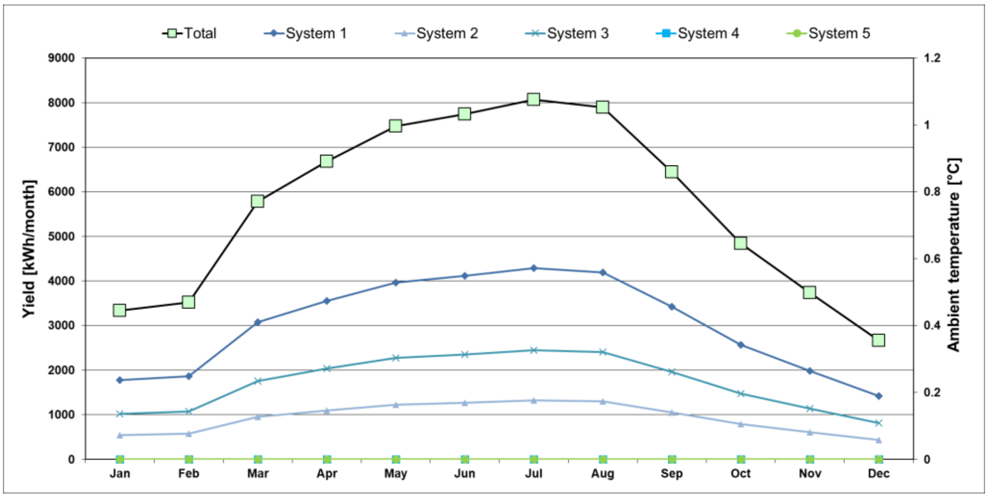
A 1980s multifamily house CS3 has a treated floor area of 1500 m². This project is carried out as a step by step renovation from 2022, the fully refurbished condition to EnerPHit standard is anticipated for the following evaluation.

Space heating demand after retrofit is 15 kWh/(m²a).

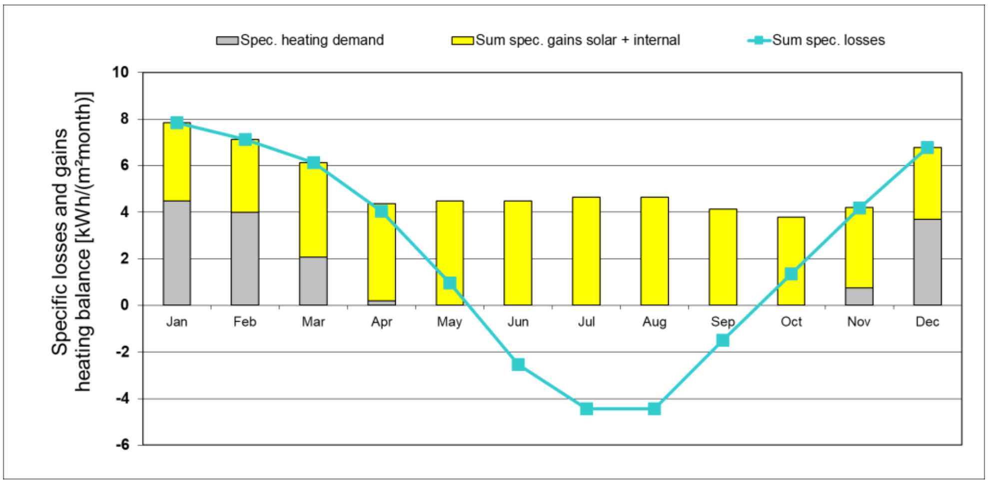
The building was not yet equipped with a PV system. Therefore, the full RES potential was analyzed based a PV system assumed to use the available roof area.

CS3 as seen from a neighbouring building before refurbishment

The PHPP calculations estimate a mean annual electricity yield of 68200 kWh which corresponds approximately to the estimated annual electricity demand of 64500 kWh. However, factoring in storage and grid losses as are inevitable for year-round availability of power drive the ***PER*** demand up to 83900 kWh. This is mainly due to the anti-correlation of PV power availability in the summer and space heating demand in the winter.



CS3 PHPP estimated PV yield per month



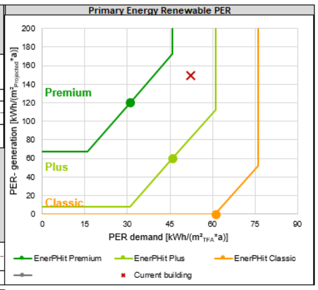
CS3 PHPP calculation of area-specific space heating demand (grey bars)

Energy generation Reference: Projected building footprint area	Final energy		PER		PE		CO_2	
	Final energy generation	**Final energy generation**	PER factor	**PER specific value**	PE factor	PE Value	Emission factor (CO_2-eq)	CO_2eq emissions
	kWh/a	kWh/(m²$A_{Projected}$*a	kWh/kWh	kWh/(m²$A_{Projected}$a)	kWh/kWh	kWh/(m²a)	kg/kWh	kg/a
				148.9		**0.0**		**8865.9**
PV electricity	68199	148.9	1.00	148.9	0.00	0.0	0.130	8865.9
Solar thermal system	0	0.0	-	0.0	1.22	0.0		
		0.0						

PE demand requirement in case of verification through PE (non-renewable) [kWh/(m²a)]	-	**Current building reaches**	**106**	**Requirement met?**	-

Achievable energy standard through the verification of renewable primary energy (assessment of individual aspects)	**Useful energy, performance**				**Airtightness**
	Annual heat. dem	**Heating load**	**Useful cool. energy**	**Cooling load**	n_{50}
	Treated floor area	Treated floor area	Treated floor area	Treated floor area	
	kWh/(m²a)	W/m²	kWh/(m²a)	W/m²	1/h
Requirement EnerPHit Premium Requirement EnerPHit Plus Requirement EnerPHit Classic	15		16	10	1.00
Requirement					
Current building reaches following class for	15	12	15	11	1.0
	Premium		Premium		Premium

Summary Though, from the scientific point of view, not entirely correct, different energy carriers will be added together here. This is done to meet the criteria of other energy standards.	**Final energy** MWh/a	**PER specific valu** MWh/a	**PE value** 1-PE factors (non-renewable) PHI Certification MWh/a	**CO2eq emissions** 1-CO2 factors GEMIS (Germany) kg/a	**CO_2eq substitution balance** 1-CO2 factors GEMIS (Germany) kg/a
Demand	**64.9**	**83.9**	168.84	34547	34547
Generation	**-68.2**	**-68.2**	0.00	8866	-27416
Demand, cumulative generation (annual balance)	-3.26	15.74	168.84	43412	7131
Demand w/o household electricity	**50.2**	**66.2**	130.46	26694	26694
Demand w/o household electricity, cum. generation	-18.02	-1.97	130.46	35560	-722



CS2 PHPP snippet of PER rating worksheet

With regard to the building footprint area the PV yield amounts to 148.9 kWh/(m²a) which means a full use of the available potential. This is reflected as a very good score within the ***EnerPHit plus*** rating (red mark in the plot).

CS3 thus fully meets the requirements for a future proof building with minimized space heating demand and maximized RES yield on the available area.

In this case of a multifamily building (that has a quite limited roof area with regard to the living area) despite a mild and sunny climate a positive balance in absolute ***PER*** terms is not possible. However, the production covers about the net electricity use of the building.

For the hypothetical PV system no measured data is available.

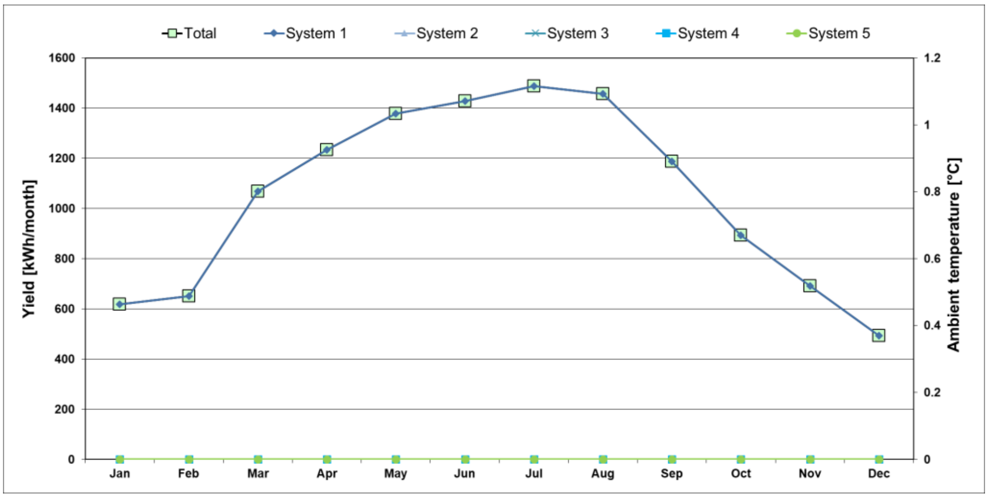
CS4 Athens/Maroussi

Small multifamily building with three flats from the 1970ies and refurbished in 2022 to EnerPHit standard, it was not yet equipped with a PV system, but three 4 m² solar thermal domestic hot water systems are in place that cover more than 90 % of the DHW demand.

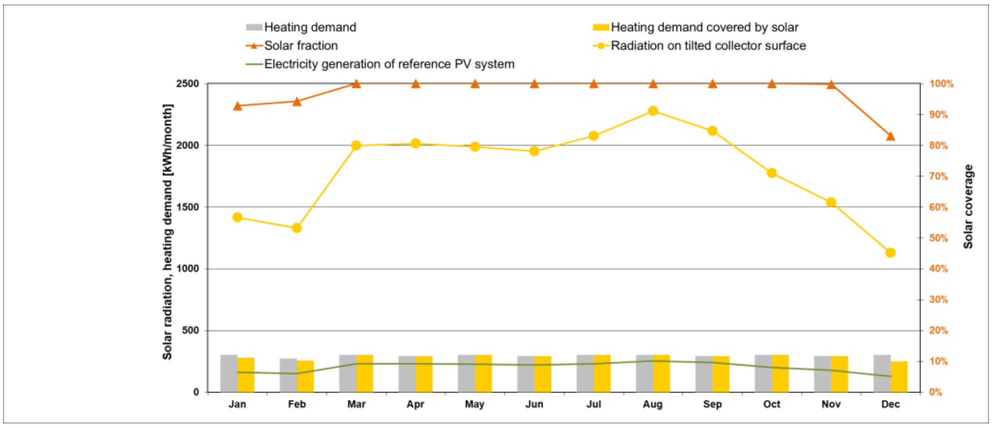
Space heating demand after retrofit is 14 kWh/(m²a).

CS4 as seen from a neighbouring building, before refurbishment

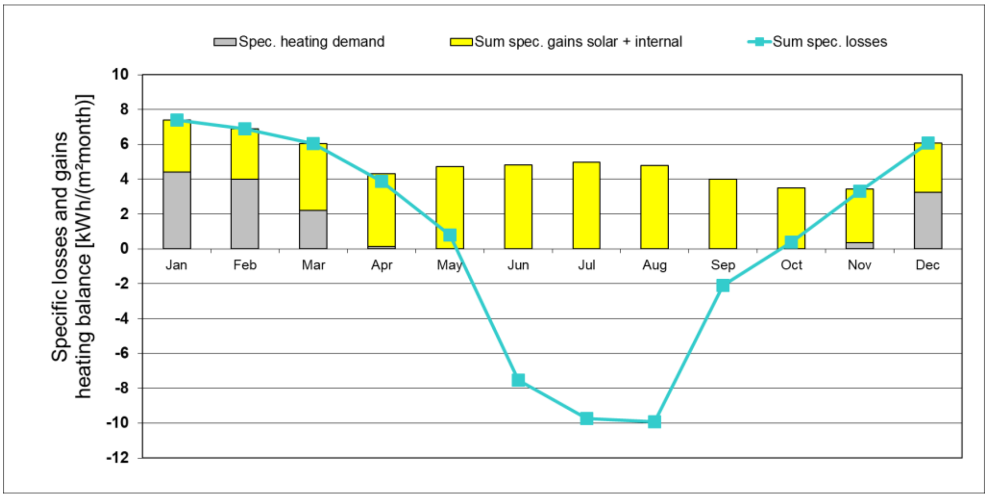
The PHPP calculations estimate a mean annual yield of 12500 kWh which is on par with the estimated annual electricity demand of 12300 kWh. Another 3400 kWh of useful heat are delivered by the solar thermal system. Factoring in storage and grid losses as are inevitable for year-round availability of electrical power drive the ***PER*** demand up to 12800 kWh. This is mainly due to the anti-correlation of PV power availability in the summer and space heating demand in the winter.



CS4 PHPP estimated PV yield per month



CS4 PHPP estimated solar thermal yield per month

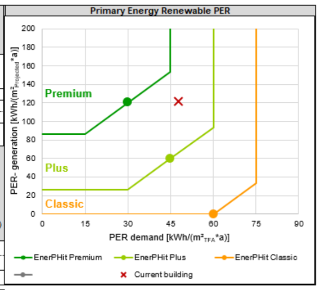


CS4 PHPP calculation of area-specific space heating demand (grey bars)

Energy generation Reference: Projected building footprint area	Final energy: Final energy generation kWh/a	Final energy: Final energy generation kWh/(m²A_Projected*a)	PER: PER factor kWh/kWh	PER: PER specific value kWh/(m²A_Projected a)	PE: PE factor kWh/kWh	PE: PE Value kWh/(m²a)	CO_2: Emission factor (CO_2-eq) kg/kWh	CO_2: CO_2eq emissions kg/a
				121.2		35.2		1792.8
PV electricity	12587	104.3	1.00	104.3	0.00	0.0	0.130	1636.3
Solar thermal system	3478	28.8	0.59	17.0	1.22	35.2	0.045	156.5
		0.0						

PE demand requirement in case of verification through PE (non-renewable) [kWh/(m²a)]	120	Current building reaches	85	Requirement met?	yes

Achievable energy standard through the verification of renewable primary energy (assessment of individual aspects)	Useful energy, performance: Annual heat. dem Treated floor area kWh/(m²a)	Heating load Treated floor area W/m²	Useful cool. energy Treated floor area kWh/(m²a)	Cooling load Treated floor area W/m²	Airtightness n_{50} 1/h
Requirement EnerPHit Premium Requirement EnerPHit Plus Requirement EnerPHit Classic	15		16	11	1.00
Requirement					
Current building reaches following class for :	14	11	13	9	0.9
	Premium		Premium		Premium



Summary Though, from the scientific point of view, not entirely correct, different energy carriers will be added together here. This is done to meet the criteria of other energy standards.	Final energy MWh/a	PER specific value MWh/a	PE value 1-PE factors (non-renewable) PHI Certification MWh/a	CO2eq emissions 1-CO2 factors GEMIS (Germany) kg/a	CO_2eq substitution balance 1-CO2 factors GEMIS (Germany) kg/a
Demand	12.3	12.8	22.81	4823	4823
Generation	-16.1	-14.6	-4.25	1793	-5783
Demand, cumulative generation (annual balance)	-3.81	-1.81	18.56	6616	-960
Demand w/o household electricity	6.7	6.1	8.28	1851	1851
Demand w/o household electricity, cum. generation	-9.40	-8.48	4.03	3644	-3932

CS4 PHPP snippet of PER rating worksheet

With regard to the building footprint area the PV yield amounts to 121 kWh/(m²a) which means a full use of the available potential. This is reflected as a very good score within the ***EnerPHit plus*** rating (red mark in the plot).

CS4 thus fully meets the requirements for a future proof building with minimized space heating demand and maximized RES yield on the available area.

In this case of a multifamily building (that has a limited roof area with regard to the living area) in a mild and sunny climate a positive balance in absolute ***PER*** terms is not possible. However, the production just covers the ***PER*** rated energy demand of the building.

For the hypothetical PV system no measured data is available.

SPAIN

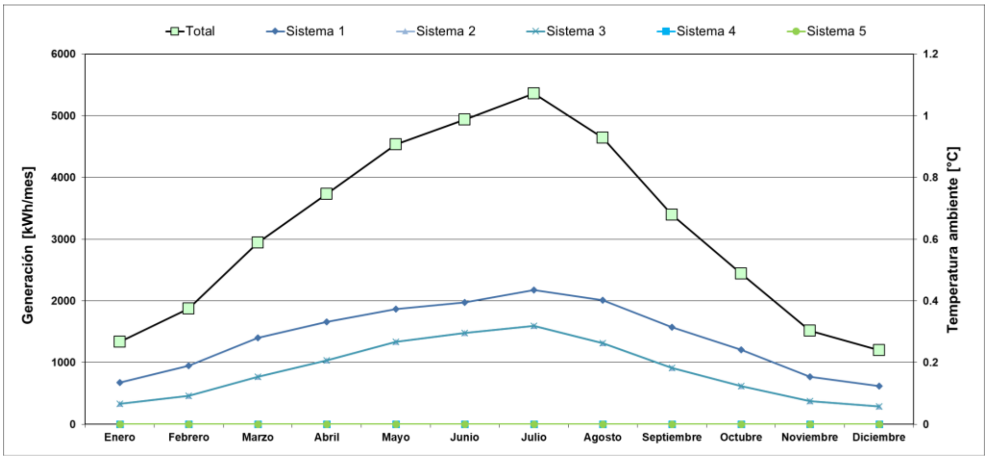
CS17 Teruel

Multifamily house from 1970, retrofitted in 2020 to EnerPHit standard. No RES system have been fitted as yet, therefore a straightforward PV installation on the roof is hypothesized to explore the potential.

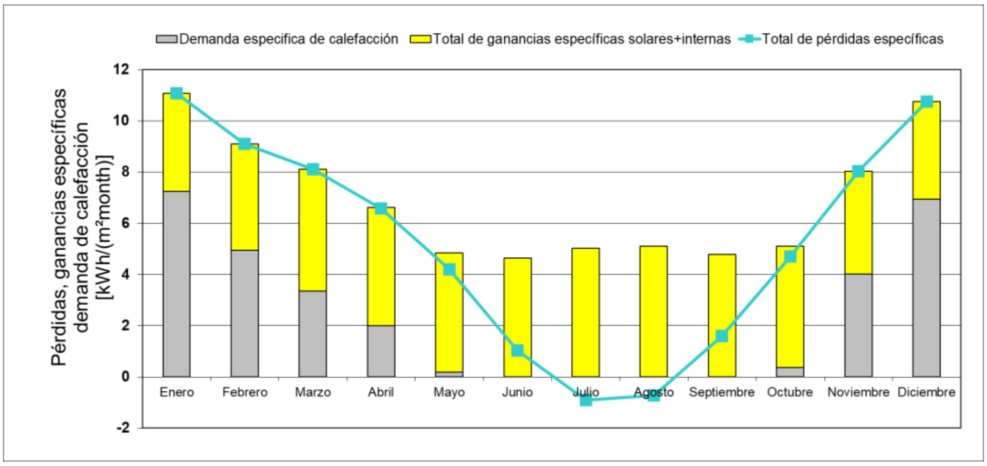
Space heating demand after retrofit is 29 kWh/(m²a).

CS17 as seen from the street, before refurbishment

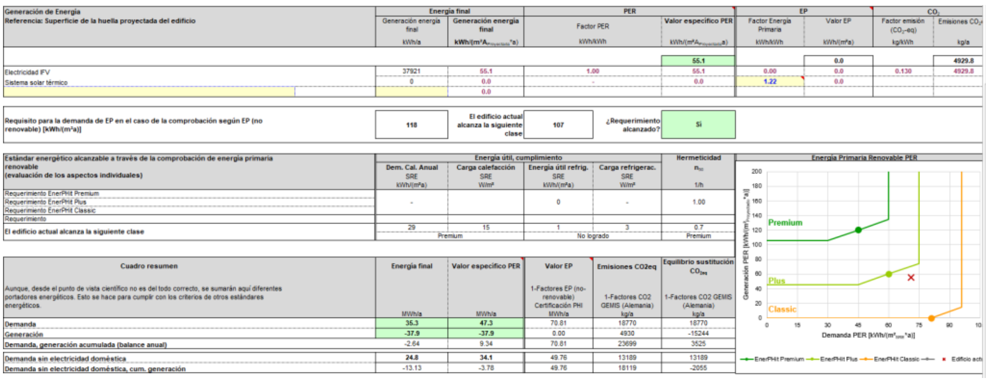
The PHPP calculations estimate a mean annual PV electricity yield of 37900 kWh which is roughly on par with the estimated annual electricity demand of 35200 kWh, despite the use of electric resistance heaters. However, factoring in storage and grid losses as are inevitable for year-round availability of electrical power drive the ***PER*** demand up to 47300 kWh. This is mainly due to the anti-correlation of PV power availability in the summer and space heating demand in the winter.



CS17 PHPP estimated PV yield per month



CS17 PHPP calculation of area-specific space heating demand (grey bars)



CS17 PHPP snippet of PER rating worksheet

With regard to the building footprint area the PV yield amounts to 55.1 kWh/(m²a). Despite the low value this means a full use of the available potential, due to the unfavorable northeast orientation of the main roof. The score within the ***PER*** rating system (red mark in the plot) is not achieving the ***EnerPHit plus*** class. This is mainly due to the high electricity demand, due to use of resistance heaters and could be improved with the use of heat pumps instead.

CS17 thus cannot yet meet all the requirements for a future proof building. Nevertheless the minimized space heating demand is a good base and building services systems have a chance to get replaced by heat pump technology at a later date. With a heat pump for space heating the *EnerPHit plus* rating is within reach.

In this case of a 5-storey multifamily building (that has a quite limited roof area with regard to the living area and also an unfavorable orientation) in a mild and sunny climate a positive balance in absolute ***PER*** terms is not possible. However, the production just covers the final energy demand of the building.

For the hypothetical PV system no measured data is available.

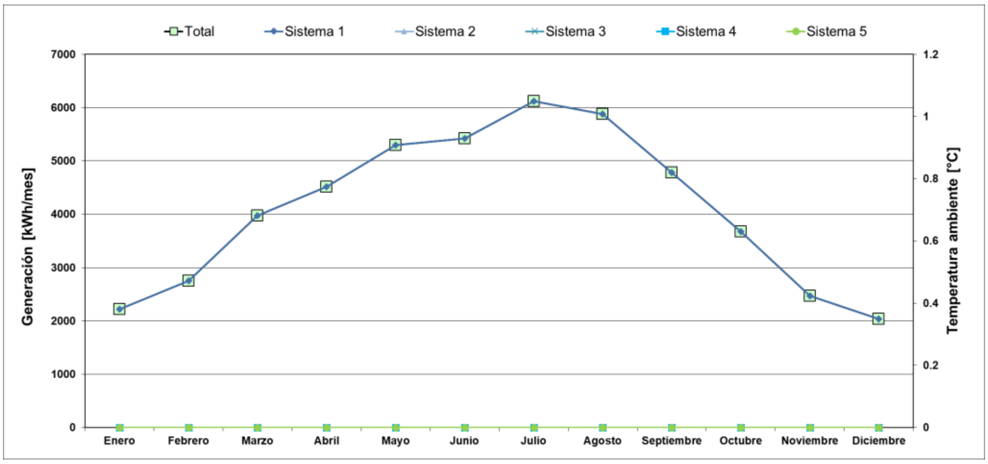
OP19 Madrid

Office building from 1972 refurbished to EnerPHit standard in 2023 and converted into flats. Only a very small PV system has been fitted as yet, therefore a full PV installation on the roof is hypothesized to explore the potential.

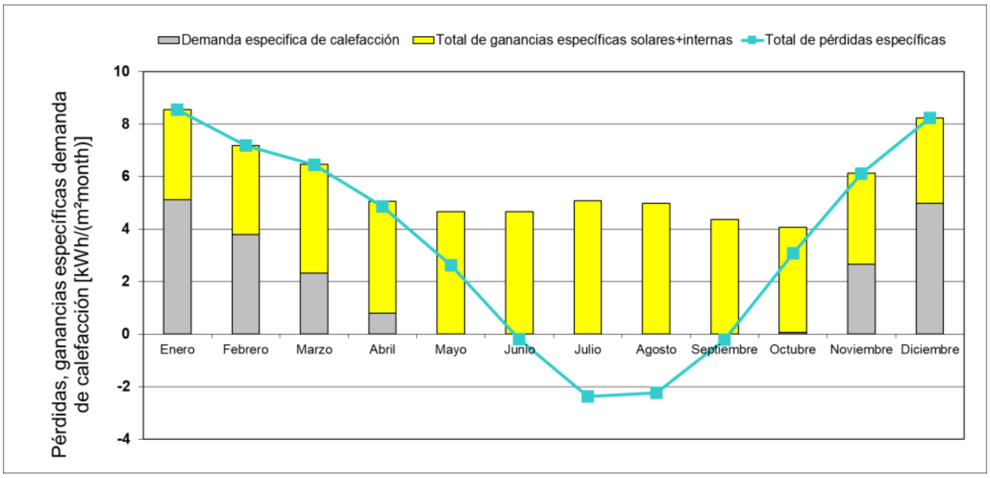
Space heating demand after retrofit is 20 kWh/(m²a).

OP19 as seen from the street, after refurbishment and conversion into flats

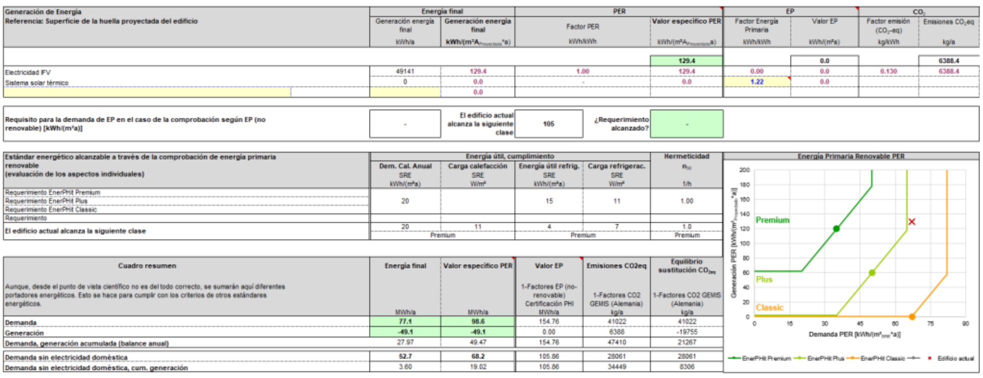
The PHPP calculations estimate a mean annual PV electricity yield of 40100 kWh which is less than the estimated annual electricity demand of 77100 kWh, due in part to the use of electric resistance heaters. Factoring in storage and grid losses as are inevitable for year-round availability of electrical power drive the ***PER*** demand up to 98699 kWh. This is mainly due to the anti-correlation of PV power availability in the summer and space heating demand in the winter.



OP19 PHPP estimated PV yield per month



OP19 PHPP calculation of area-specific space heating demand (grey bars)



OP19 PHPP snippet of PER rating worksheet

With regard to the building footprint area the PV yield amounts to 129 kWh/(m²a) which means a full use of the available potential. The score within the ***PER*** rating system (red mark in the plot) is just missing the ***EnerPHit plus*** class, though. This is mainly due to the high electricity demand, due to the use of resistance heaters and could be improved with the use of heat pumps instead.

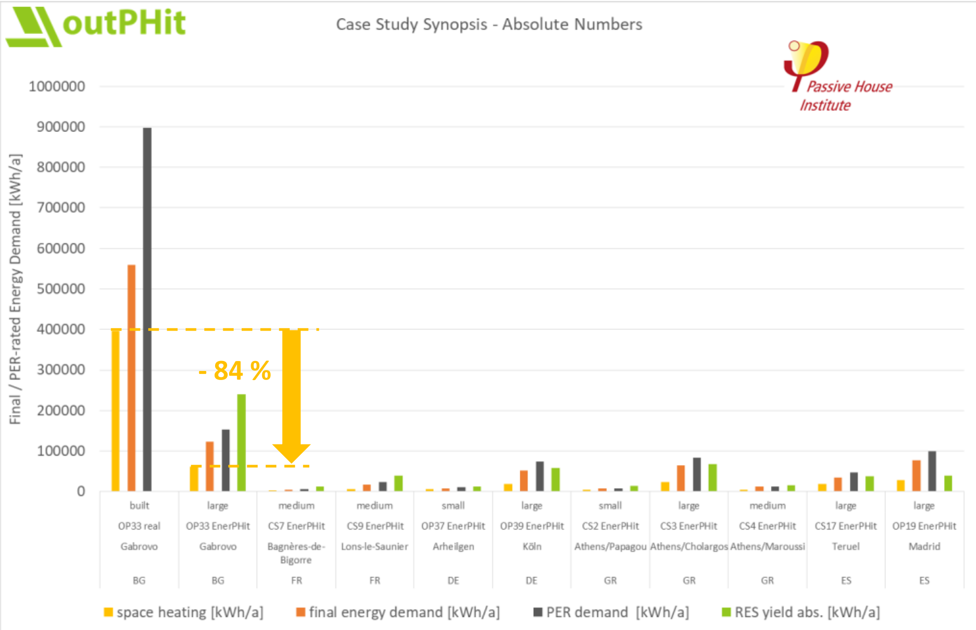
OP19 thus cannot yet meet all the requirements for a future proof building. Nevertheless the minimized space heating demand is a good base and building services systems have a chance to get replaced by heat pump technology at a later date. With a heat pump for space heating the *EnerPHit plus* rating is certainly achieved.

In this case of a 8-storey multifamily building (that has a very limited roof area with regard to the living area) in a mild and sunny climate a positive balance in absolute ***PER*** terms is not possible. However, the production covers a very meaningful share in the final energy demand of the building.

For the hypothetical PV system no measured data is available.

SUMMARY OF CASE STUDY PROJECTS RES POTENTIAL

The Case Study lineup could highlight the importance of a minimized space heating demand as a prerequisite of high RES coverage. This reduction in energy comes along with a reduction in peak power demand in the winter, which unburdens the power grid at a critical time, when PV production is very low and the system relies on wind power and expensive stored energy (cf. table below).

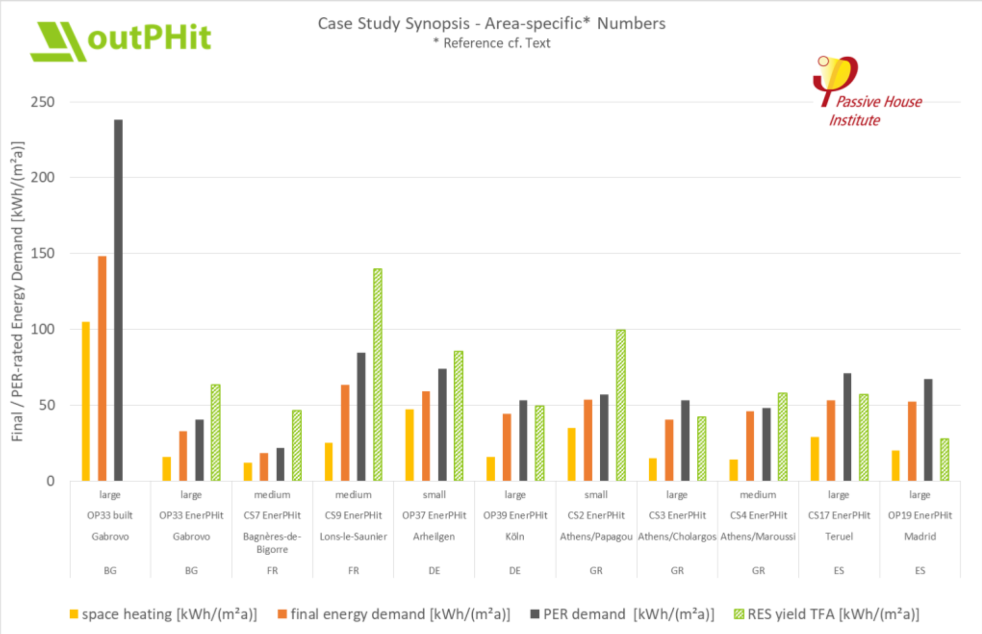


Synoptic View of Case Study Energy Demand / Generation, in Absolute Numbers

The comparison of absolute energy figures gives a good impression of what the ***EnerPHit*** standard can do beyond a conventional shallow retrofit: The OP33/Gabrovo example from Bulgaria achieves an 84 % reduction in space heating energy demand over the refurbished as-built, code compliant condition, with moderate effort.

The space heating demand is the single biggest driver for energy use in buildings in Europe and can be tackled very effectively and in a cost-effective manner. It presents the proverbial lowest-hanging fruit among possible energy efficiency improvements.

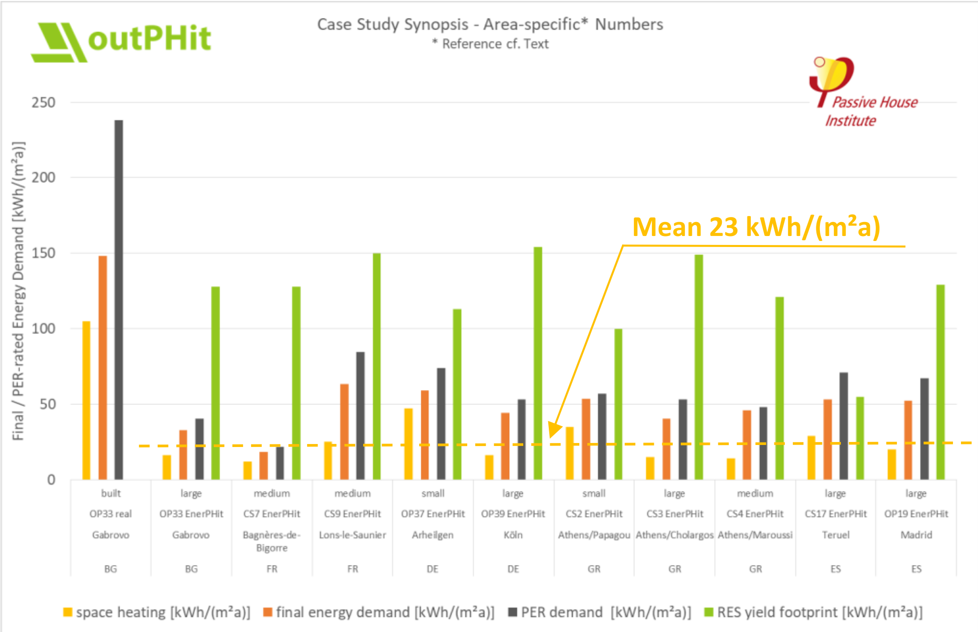
Greatly reduced energy demand in some instances facilitates even absolute ***PER*** coverage of buildings: Enough renewable energy can be harvested to supply the building year-round, even if the losses in various energy storage and energy conversion processes are factored in. This is remarkable, as most Case Study projects are located within cities or towns and only roof areas can be used for RES deployment.



Synoptic View of Case Study Energy Demand / Generation, Area-specific Numbers, referenced to Treated Floor Area (TFA)

A view of the area-specific numbers makes differently sized projects more comparable. Obvious in all ***EnerPHit*** cases is the very low space heating demand with a mean value of only 23 kWh/(m²a)- the precondition for a meaningful RES implementation in buildings.

Referencing energy demand to Treated Floor Area (TFA, the conditioned useful area within a building) is common practice and makes sense from an energy efficiency point of view: The achieved benefit (conditioned space at comfortable conditions) is related to the effort spent (energy use). For RES production, however, this reference leads to a systematic negative bias for larger, more compact structures that provide less external/roof area for a given interior space. The chart illustrates this with tall RES yield bars (green, hatched) for small buildings (CS2, CS9, CS37) and much shorter bars for large buildings (CS3, OP19,OP39). All despite the fact that either building made good use of the available roof area.



Synoptic View of Case Study Energy Demand / Generation, Area-specific Numbers, demand referenced to Treated Floor Area (TFA), RES production to building footprint

With regard to the projected building footprint a high RES potential can be realized, more than 100 kWh/(m²a) in most cases and up to a good 150 kWh/(m²a) in some. Just in one out of ten Case Studies (10 %) the RES potential is only half the average, due to unfavourable local conditions (CS17, Teruel/ES).

The synoptic plot exemplifies why using the building footprint as the reference is the adequate way to rate the RES potential and compare the rating across a number of different projects. It immediately corresponds to the available roof area which is available for PV and solar thermal panels installation.

The individual figures are further given in the following table, for further study and reference.

	BG	BG	FR	FR	DE	DE	GR	GR	GR	ES	ES	
	Gabrovo	Gabrovo	Bagnères-de-Bigorre	Lons-le-Saunier	Arheilgen	Köln	Athens/Papagou	Athens/Cholargos	Athens/Maroussi	Teruel	Madrid	
	OP33 built	OP33 EnerPHit	CS7 EnerPHit	CS9 EnerPHit	OP37 EnerPHit	OP39 EnerPHit	CS2 EnerPHit	CS3 EnerPHit	CS4 EnerPHit	CS17 EnerPHit	OP19 EnerPHit	EnerPHit
	large	large	medium	medium	small	large	small	large	medium	large	large	Mean
space heating [kWh/a]	396593	60821	3354	6952	6463	18756	5201	24297	3858	19307	29033	17804
final energy demand [kWh/a]	560000	123000	5300	17600	8116	52145	7900	64500	12300	35200	77100	40316
PER demand [kWh/a]	898000	153000	6300	23600	11700	73645	8400	83900	12800	47300	98699	51934
RES yield abs. [kWh/a]	0	240000	12900	38900	11750	57600	14800	68200	15900	37900	40100	53805
space heating [kWh/(m²a)]	105	16	12	25	47	16	35	15	14	29	20	22.9
final energy demand [kWh/(m²a)]	148	33	18	63	59	44	53	40	46	53	52	46.2
PER demand [kWh/(m²a)]	238	40.5	21.7	84.7	74	53	57	53	48	71	67	57.0
RES yield footprint [kWh/(m²a)]	0	128	128	150	113	154	100	149	121	55	129	122.7
Heating load [W/m²]	53	13	10.3	15.3	22.8	9.8	21.2	11.7	10.5	14.8	10.6	14

Tabulated values of Case Study Energy Demand / Generation, Absolute and Area-specific Numbers

THE IMPACT OF EV CHARGING

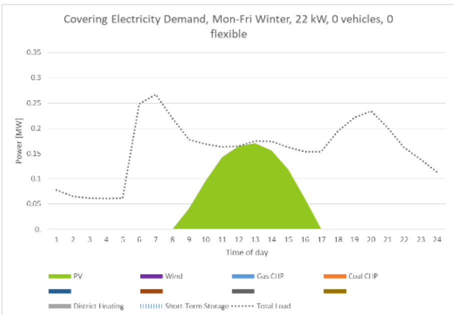
The electricity consumption due to the recharging of electrical vehicle (EV) batteries is a developing new use case in the domestic domain. Housing companies and utilities as well as electrical design engineers must understand the implications in terms of required grid and distribution dimensions, business and costing models, and more.

A high density urban block in a German cool-temperate climate (ca. latitude 52.5°N) was chosen for the study and comprises 450 flats with an average size 65m², totaling 30400 m² treated floor area. It is inhabited by 624 persons. An all-electric supply for the block is achieved by the use of air source heat pumps for space heating and electric instant water heaters combined with drain water heat recovery in showers for domestic hot water. The resulting load profile for all energy except EV charging demand in the block is given in Fig. 1 as a reference scenario. The coverage by PV yield from the roofs is plotted as a reference for clear winter and summer days respectively.

On weekdays the camelback curve typical for residential electricity use is exhibited, due to increased activity in the morning, before leaving home and again in the evening after common work/school hours. A slight hump around noon indicates cooking of meals at that time of day.

More relaxed and scattered behaviour takes over on Saturdays and even more on Sundays when the morning hump and the noon hump tend to merge, while the evening hump largely remains.

Peak loads are around or below 0.25 MW.



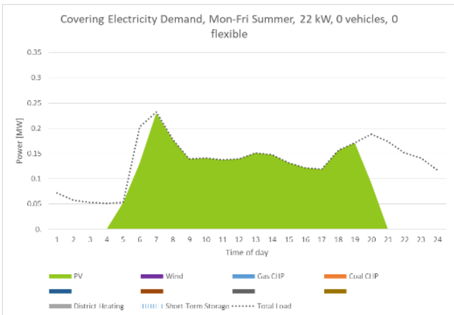


Fig 1.: Load curves for the case study block including all energy services except EV charging

In order to be able to study the impact of EV charging, the temporal distribution of arriving vehicles in a typical residential area was derived from detailed surveys in [Pinkofsky 2005]. Data in hourly resolution for normal weekdays, Saturday and Sunday was provided for use in the further investigation.

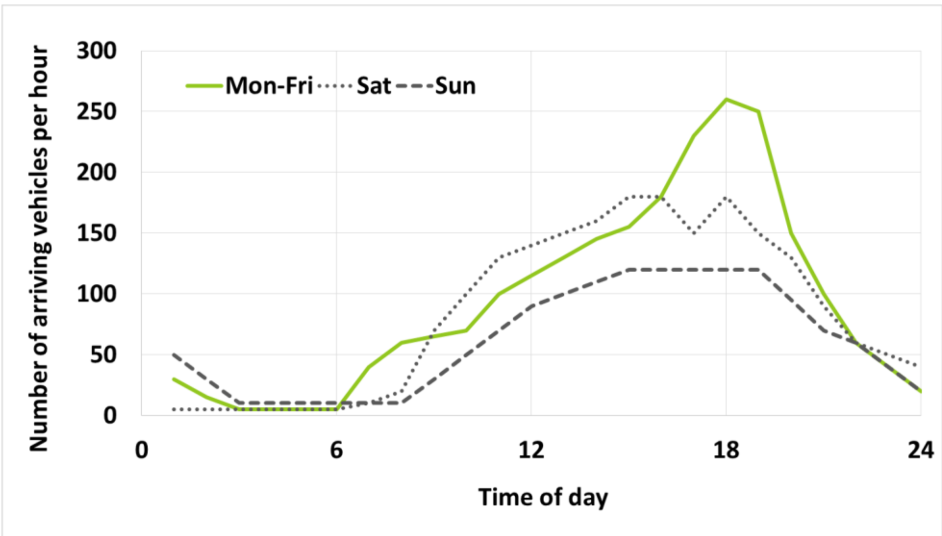


Fig 2.: Temporal distribution of arriving vehicles per time of day for different days of the week

The data illustrates typical habits in Germany but is also considered valid for the EU as a whole. After a nearly silent time during the late night some few persons return from night shifts or similar in the early morning. Shopping and other small chores result in some traffic during the day while the bulk of cars returns in the evening, after work hours are completed. Some more trickle in during the later evening.

On Saturdays there is a tendency for decreased activity that is also more evenly distributed over the daytime, an effect that even increases on Sundays.

This information was fed into the tool [**districtPH**] that was developed within the EU FP7 **SINFONIA** project (GA#609019).

The study further assumes the average mileage of 15000 km/year, of which 50 % are assumed to be recharged at home. 0.37 cars per person are owned by the inhabitants of the block (totaling 230 vehicles), public transport is assumed a viable alternative. Vehicles are characterized by an effective energy consumption of 20 kWh/100 km. The average daily energy use for EV charging per vehicle is thus

$$15000\frac{km}{a}\cdot 50\% \ \cdot 20\frac{kWh}{100km} \div 365\frac{d}{a} = \underline{4\frac{kWh}{d}}$$

If the normal household electricity consumption amounts to the typical 4-8 kWh/d the EV charging adds a meaningful 50-100% increase.

The total number of cars, power capacity of chargers (3 kW single phase and 11 kW & 22 kW three phase), and, for a transitional period, the share of EV were varied. First, the transitional situation with a share of 50 % EV is considered (115 electric cars).

It was assumed, that cars are connected to the charger upon arrival. It was further assumed that arriving vehicles are connected to the charger equally distributed across the respective hour of the day. The mean charging duration can then be calculated and a load profile for EV charging be determined.

As a first case the use of cheap single phase 240 V, 16 A chargers with a capacity of 3 kW and a share of 50 % EV without flexibility option or district battery was simulated; the resulting load curves are given in fig. 2. For reference the PV yield potential for typical winter and summer days is also given.

Peak loads increase slightly and the weekday evening hump becomes more distinct as the majority of cars are charged after returning home in the late afternoon or evening (cf Fig. 2). It now reaches roughly the same peak power as the morning hump. Otherwise no significant changes compared to the base case can be observed.

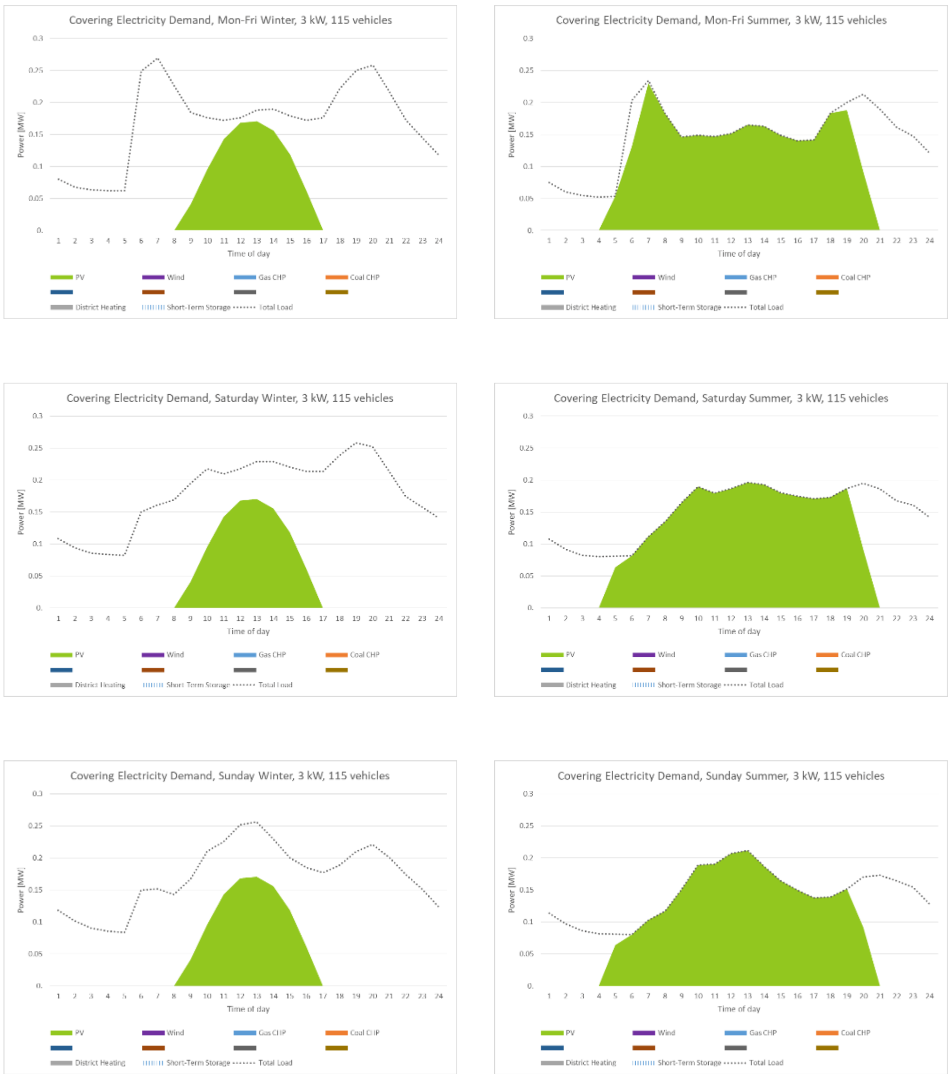


Fig 3.: Load curve for the block with EV charging, 3 kW chargers, 50% EV

The load on weekdays is still following the camelback pattern. EV charging does not change the picture here. In the weekend this pattern with morning and evening peaks becomes blurred as daily routines are less defined. In the winter the very limited PV yield in central Europe (ca. latitude 52.5° N) cannot cover the peak load and even less the daily energy demand. As all buildings meet the ***Passive House Standard*** and thus have a minimal space heating demand the on-site renewables can still provide some bit. For buildings with higher heating demand a much higher level of energy consumption would render a renewable energy supply much more difficult. During summer, however, even without batteries or flexibility options a large share of the daily energy demand can be met by on-site PV yield.

It was also tested how the load curve changes, if the charger capacity is increased to 11 kW (three phase 400 V, 16 A). As a result the load curve is slightly steeper as the charging processes take place more quickly, but the difference is very small.

Since the average energy demand for EV charging is low at just 4 kWh/d and charge duration thus is only short, the difference in the load profiles is not very significant as can be seen in Fig. 4. Only weekdays are shown.

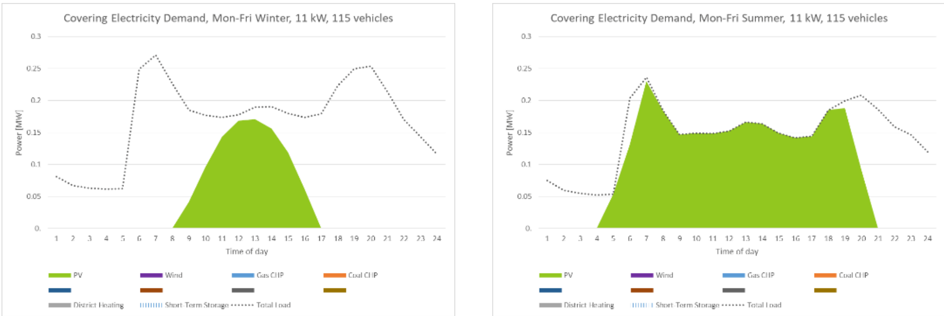


Fig 4.: Load curve for the block with EV charging, 11 kW chargers, 50% EV

Even if the charger capacity is increased to 22 kW, which is deemed the highest practical capacity for a residential application, the situation does not noticeably change, for the same reason as before (Fig. 5).

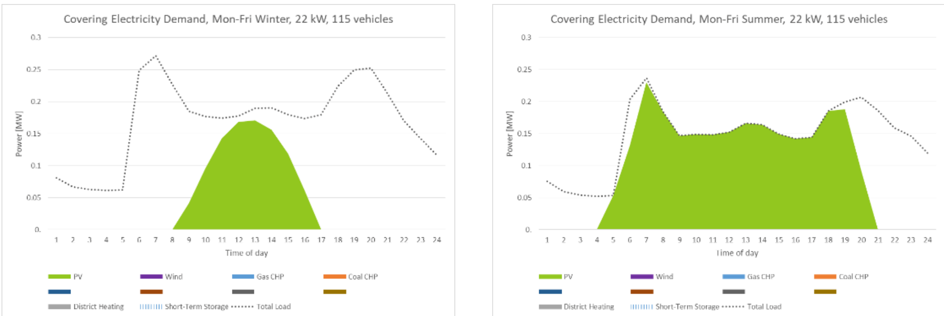


Fig 5.: Load curve for the block with EV charging, 22 kW chargers, 50% EV

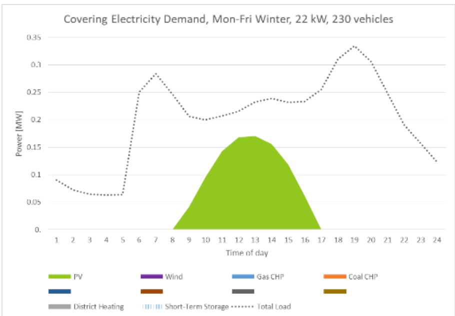
This suggests a first conclusion for EV charging:

While EV's present only 50 % of all vehicles the charger capacity is not a significant variable for the resulting grid load in a residential districts perspective.

As charging with 3 kW only can be tedious in the event of higher total charge demand, as happens from time to time, it is considered probable that installing 11 kW chargers will be the preferred solution, whereas 22 kW requires more expensive cables and components that will be poorly used and may therefore be economically unfavourable.

The same effects were then studied for a future scenario with 100 % EV. As the charger capacity had little significance before only the 22 kW case (most critical) is presented here. Naturally, the total load increases with the number of EV in use on the assumption that vehicles are used in a similar way. However, the increase is not dramatic in the context of the total energy demand.

On the other hand discontinuities like the evening hump become even more pronounced, now growing larger than the traditional morning hump and peaking at ~330 kW. This presents an increase in peak load on the order of one third, which is unfavourable for the grid operation, particularly in the winter, as can be seen in Fig. 6. In the summer the total load is lower due to the absence of space heating. The peak is below 300 kW but the evening hump is also larger than the morning hump.



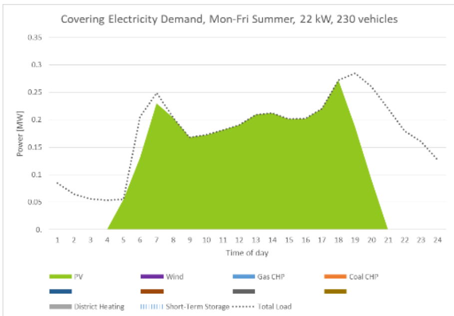
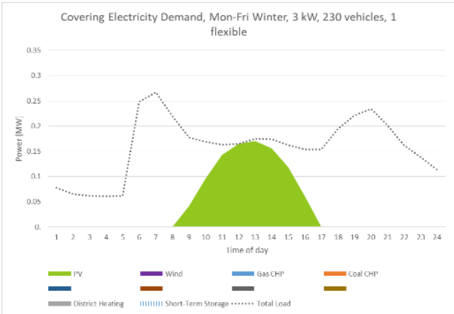


Fig. 6: Load curve for the block with EV charging, 22 kW chargers, 100 % EV

Once only EV's are present the charger capacity is a significant variable for the resulting peak grid load in the winter.

Demand-Response technology can help shift some or most of the EV charging to times with a low demand/supply proportion. This is tested in the study by a „flexible time of day" load-distribution: EV's are assumed to be charged at off-peak times of the day when the grid load is low. The presented case assumes 100 % of all domestic charging activity to be temporally flexible to highlight the potential; in real life this extreme is, of course not likely to occur.



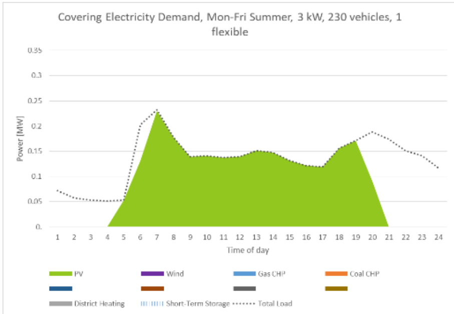


Fig. 7: Load curve for the block with EV charging, 3 kW chargers, 100 % EV and full temporal flexibility for charging

As can be studied in Fig. 7 charging EV off peak times can cut the evening hump considerably and thus support a stable grid. Even if some small part of the charging were not flexible, the load would remain manageable. In turn the electricity demand at off-peak times will rise, to cover the charging energy. It is not given in the plot, as this study did not focus on modelling the different flexibility mechanisms. But probable times can be clearly identified in the late evening and night (22:00h – 05:00h). Particularly in the winter, when wind power will dominate the supply, this schedule is attractive, whereas in the summer the dominant PV power may suggest a window centered on noon (09:00 h – 17:00 h) to make good use of the abundant solar energy. This does, of course, collide with the daily chores of most people who leave for work, school etc. during the day, calling for storage to shift the energy in time.

Alternatively, a (fully usable) battery storage capacity of 1.5 MWh on the district level was tested. For the 450 households this means a 3.3 kWh share in storage capacity, following the rule of thumb of covering from half a day to a full day of normal household electricity demand.

As illustrated by the results in Fig. 8 the battery does not help at all during the winter when PV yield is minimal and the battery cannot be charged (but load- and energy management are most critical). Here, the temporal flexibility option is the only realistic way to unburden the power grid. During the summer, however, the battery makes a 100 % supply with on-site PV electricity viable in clear weather.

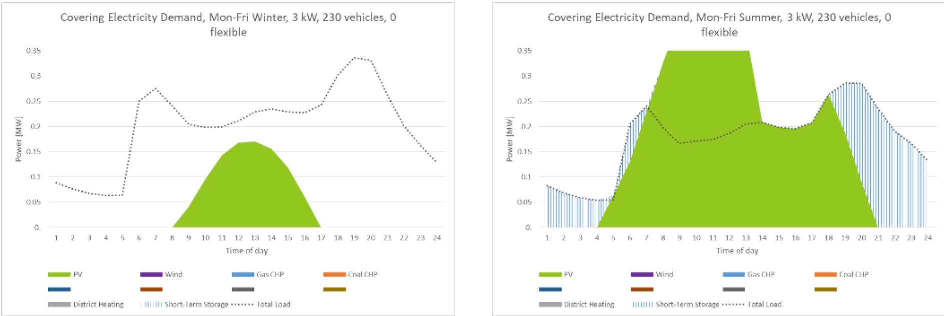


Fig. 8: Load curve for the block with EV charging, 3 kW chargers, 100 % EV and 1.5 MWh battery

This suggests another conclusion for EV charging:

Once EVs become the norm it will be important to shift EV charging to the (nightly) off-peak hours in the winter whenever tolerable to limit the grid load and avoid uneconomical grid capacity expansion.

Electricity tariffs for EV charging could incentivise this behaviour. Technologically the temporal shifting poses no particular challenges as the CCS charging standard with power line communication (based on HomePlug GreenPHY) between vehicle and charger/grid can already provide this functionality.

Regarding the limitation of grid loading by peak production of PV systems in the summer Fig. 8 already gives a clue: A reasonably sized battery storage can facilitate a near 100 % supply with on-site electricity in favourable conditions. However, shortly after noon the battery is fully charged. The peak production meets a lull in consumption before the evening hump rises. As a result the PV system feeds its full rated power into the grid at noon and results in very high loads on the power transmission systems. This suggests a conclusion for a storage approach on household and district level alike:

Unless battery storage is expanded to uneconomic capacity, that sits idle most of the time, the peak feed-in power in the summer can be a critical situation even in a district storage approach.

THE IMPACT OF BATTERY STORAGE ON GRID LOAD IN A DISTRICT PERSPECTIVE

One important conclusion from the previous chapter was that some battery storage capacity on the district level can indeed succeed to supply the block with on-site electricity during the summer almost exclusively. However, economic constraints prevent a storage capacity of more than about one half-day to one day's equivalent of electricity use during summer in a residential context. The reasons have been researched as part of the outPHit project and are detailed in [Ochs, 2022]. The essence is that storage capacity beyond the stated limit does not increase the self-sufficiency to a relevant degree unless its storage duration would facilitate a seasonal (long-term) shift of energy. Battery storage cannot provide this characteristic and chemical energy storage (e.g. based on electrolytic generation of hydrogen) is technologically not mature for small scale applications and thermodynamically inefficient, therefore prohibitively expensive.
Building on these known constraints the districtPH model already introduced above assumes an effective storage capacity[1] of 1.5 MWh in total or an average of 3.3 kWh per apartment, respectively. In the following the effect of this district storage capacity will be illustrated by 10-day periods in all four seasons.

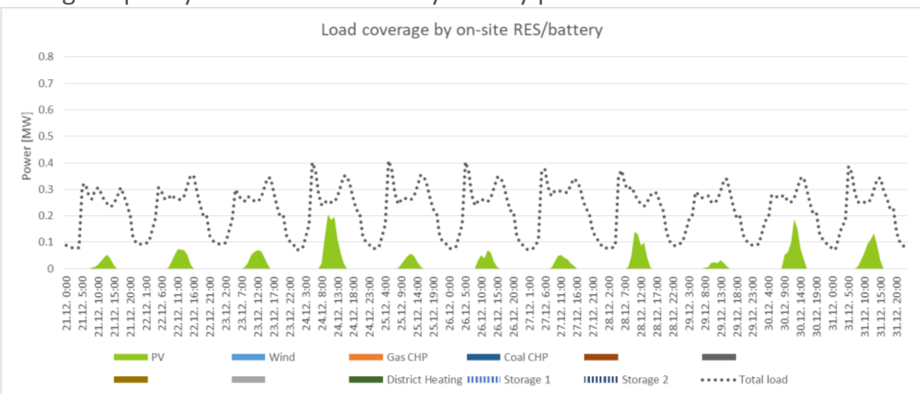


Fig. 9: Load curve for the block with EV charging, 3 kW chargers, 100 % EV, no flexibility and 1.5 MWh battery for a 10-day period in the <u>winter.</u> Peak load ~ 400 kW

The findings already discussed for Fig. 8 for a weekday still hold for the longer period of time presented in Fig. 9. Even on sunny days the PV system can supply only a small fraction of the energy demand within the block. The battery storage

[1] As deep cycling lithium-ion batteries decreases the life span drastically, only about 70% of the nominal capacity will be used, thus the nominal capacity must amount to 2.15 MWh or 4.75 kWh per flat.

has no effect at all as there is never any surplus yield to charge it. The monetary investment into storage cannot earn any interest during the winter.

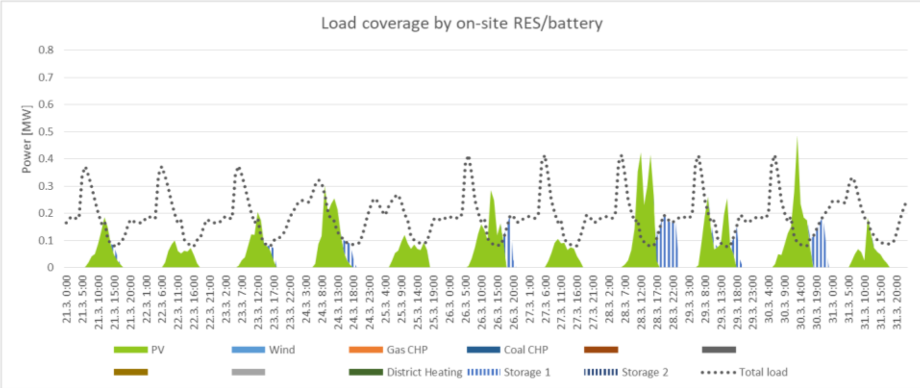


Fig. 10: Load curve for the block with EV charging, 3 kW chargers, 100 % EV and 1.5 MWh battery for a 10-day period in the <u>spring.</u> Peak load ~ 400 kW

During spring the space heating energy demand decreases and the solar irradiation increases (Fig. 10), both in intensity and duration. The power demand is generally reduced and concentrates in late night/early morning hours for some space heating. On sunny days a surplus PV yield remains that can be stored in the battery for use in the evening. Still the effect is limited and large amounts of electricity must be supplied by the grid.

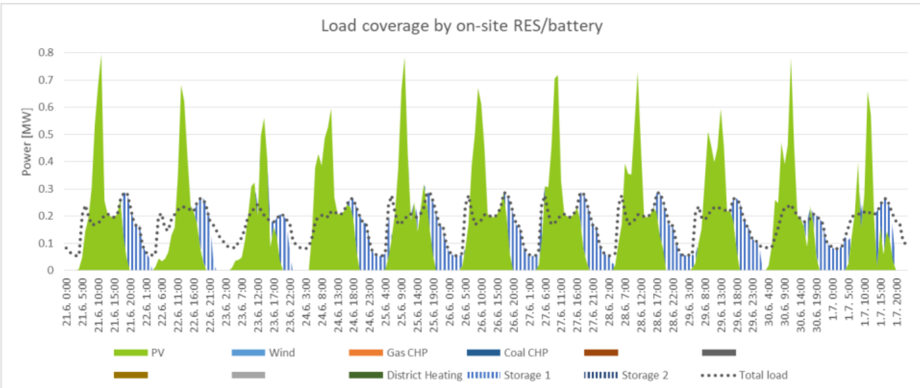


Fig. 11: Load curve for the block with EV charging, 3 kW chargers, 100 % EV and 1.5 MWh battery for a 10-day period in the <u>summer.</u> Peak load ~ 300 / 800 kW

As can be studied in Fig. 11 the summer has the lowest electricity load and the PV system supplies a large amount of energy. The battery capacity is now useful to shift energy from the day to the night, and thus the district's energy demand can be covered with on-site RE for long periods of time. Short periods still remain when energy must be supplied from the grid- the district is not autonomous. The PV peak power is quite high, and, after the battery is fully charged, is fed into the grid. This causes a challenging situation for grid operators in the summer and calls for flexible loads on the grid level. Electrolysis of water for chemical seasonal energy storage in large units are the logical solution for a 100 % RE scenario.

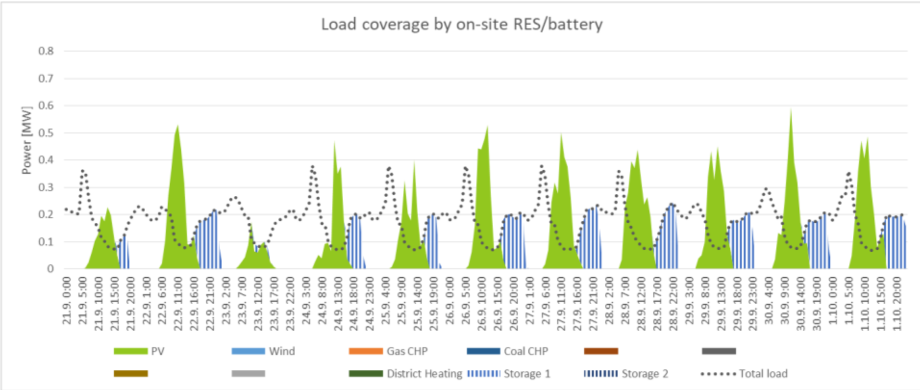


Fig. 12: Load curve for the block with EV charging, 3 kW chargers, 100 % EV and 1.5 MWh battery for a 10-day period in the autumn. Peak load 400 / 500 kW

In the autumn period shown in Fig. 12 a similar situation as presented for the spring in Fig. 10 prevails and the battery storage is useful, but no longer sufficient for a nearly full on-site load coverage as days become shorter, colder and less sunny.

Wrapping up the observations across the seasons it becomes clear that the battery storage can indeed be utilised to shift solar energy from day to night in summer and unburden the power grid from most of the *supply load*. This load, however, is reduced in comparison to what is required during the winter peaks anyhow, and these effects were even much more pronounced in districts with less energy efficient buildings. On the other hand serious *feed-in loads* must be handled by the grid despite the presence of battery storage. For an energy efficient district with ***EnerPHit*** or ***Passive House*** standard and hence a very low space heating demand, this summer feed-in load will be about twice as high as the peak load in the winter. Here can lie a challenge for grid operators.

In a residential district with very energy efficient buildings the peak feed-in power from PV systems in the summer can present the design load scenario for the grid connection capacity.

GRID CONNECTION CAPACITY OPTIMISATION POTENTIAL

Currently there exist no optimised engineering rules for the grid connection of highly energy efficient districts or buildings. [DIN 18015-1] suggests a good 300 kW capacity for 450 households with electric preparation of domestic hot water (Fig. 13). Explicit allowances for heat pump heating, EV charging and PV systems would be added on top such that no constraints need to be expected from the grid connection capacity design. Nonetheless, these practices will miss an obvious optimisation potential and force provisioning grid capacity that is seldom used.

For the dashed line in Fig. 13, therefore, a hypothetical allowance for a space heating load of 10 W/m² (as is typical for Passive House buildings) is added, assuming heat pumps with a conservative COP of merely 2.
A linear function is superimposed as the weather will force a 100 % coincidence for space heating.

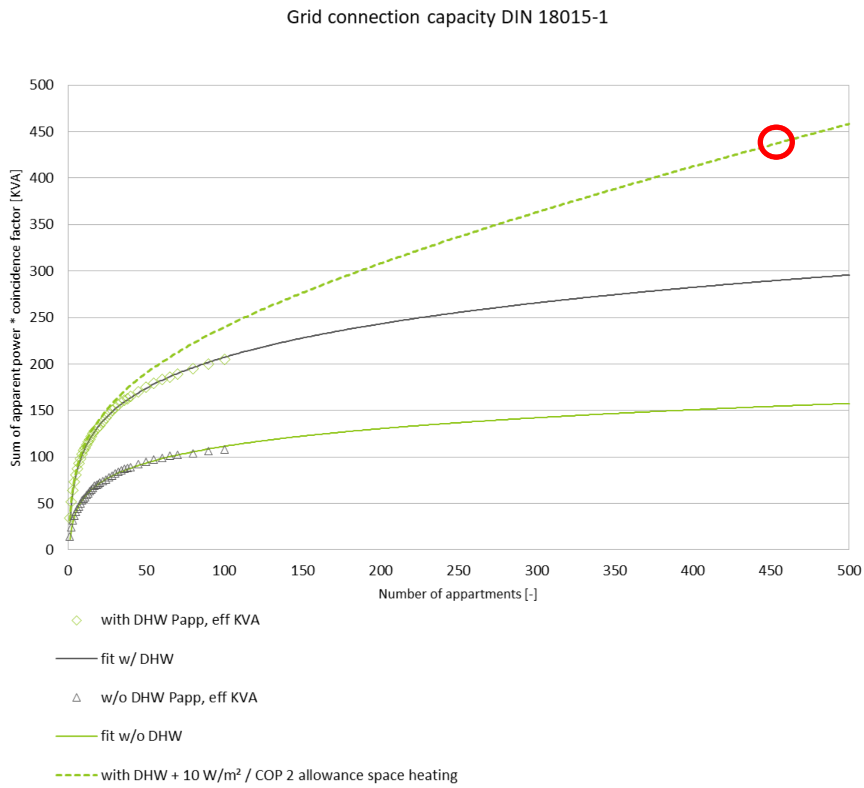


Fig. 13: Design loads for household electricity with and without electric instant DHW heating according to DIN 18015-1 (marks), with extrapolation by the author

For the 450 flats of the case study a design load of 436 kW is then estimated, just matching the expected winter demand with a margin of about 10 %, including 3 kW EV-charging without flexibility. It goes without saying that the PV-peaks in the summer must be cut in order to minimise the grid connection capacity in such a drastic way.

The fit functions for the extrapolation resemble the form $f(x) = a + b \cdot x^n$ with parameters listed in the following table.

	a	b	n
With DHW	-206.364	237.497	0.120441
Without DHW	-176.023	187.723	0.092505

It is interesting to note, that EV charging with low power (3kW) seems to be covered by the current household electricity load assumptions.

In areas with considerably less efficient buildings covering the much higher space heating loads with heat pump technology in the winter (compare e.g.

[Schlemminger e.a. 2022]), along with EV charging, will necessarily demand a grid capacity expansion [Gupta 2021]. This is very costly but brings about the advantage that the reinforced infrastructure will be able to handle high summer feed-in peaks, too [Hartvigsson e.a. 2021].

Careful design should explore the detailed trade-offs and optimisation potential between maxing out the PV energy feed-in and limiting the expenses on the infrastructure capacity.
In the summer time it may be helpful to avoid charging the battery storage in the morning and, after finishing, redirect the full PV yield to the grid. It might be preferable to devise controls that will both charge the batteries *and* feed into the grid at the same time, each with limited power. By applying this *peak-shaving* approach to the feed-in load the grid can be unburdened and enough electricity will still be stored for use in the evening.

On this condition new, optimised engineering rules for grid connection capacity could be devised for areas with very energy efficient buildings, that allot only the required capacity. The saved capacity can then be used to serve other customers. The process can be further incentivised by increasing the demand charge.

Large, more remote PV plants are less prone to overload the electricity distribution system as they are directly connected to a higher level of the grid and can offload power to large electrolysis plants more easily as required. Further, appropriate strategies for the desired 100 % RE supply in the future include an important role of large scale wind power development for the winter energy supply.

ECONOMIC CONSIDERATIONS, DISTRICT AND STORAGE APPROACH

All battery storage concepts suffer from the fact, that they can be fully used only in the summer, about 1/3 of the year. During another 1/3, split between spring and autumn the storage can contribute some benefit, but is never fully used while in the winter, also 1/3 of the time, there is never enough PV-yield to charge the battery at all. Such poor usage is a severe disadvantage for any investment. If it cannot be offset by extremely cheap prices, or other concepts in the wider scope offer additional benefit, it is not economically viable. This could, for example, be a reasonable number of charge/discharge cycles in the winter time when surplus wind power is stored during storms. However, this might be more effectively implemented at a higher grid level where storage capacity can be built, operated and exploited most effectively and without complex tariff models and controls.

Form the previous chapters it follows also that battery storage for RE from on-site PV systems works best in the summer, when abundant yield meets a reduced demand and grid electricity prices are high. Following the rules of a free market, however, it can be expected that electricity during this season will generally be particularly cheap in the future. Even under the current (2024) price regime a battery storage system can only be economically viable if the investment cost is below ~800 €/kWh. This finding is backed up by calculations with the [PVecon] tool developed in outPHit, cf. Fig. 14 (from ***D.4.2_PV Economy Evaluation Kit with Tool***). Therefore, a per-household approach to energy storage is unlikely to succeed, space and maintenance requirements add to this, too.

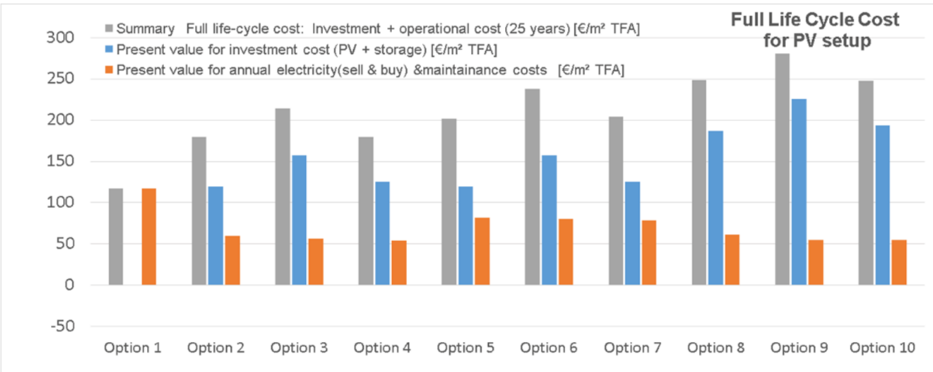


Fig. 14: Life-cycle cost overview from PV econ for various combinations of PV systems and storage options.

Option 1:	no PV modules	
Option 2:	44 south oriented PV modules,	no storage
Option 3:	44 south oriented PV modules,	battery
Option 4:	44 south oriented PV modules,	small thermal st.
Option 5:	22 west + 22 east oriented PV modules,	no storage

Option 6:	22 west + 22 east oriented PV modules,	battery
Option 7:	22 west + 22 east oriented PV modules,	small thermal st.
Option 8:	44 south oriented 25 wall mounted PV modules,	no storage
Option 9:	44 south oriented 25 wall mounted PV modules,	battery
Option10:	44 south oriented 25 wall mounted PV modules,	small thermal st.

A district perspective, on the other hand, offers a smoothing of the total load curve due to numerous effects of coincidences of different electricity uses. This facilitates a more intensive use of storage capacities, with impact on the economy. Plus, on a district scale (e.g. at 1.5 MWh effective capacity as in the case study, translating to about 5-6 h autonomy in the summer) economies of scale can be used and professional maintenance be ensured. This can in turn benefit the economy again, as it tends to extend the useful life of the storage system.

As the previous chapter could point out, a combination of district *and* battery storage can add special virtues in terms of load management, particularly in shaving the PV feed-in peaks in the summer and thus relieving the grid from a serious challenge. Adapted engineering rules for the grid connection of very energy efficient buildings may offer better management of existing bottlenecks in the electricity distribution grid.

If a suitable business case can be defined a district storage nearby the consumers can also assist grid stability in the winter if its charge is increased during storms and decreased in short peak load conditions. However, as the demand is increased systematically in the winter due to cold and overcast weather, for long periods of time, wind power and a meaningful contribution from seasonal storage must necessarily fill the majority of the gap. This leaves only limited room for the battery storage with only about 3.5 h of autonomy under the increased winter demand.

If the main effect is indeed peak shaving, both in the summer and in the winter, a battery storage will have to be considered an element of the distribution grid. Hence, it is less likely to be implemented by prosumers but rather by utilities that add this element e.g. to the low voltage substations that connect to the higher voltage levels as well as on the mid-voltage regional grid level. Typical capacities here range from 250 to 1000 kVA, so our case study district is a good example even in this regard. The detailed purpose and requirements for battery storage may well change in the process of the energy transition until the year of 2050.

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