Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

HEAT PUMP, SOLAR PV AND BATTERY SYSTEMS MODELLING

The development of simulation and optimization models for energy-flexible operation in the built environment

ZEN MEMO No. 49 – 2023

Benjamin Manrique Delgado, Harald Taxt Walnum, Igor Sartori | SINTEF Community

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Preface

Acknowledgements

This memo has been written within the Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN). The authors gratefully acknowledge the support from the Research Council of Norway, the Norwegian University of Science and Technology (NTNU), SINTEF, the municipalities of Oslo, Bergen, Trondheim, Bodø, Bærum, Elverum and Steinkjer, Sør-Trøndelag county, Norwegian Directorate for Public Construction and Property Management, Norwegian Water Resources and Energy Directorate, Norwegian Building Authority, ByBo, Elverum Tomteselskap, TOBB, Snøhetta, ÅF Engineering AS , Asplan Viak, Multiconsult, Sweco, Civitas, FutureBuilt, Hunton, Moelven, Norcem, Skanska, GK, Caverion, Nord-Trøndelag Elektrisitetsverk - Energi, Smart Grid Services Cluster, Statkraft Varme, Energy Norway and Norsk Fjernvarme.

The Research Centre on Zero Emission Neighbourhoods (ZEN) in Smart Cities

The ZEN Research Centre develops solutions for future buildings and neighbourhoods with no greenhouse gas emissions and thereby contributes to a low carbon society.

Researchers, municipalities, industry and governmental organizations work together in the ZEN Research Centre in order to plan, develop and run neighbourhoods with zero greenhouse gas emissions. The ZEN Centre has nine pilot projects spread over all of Norway that encompass an area of more than 1 million m2 and more than 30 000 inhabitants in total.

In order to achieve its high ambitions, the Centre will, together with its partners:

- Develop neighbourhood design and planning instruments while integrating science-based knowledge on greenhouse gas emissions;
- Create new business models, roles, and services that address the lack of flexibility towards markets and catalyze the development of innovations for a broader public use; This includes studies of political instruments and market design;
- Create cost effective and resource and energy efficient buildings by developing low carbon technologies and construction systems based on lifecycle design strategies;
- Develop technologies and solutions for the design and operation of energy flexible neighbourhoods;
- Develop a decision-support tool for optimizing local energy systems and their interaction with the larger system;
- Create and manage a series of neighbourhood-scale living labs, which will act as innovation hubs and a testing ground for the solutions developed in the ZEN Research Centre. The pilot projects are Furuset in Oslo, Fornebu in Bærum, Sluppen and Campus NTNU in Trondheim, an NRK-site in Steinkjer, Ydalir in Elverum, Campus Evenstad, NyBy Bodø, and Zero Village Bergen.

The ZEN Research Centre will last eight years (2017-2024), and the budget is approximately NOK 380 million, funded by the Research Council of Norway, the research partners NTNU and SINTEF, and the user partners from the private and public sector. The Norwegian University of Science and Technology (NTNU) is the host and leads the Centre together with SINTEF.

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Abstract

This memo describes the implementation of calculation models for the operation of heat pumps, solar photovoltaic (PV) panels, and electric batteries within the FLEXor energy optimization tool. The heat pump model can be used to implement ground-source heat pumps, air-source heat pumps, and air-to-air heat pumps. There are two efficiency calculation modes: a simplified model where constant coefficients of performance as given by the user, and a dynamic, temperature-dependent model, where the coefficients of performance are calculated based on source and supply temperatures according to the NS3031 standard. There are also two calculation methods available for the PV system; the first method consists of pre-calculated user-given specific production profiles where the user provides a time-series of electricity generation, while the second method uses geographical and weather data to calculate the production profiles using the Python library Global Solar Energy Estimator. The battery model is a state space model with two variables: charging and discharging of the battery, and independent charging and discharging efficiencies can be implemented. These three models, as well as FLEXor, are implemented in Python.

FLEXor is a simulation and optimization tool for energy generation, demand, and use in the built environment. It is implemented in Python. All the sub-models in FLEXor, including the ones described in this memo, are designed to be self-standing. Thus, they are self-contained, and do not include the control and/or optimization of other components. However, these models are to become part of a larger high-level model, FLEXor, that may include DHW tanks, electric vehicles, and other different components. Therefore, the models are designed to be i)linear, ii)in state space form (when applicable), and iii)transparent. This will allow the high-level model to be fast, lean, relatively simple, and able to leave a component out of the optimization process if necessary.

Contents

1 Framework

1.1 Heat pump

Heat pumps in buildings are typically used as decentralized heat generation components meant to reduce the net energy demand of the building, as they require less energy input as compared to other heat generation technologies. Heat pumps can be used to cover most of the space heating demand and part of the domestic hot water (DHW) heating demand, although not all types of heat pumps can cover the latter. Since the initial investment costs of heat pumps are considerably higher than other technologies, such as direct electric heaters, they are typically designed to cover a fraction of the expected peak space heating demand; to cover the rest of the demand (i.e. days with very high space heating demand), a top heating system is typically installed to assist the heat pump. This low-investment technology usually runs a limited number of hours in the year, but also serves as backup system in case the heat pump fails or needs maintenance.

1.2 Solar PV

Photovoltaic (PV) systems in buildings are typically used as decentralized energy generation components meant to reduce the electricity import from the grid and to reduce the net energy demand of the building. Moreover, if electric vehicles (EV) or batteries are present, the energy generation from the PV system can be stored in those components, either to operate the components themselves – as is the case in the EV – or to be used later in to operate other building services, such as space heating or DHW preparation. The models presented in this memo exclusively address the electricity generation by the PV system; its utilisation, storage or exchange with the grid is calculated by FLEXor, the overarching energy simulation and/or optimization model.

Two models for PV generation have been implemented, giving users the option to supply pre-calculated time-series (or profiles) of electricity generation, or to let the model calculate the time-series. The first option, named *specific production* model, gives the user more freedom to test different PV generation scenarios, as they have the option to modify the generation profiles to fit specific needs. For example, the user can give specific production profiles that correspond to years with very high or very low annual generation, focus on peak days or weeks, or even implement unique situations, such as sudden drops or increases in generation.

The second option, instead, named *calculation* model, uses geographical and meteorological data and parameters of the PV system to calculate the generation profile. Thus, the user does not need to calculate the generation profiles separately. This approach can be easier for the user, and it is suitable when there are no special conditions or requirements on the electricity supply by the PV system.

1.3 Battery

Electric batteries in buildings are typically used as decentralized energy storage components meant to store surplus electricity generation from onsite PV systems. That is, when the generation from the PV systems is higher than the electricity demand of the building, the excess is stored in the electric battery for later use. This can help to increase the share of PV generation that is used onsite, which can be beneficial for both the building owner and the grid operator. For the building owner it is more economically attractive to use the generation onsite than to sell it, since the income from selling electricity to the grid is typically lower than the cost of buying electricity. Moreover, through smart control systems, it can be possible to use the energy stored in the battery when electricity prices are high, or to use it during peak demand hours to reduce grid tariffs on peak power demand (*effektledd* tariffs). For the grid operator the surplus from a single, small PV system may be negligible, but as PV systems become more popular, the simultaneous export of surplus from several systems may require additional control systems and infrastructure, which can be costly.

2 Models

2.1 Heat pump

The heat pump model, at its core is a simple calculation as shown in Equation 1 where y_{in} is the electricity input to heat pump and q_{SH} and q_{DHW} are the heat output from the heat pump intended for space heating and for DHW heating, respectively, and COP_{SH} and COP_{DHW} are the coefficients of performance of the heat pump for supplying heat intended space heating and for DHW heating, respectively. The operation of the heat pump is constrained by the conditions given in Equations 2, 3 and 4, where $Q_{HP,SH}$, $Q_{HP,DHW}$, and Q_{HP} are the heat pump capacities for delivering heat intended for space heating, for DHW heating, and in total, respectively. The two sub-models – constant performance model and temperature-dependent model – mainly differ in how COP_{SH}, COP_{DHW}, $Q_{HP,SH}$ and $Q_{HP,DHW}$ are calculated.

Eq. 1 $$y_{in}(t) = \frac{q_{SH}(t)}{COP_{SH}(t)} + \frac{q_{DHW}(t)}{COP_{DHW}(t)}$$

Eq. 2 $$q_{SH}(t) \leq Q_{HP,SH}(t)$$

Eq. 3 $$q_{DHW}(t) \leq Q_{HP,DHW}(t)$$

Eq. 4 $$q_{SH}(t) + q_{DHW}(t) \leq Q_{HP}(t)$$

2.1.1 Constant performance model

The constant performance model requires only three input parameters: the installed capacity of the heat pump Q_{HP}, a nominal COP for space heating, and a nominal COP for DHW heating. In this model, none of the COPs nor the heat pump capacities are temperature dependent. COP_{SH} and COP_{DHW} are constant values given by the user, whereas the heat pump capacities are calculated based on Equation 5, which simply states that the total heat output of the heat pump cannot exceed its installed capacity.

Eq. 5 $$Q_{HP,SH}(t) + Q_{HP,DHW}(t) \leq Q_{HP}$$

2.1.2 Temperature-dependent performance

The temperature-dependent model requires the three input parameters given in the constant performance model – installed capacity and two nominal COPs – plus three more: temperature of the heat source, supply temperature for space heating, and supply temperature for DHW preparation. The model uses performance tables for heat pumps from the Norwegian Standard SN-NSPEK 3031:2021 for the calculation of buildings' energy performance. The tables for the calculation of GSHP, ASHP, and A2A heat pumps are shown in Table 1. For each timestep during the optimization, both the heat delivery capacities and the COPs for space heating and for DHW heating are calculated by multiplying the installed capacity of the heat pump by the factors interpolated based on the table. There are two considerations with regards to the A2A heat pump. First, this type of heat pump cannot deliver heat for DHW heating. Second, the supply temperature is assumed to be a constant value of 20° C.

Two optional input parameters can be given: the maximum coverage factor for space heating and the maximum coverage factor for DHW heating. These parameters can be used to specify a limit on the contribution of heat by the heat pump to the total demand for space heating or DHW heating. This limit is set and valid for each timestep, not for the sum of the heat demand during the calculation interval.

Table 1: Table for the calculation of heat delivery capacity and COP for GSHP, ASHP and A2A heat pumps, based on SN-NSPEK 3031:2021.

		Q_{HP}			COP		
		T_{sou}			T_{sou}		
	T_{sup}	**-5**	**0**	**5**	**-5**	**0**	**5**
GSHP	35	0.92	1	1.15	0.78	1	1.1
	55	0.82	0.91	1	0.43	0.58	0.73
	T_{sup}	**-15**	**2**	**7**	**-15**	**2**	**7**
ASHP	35	0.55	0.73	1	0.48	0.71	1
	55	0.44	0.65	0.89	0.32	0.45	0.68
	T_{sup}	**-15**	**2**	**7**	**-15**	**2**	**7**
A2A	20	0.54	0.79	1	0.62	0.72	1

2.2 Solar PV

2.2.1 Specific production model

The specific production model requires only three inputs: an identifier (or name), a multiplier (area or installed capacity), and a time-series (electricity generation profile). The model reads the time-series and multiplies it by the given multiplier. By default, the multiplier is given as area of the PV system in m^2, and the time-series given as Wh/h/m^2; however, it is also possible to give the installed capacity of PV in kWp (kilowatt peak) and the time-series in Wh/h/kWp. The model does not perform any calculations for system losses. This includes typical losses during operation, such as inverter losses, and other sources of inefficiency, such as module degradation. The electricity generation profile supplied by the user should include these losses.

PVGIS

When using the specific production model, PVGIS is a readily accessible option for the pre-calculation of the electricity generation by a PV system. The Photovoltaic Geographical Information System PVGIS[1] is an online tool that allows users to get data on solar radiation and photovoltaic energy production at a specific location. The location can be defined by the user by giving coordinates or the name of the location, after which the solar radiation database and year(s) are chosen. The user can also define some of the PV system parameters, such as the installed peak power, its technology, system losses (as percentage) and orientation; this last parameter can also be optimized by PVGIS itself. Please refer to the model documentation for further details.

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[1] "JRC Photovoltaic Geographical Information System (PVGIS) - European Commission."

2.2.2 Calculation model

The calculation model uses the Global Solar Energy Estimator (GSEE)[2] library to calculate the electricity output from a PV system. This model requires other input data and parameters than what is required in the specific production model. Namely, the user must specify the geographical coordinates (latitude and longitude), panel tilt, azimuth, tracking and installed capacity, and give time-series of outdoor temperature, global horizontal radiation in W/m^2, and either diffuse horizontal radiation in W/m^2 or the fraction of global horizontal radiation that corresponds to diffuse radiation.

2.3 Battery

The state space model of the battery consists of one internal state – the state-of-charge (SoC) of the battery $\boldsymbol{Y_{SoC}}$ – and one input and one output – charging power $\boldsymbol{y_{charge}}$ and discharging power $\boldsymbol{y_{discharge}}$. The balance equation of the battery is shown in Equation 6

$$\textbf{Eq. 6} \quad \boldsymbol{Y_{SOC}(t+1) = Y_{SoC}(t) + \frac{y_{charge}(t)}{\eta_{charge} * CAP}\Delta t + \frac{y_{discharge}(t)}{\eta_{discharge} * CAP}\Delta t}$$

where η_{charge} and $\eta_{discharge}$ are the charging and discharging efficiencies, respectively, CAP is the battery capacity, and Δt is the model timestep. The system can be represented by a discrete state space model as

$$\textbf{Eq. 7} \quad \boldsymbol{x(t+1) = \mathrm{A}_d x(t) + \mathrm{B}_d u(t)}$$

where

$$\boldsymbol{x(t) = [Y_{SOC}(t)]}, \qquad \boldsymbol{u(t) = [y_{charge} \quad y_{discharge}]},$$

$$\boldsymbol{\mathrm{A}_d = [1]}, \qquad \boldsymbol{\mathrm{B}_d = \begin{bmatrix} \frac{\eta_{charge} * \Delta t}{CAP} & -\frac{\Delta t}{\eta_{discharge} * CAP} \end{bmatrix}},$$

where *x(t)* represents the state vector, and *u(t)* the input vector. The model is also ruled by the constraints shown in Equations 7, 8, and 9, where $Y_{SoC,min}$ and $Y_{SoC,max}$ are the minimum and maximum SoC set to zero and one by default, and y_{max} is the maximum charging and discharging rate.

$$\textbf{Eq. 8} \quad \boldsymbol{Y_{SoC,min} \leq Y_{SoC}(\mathrm{t}) \leq Y_{SoC,max}}$$

$$\textbf{Eq. 9} \quad \boldsymbol{y_{charge} \leq y_{max}}$$

$$\textbf{Eq. 10} \quad \boldsymbol{y_{discharge} \leq y_{max}}$$

3 Example results

3.1 Heat pump

The operation of a set of four heat pumps is calculated with given timeseries for outdoor temperature and for space heating and DHW heating demands in three types of buildings: a House, an Apartment building, and a Commercial building. The input parameters for the four heat pump setups are given in Table 2; the FIXED heat pump has constant COP and capacity, while all the rest have temperature-dependent COP and capacity. These COP values have been calculated based on nominal values from heat pump manufacturers. The installed capacities of the heat pumps and top heating system per building

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[2] Pfenninger and Staffell, "Long-Term Patterns of European PV Output Using 30 Years of Validated Hourly Reanalysis and Satellite Data."

type are shown in Table 3. In this example, the installed capacity of the heat pump was set to 50% of the peak load of space heating. The performance of the heat pumps in the modelled House during a test period is shown in Figure 1, where the outdoor temperature is also shown as a dashed black line. The seasonal system COP (SCOP) of the heat supply systems – comprising a heat pump and an electric heater as top heating component – are shown in Table 4 for the three building types at two supply temperature levels for space heating, 55° C and 35° C, to highlight the effect of the supply temperature on the heat pump COP. The SCOP is calculated as the ratio between the total heat demand of the building (SH + DHW) and the total electricity use of the heat pump and top heating component. Table 5 shows the percentage of the SH demand that is covered by the heat pump in each system type.

Table 2: Common input parameters for four setups of heat pumps.

	FIXED	GSHP	ASHP	A2A
COP_{sh}	3	4.7	4.6	4.5
COP_{dhw}	3	4.7	4.6	-
T_{sou}	-	3	Tout	Tout
$T_{sup,sh}$	-	55/35	55/35	20
$T_{sup,dhw}$	-	55	55	-

Table 3: Installed capacities of heat pumps and top heating systems per building type, in W.

	Heat Pump	Top- & backup heating system
House	3 350	6 700
Apartment	27 100	54 200
Commercial	21 500	43 000

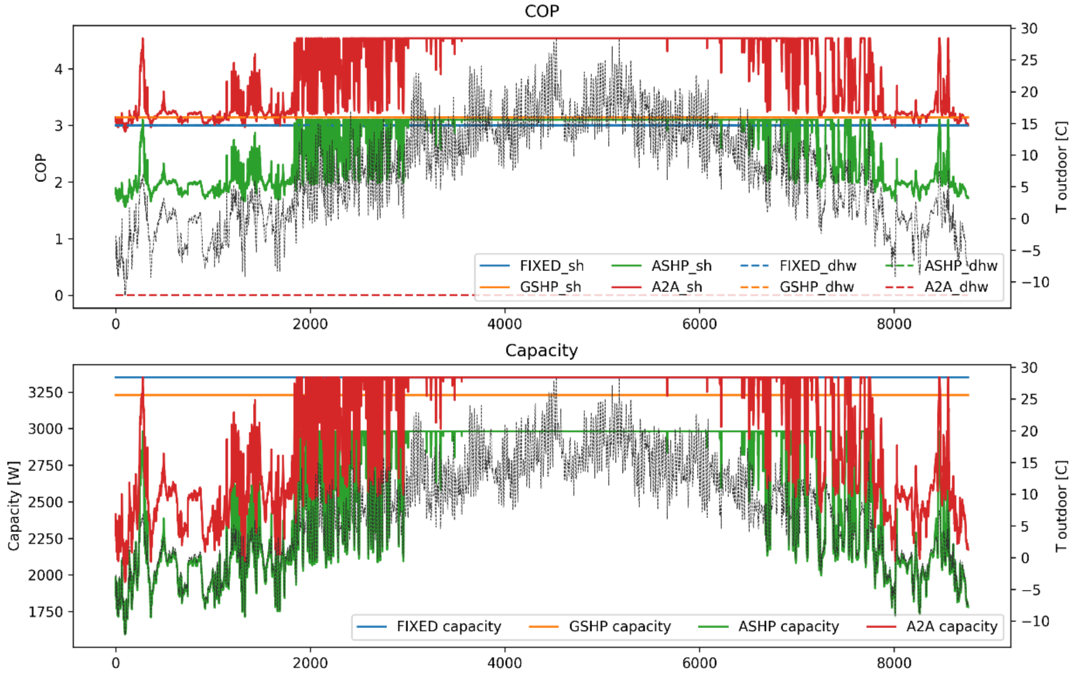

Figure 1: Example operation of four types of heat pumps in a House. The dashed black line is the outdoor temperature.

The figures show the different behaviour of the heat pumps depending on the input data and the type of performance. The *FIXED* heat pump shows constant COP and capacity values throughout the entire period, with these values being the same as those given as input. The *GSHP* similarly shows constant values for COP and capacity; nevertheless, these values are not equal to those given as input. While the input values for COP_{sh} and COP_{dhw} are equal to 4.7, the values calculated by interpolation from the data in Table 1 are 3.1. The lower, constant values are a consequence of giving a constant source temperature of 3 degrees. The ASHP and A2A heat pump show the source temperature dependency – in these cases, on the outdoor temperature – of the COPs and capacity. It can be seen in the figure that the COPs and the capacity increase and decrease in direct dependency with the outdoor temperature, except for the COP_{dhw} for A2A that is a constant zero. The drop to zero capacity shown in the bottom figure SN-NSPEK 3031:2021 guidelines indicating that heat cannot be supplied if the source temperature is below -15° C.

Table 4: Seasonal system COP (SCOP) of the heat pump and top heater systems for buildings at two different supply temperature levels (A2A always supplies @20° C).

	SH temp.	FIXED	GSHP	ASHP	A2A
Hou	**55° C**	2.4	2.4	1.7	2.0
	35° C	2.4	3.6	2.1	2.0
Apt	**55° C**	2.2	2.2	1.6	-
	35° C	2.2	3.1	2.0	-
Comm	**55° C**	2.6	2.7	1.7	-
	35° C	2.6	3.8	2.3	-

Table 5: Percentage of the SH demand covered by the heat pump.

	SH temp.	FIXED	GSHP	ASHP	A2A
Hou	**55° C**	93 %	91 %	73 %	80 %
	35° C	93 %	96 %	78 %	80 %
Apt	**55° C**	92 %	91 %	73 %	-
	35° C	92 %	95 %	78 %	-
Comm	**55° C**	95 %	94 %	78 %	-
	35° C	95 %	97 %	83 %	-

Table 6: SCOP of the heat pump and top heater systems in *Very efficient* buildings.

	FIXED	GSHP	ASHP	A2A
Hou	2.0	2.0	1.8	1.6
Apt	1.8	1.8	1.6	-
Comm	2.5	2.5	2.2	-

Table 7: Percentage of the SH demand covered by the heat pump in *Very efficient* buildings. The installed capacity of the heat pumps is shown in parentheses.

	FIXED	GSHP	ASHP	A2A
Hou (1 300 W)	88 %	92 %	72 %	75 %
Apt (10 450 W)	82 %	91 %	72 %	-
Comm (8 100 W)	96 %	97 %	85 %	-

The results in Table 4 show the annual performance of the heating system. The SCOP reflects the effect of the source and supply temperatures on the performance of the different heat pumps. The use of a top heating component (with an efficiency of 95%) reduces further the efficiency of the system when compared to the heat pump COPs: the more heat is covered by the top heating component, the lower the SCOP. Table 6 and Table 7 show the SCOP and coverage of SH demand in *Very efficient* buildings, where the supply temperature for SH is 35° C. Due to the lower SH demand of these buildings, the installed capacity of the heat pumps is smaller than in the previous examples. The SCOPs are lower in these cases compared to the results shown in Table 4. The heat demand for DHW represents a higher share of the total heat demand in very efficient buildings than in regular buildings. Moreover, for House and Apartment, the heat pumps cover lower percentages of the SH demand than in regular buildings. This could indicate that the peak loads for SH in very efficient buildings are closer to the average demand than in regular buildings. Therefore, sizing at 50% of the peak load may lead to higher participation of the top heating component, and thus lower efficiencies.

3.2 Solar PV

To compare the electricity generation of a PV system using the two models, an example case has been defined. It relates to the neighborhood Flytårnet, a pilot case in the ZEN project. The site is located in Fornebu, in the Bærum municipality in Norway. The generation for the default PV system in PVGIS was calculated for the year 2012 using the online tool, and the generation time-series is given as input data to the specific production model. It is possible to get the corresponding weather data from PVGIS, such as direct radiation, diffuse radiation, and air temperature. From those two radiation components it is possible to calculate the global horizontal radiation, and thus the complete set of input-data required for the calculation model is complete. The input parameters given in PVGIS for the calculation of the time-series are given in Table 8. To obtain the solar radiation on a horizontal surface to give as input to the calculation model, another request is made to PVGIS changing the slope of the PV system to zero. The same input parameters for the PV system are set up in the GSEE model. In both models, the system losses are set to default or suggested values; 14% and 13.6% are the default losses in PVGIS and GSEE, respectively.

Table 8: Input parameters in PVGIS for PV generation in Fornebu.

Parameter	Value	Parameter	Value
Address	Fornebu	PV tech.	Crystalline silicon
Latitude	59.904	Installed peak PV power [kWp]	1
Longitude	10.635		
Rad. Database	PVGIS-SARAH2	System losses (%)	14
Year	2012	Mounting type	Fixed
		Slope [°]	40
		Azimuth [°]	0

The monthly generation of the PV system using the input and calculation models is shown in Figure 2. The results show that the PV generation in the two models is similar, with annual totals of 907 and 910 kWh for the PVGIS and GSEE models, respectively. There are small differences on the monthly level. The generation profile from PVGIS gives slightly higher values for generation during months when solar radiation is typically low (Jan-Mar, Sep-Dec), whereas the GSEE model leads to higher values in months with higher solar radiation (Apr-Aug). Nevertheless, the highest difference amounts to under 5 kWh during the month of June, which is 4% of the total generation in that month.

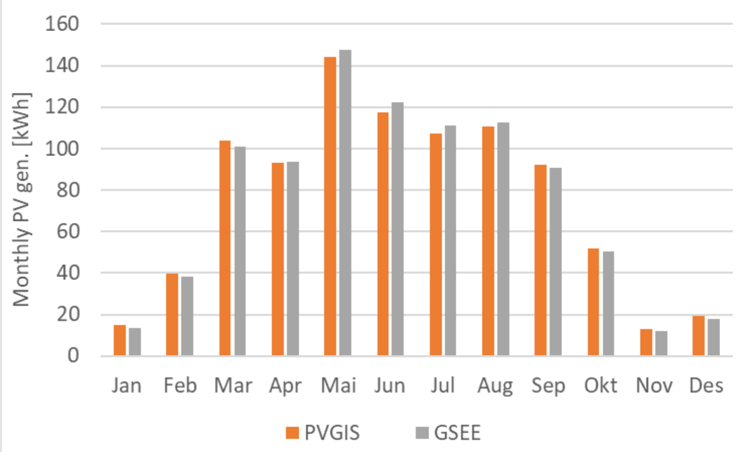

Figure 2: Monthly generation of the PV systems in the PVGIS and GSEE models.

The difference in daily generation is shown in Figure 3. Positive values indicate days when the results by the PVGIS models are higher, and negative values indicate days when the results by the GSEE model are higher. The seasonality observed in Figure 2 can also be seen here.

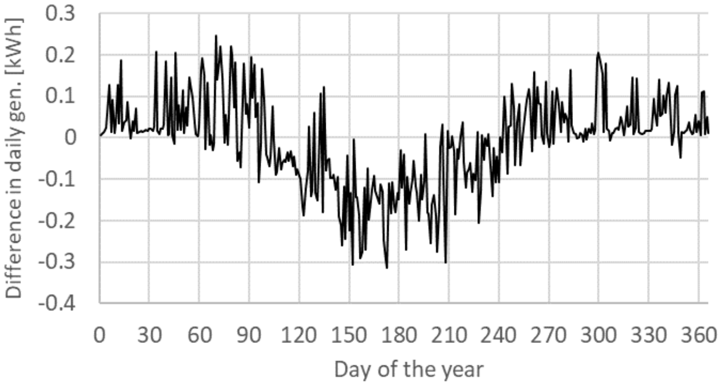

Figure 3: Difference in generation between the PVGIS and GSEE models. Positive values mean larger generation by PVGIS and vice-versa.

Figure 4 and Figure 5 show the hourly generation profiles by the two models on June 19th and December 12th, the days with the largest differences in hourly generation between the two models: on June 19th at 05:00, the GSEE model shows 150 Wh compared to 64.5 Wh by PVGIS, while in December 12th at 09:00 the PVGIS model shows 276.7 Wh compared to 213.3 Wh by GSEE.

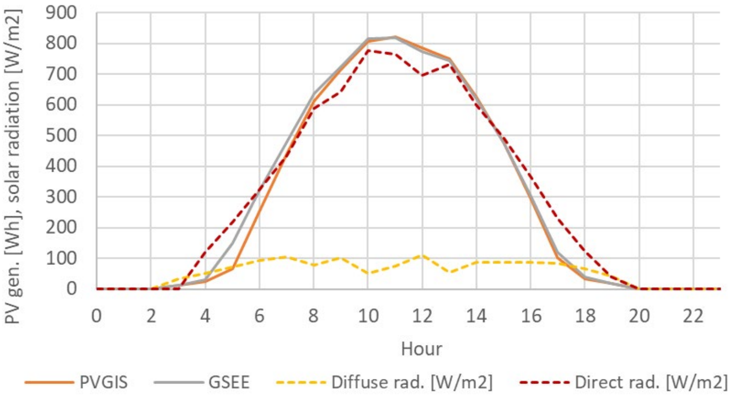

Figure 4: Hourly generation of the PV systems on June 19th.

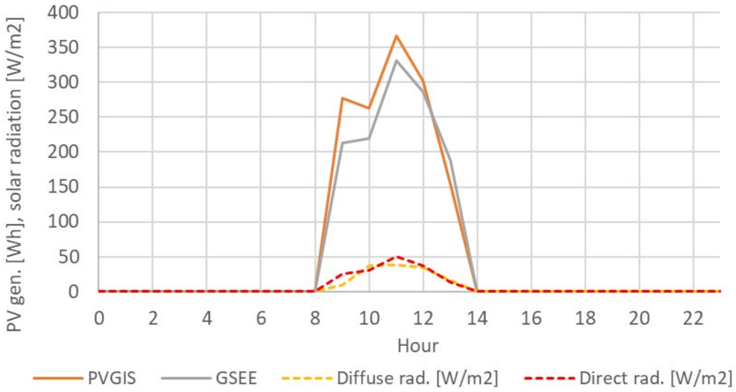

Figure 5: Hourly generation of the PV systems on December 12th.

3.3 Battery

An example case was setup to test the performance of the battery model and confirm that the constraints for its operation are being satisfied. Namely, it is necessary to confirm that the charging and discharging efficiencies, as well as the maximum charging and discharging rates, are working as intended. The input parameters for the battery are shown in Table 9, and the performance during one week of operation is shown in Figure 6.

Table 9: Input parameters for the example case of the battery model.

Parameter	Symbol	Value
Capacity	-	1000
Charging efficiency	η_{charge}	0.9
Discharging efficiency	$\eta_{discharge}$	0.8
Max. charging and discharging rate	y_{max}	0.5

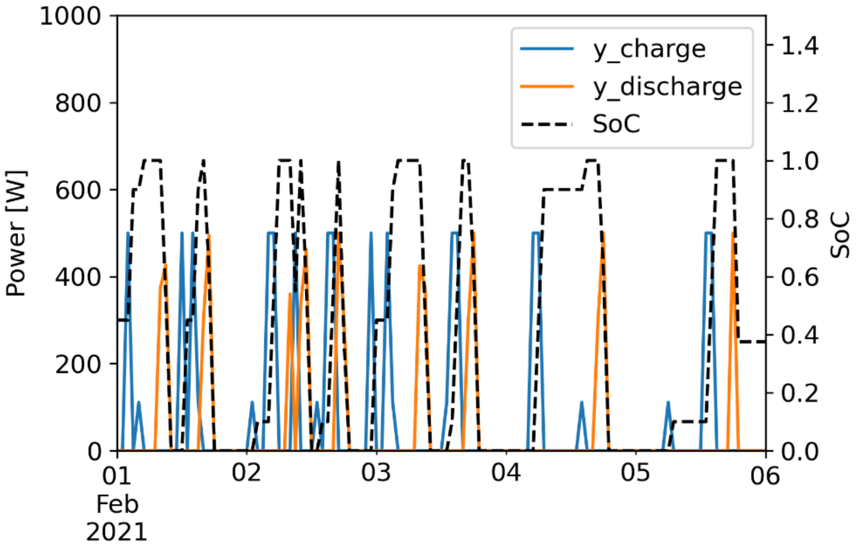

Figure 6: Performance of the battery in the example case.

The operation of the battery in the example case shows a few aspects of the behaviour of the model. The SoC of the battery is kept within the boundaries of 0 and 1, as defined in the model. As well the maximum charging and discharging rate is respected: its values being set at 0.5, and the capacity of the battery being 1000 Wh, the maximum allowed rates are both 500 W. The figure shows that this limit is respected by both y_{charge} and $y_{discharge}$. To confirm the correct operation of η_{charge} and $\eta_{discharge}$, the values for y_{charge}, $y_{discharge}$, and SoC for a period of 14 hours during Feb 3rd are shown in Table 10. The SoC starts fully charged with a value of 1, corresponding to 1000 Wh. Then, the battery delivers (i.e. discharges) 428.8 Wh at 8:00, which leads to a decrease in the SoC of 428.8/0.8 = 531.0 Wh. Since the battery started at 1000 Wh, its charge the following timestep is 1000 – 531 = 469, or a SoC of 0.469. At 13:00, the battery charges 111.1 Wh. With $\eta_{charge} = 0.9$, the battery charges exactly 100 Wh, and thus its SoC increases from 0.0 to 0.1 the following timestep. This indicates that the efficiencies have been implemented correctly.

Table 10: Data of a selected period within the example case for battery operation.

Timestep	y_{charge}	$y_{discharge}$	SoC
03.02.2021 07:00	0.0	0.0	1.000
03.02.2021 08:00	0.0	424.8	1.000
03.02.2021 09:00	0.0	375.2	0.469
03.02.2021 10:00	0.0	0.0	0.000
03.02.2021 11:00	0.0	0.0	0.000
03.02.2021 12:00	0.0	0.0	0.000
03.02.2021 13:00	111.1	0.0	0.000
03.02.2021 14:00	500.0	0.0	0.100
03.02.2021 15:00	500.0	0.0	0.550
03.02.2021 16:00	0.0	0.0	1.000
03.02.2021 17:00	0.0	300.1	1.000
03.02.2021 18:00	0.0	499.9	0.625
03.02.2021 19:00	0.0	0.0	0.000
03.02.2021 20:00	0.0	0.0	0.000

4 Closing remarks

A model for the simulation of heat pumps has been implemented in FLEXor, a simulation and optimization tool for energy use in the built environment, which allows two performance calculation modes: constant performance and temperature-dependent performance. These models let the user choose between two levels of accuracy for this type of heat supply component. Moreover, the temperature-dependent performance model is based on the heat pump performance guidelines from the SN-NSPEK 3031:2021 standard. The results show that the model is able to calculate the performance as constant or based on the heat source temperature.

Two models for PV generation have also been implemented in FLEXor. These models give users the option to supply pre-calculated time-series (or profiles) of electricity generation, or to let the model calculate the time-series. The first option gives the user more freedom to test different PV generation scenarios, as they have the option to modify the generation profiles to fit specific needs. The second option, which uses the open-source GSEE model, uses geographical and meteorological data and parameters of the PV system to calculate the generation profile. Thus, the user does not need to calculate the generation profiles separately. In this memo, the results of the GSEE model have been compared to results from the PVGIS online tool, based on the location of the neighborhood Flytårnet, a pilot case in the ZEN project. The site is located in Fornebu, in the Bærum municipality in Norway. The generation profiles are similar, although some seasonal differences can be seen. While this exercise does not constitute a validation process, the results can be deemed acceptable for the purposes of the FLEXor tool.

Finally, a model for an electric battery has also been implemented. The model can calculate the charging and discharging of the battery as well as its SoC, and these energy exchanges are affected by their respective efficiencies. Moreover, the model can keep the SoC of the battery between boundaries, and a limit can be set for the charging and discharging rates.

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