ZEB Project report 28 – 2016

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The Research Centre on Zero Emission Buildings

SINTEF Academic Press

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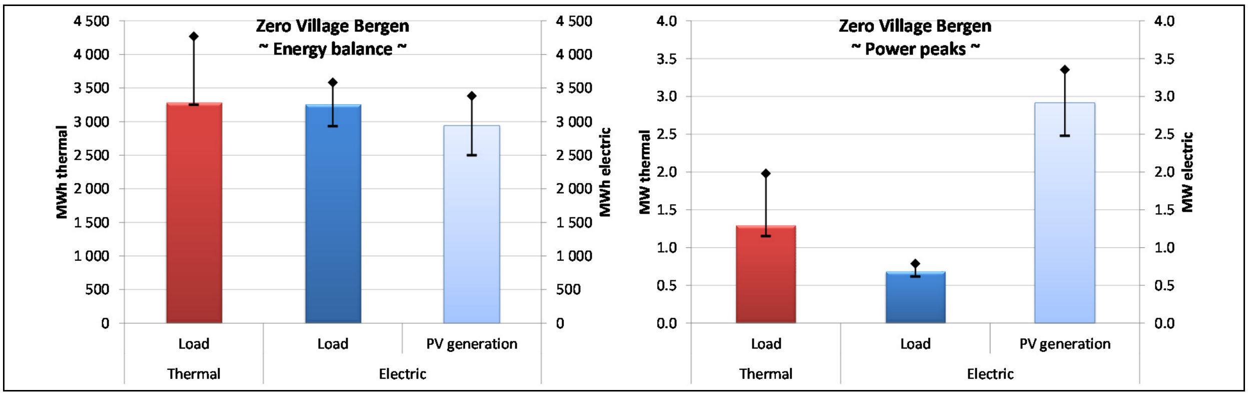
Abstract

The Zero Village Bergen consists of a total floor area of ca. 92 000 m^2, with more than 700 dwellings divided between terraced houses (68% of total floor area) and apartment blocks (25%) and some area dedicated to non-residential purposes such as offices, shops, and a kindergarten (7%). The project is currently in the planning phase and the strategy for achieving the ZEB-O goal[1] is based on three steps: first, minimize energy demand through energy efficiency of the buildings; second, maximize PV generation on the buildings' footprint; and third, consider additional measures onsite and nearby (e.g. local heating system with biomass based cogeneration). At the current stage the project has reached the evaluation of step two, and the results are presented in this report, together with some useful insights for step three.

For the residential buildings, the thermal load is calculated by dynamic building energy performance simulations (using the software IDA ICE), and two types of buildings have been simulated: a terraced house and an apartment block. Both buildings have envelope properties that qualify them as passive house buildings according to the Norwegian standard. Since the significance of DHW and internal gains is higher in highly insulated buildings than in conventional ones, special attention has been given to these two types of energy use. For the internal gains, stochastic lighting and plug loads, hourly profiles are obtained from a Time of Use Data (TUD) methodology and used as input in the simulations. Hundreds of stochastic profiles have been generated and a weighted average has been calculated considering the national average household size of 2.2 persons. For DHW, data from surveys of actual hot water use have been used as input to the simulations. For the non-residential buildings, the energy demand is calculated from real measurements of similar (highly energy efficient) buildings, and adjusted for a typical climatic year.

PV generation profiles are obtained using state of the art software (PVsyst) considering the variety of roof orientations and shading effects from a 3D modelling. Both load and generation profiles have hourly resolution and are based on the same weather data file in order to guarantee consistency when addressing the mismatch between the two. A sensitivity analysis has been performed on both the loads and the PV generation.

The results are shown graphically in the figure below, including the sensitivity analysis' range, offering at a glance the powerful visual impression that while the PV generation struggles to cover just the electric load, the peak power due to the PV generation is significantly higher than the electric peak load, and even higher than both thermal and electric peak loads together.



Aggregated energy balance (left) and peak power (right) showing the thermal and electric loads and the PV generation, with min-max markers from sensitivity analysis.

[1] see §1 for further details on the ZEB ambition level.

The main findings can be summarized as follows:

- The aggregated annual thermal load is approximately the same as the electric load (3.3 GWh) for the entire Zero Village Bergen;
- The aggregated annual PV generation (2.9 GWh) covers ca. 90% of the electric load;
- Even so, PV peak generation (2.9 MW) is ca. 4 times higher than the electric peak load (0.7 MW) giving a GM[2] of ca. 4;
- This implies that the local electric grid dimensioning capacity might be determined by the PV peak generation rather than by the peak load (depending on the choice of the thermal system and the expected load from electric vehicles, not considered here).

The heating system for the Zero Village Bergen is not yet decided, since this will be the task in step three. However, the two most probable options on the design table are either an all-electric solution (with heat pumps in the buildings or at a local district heating station) or a thermal-carrier solution with a local district system (whether or not connected to the city district heating). The analysis of the energy balance and mismatch between loads and PV generation offers useful insights for the next step in the design phase:

- <u>All-electric solution</u>
  If the thermal load is met by heat pumps the total electric load will be ca. 1/3 higher, assuming a seasonal COP of ca. 3 for the heat pump system, meaning that the ZEB-O target is not reached unless further generation (or load reduction) measures are considered[3].
  The peak load can roughly be estimated at around 2 MW, giving a GM of ca. 1.5, and meaning that the local electric grid does not need to be largely over dimensioned due to the PV system. This might normally be regarded as a positive feature;

- <u>Thermal-carrier solution</u>
  If the thermal load is met by a biomass based cogeneration system, this would provide at the same time a small additional load – counted in carbon emissions – and extra electricity generation, so that the overall ZEB-O goal may actually be reached. This will depend on the specific conversion factors used for biomass and electricity.
  The electric peak load would remain unchanged and so the GM. Having a high GM might not be a problem and may even be an advantage. It simply means that the dimensioning of the grid capacity is based on the PV peak generation in summer, while that capacity is free overnight year-round to be used for charging e-vehicles.

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[2] GM = Generation Multiple; tells what the required grid connection capacity is due to the PV system compared to what it would be due to the load alone. See §4.1 for further details.

[3] It is worth noting that the ZEB-O (Zero Emission Building – Operation) is a more ambitious target than the nearly ZEB (Zero Energy Building) level defined in the European EPBD (Energy Performance of Buildings Directive) and related standards (ISO 5200-1/EN 15603: 2015), which only consider the thermal load – and lighting for non-residential buildings only – at least as the default option. In that view the Zero Village Bergen would appear as a "Plus Energy" neighbourhood even with a seasonal COP of just 2.

Contents

Acronyms

AC	Alternating current
CAV	Constant Air Volume
CHP	Combined Heat and Power
DC	Direct current
DHW	Domestic Hot Water
GFA	Gross Floor Area
HVAC	Heating Ventilation and Air Conditioning
IAM	Incidence Angle Modifier
kWp	Kilowatt Peak
LID	Light Induced Degradation
MPP	Maximum Power Point
NIA	Net Internal Area
NOCT	Nominal Operating Cell Temperature
PR	Performance Ratio
PV	Photovoltaic
STC	Standard Test Conditions
SFP	Specific Fan Power
TUD	Time of Use Data
VHR	Ventilation Heat Recovery
ZEB	Zero Emission/Energy Building
ZVB	Zero Village Bergen

1. Introduction and Areas overview

Zero Village Bergen is a large development project consisting of several types of multifamily residential buildings consisting of 2-4 floors, all together approximately 800 units. The development site is located at Ådland, about 15 km south-east of Bergen, near the airport (Flesland), see Figure 1.1.

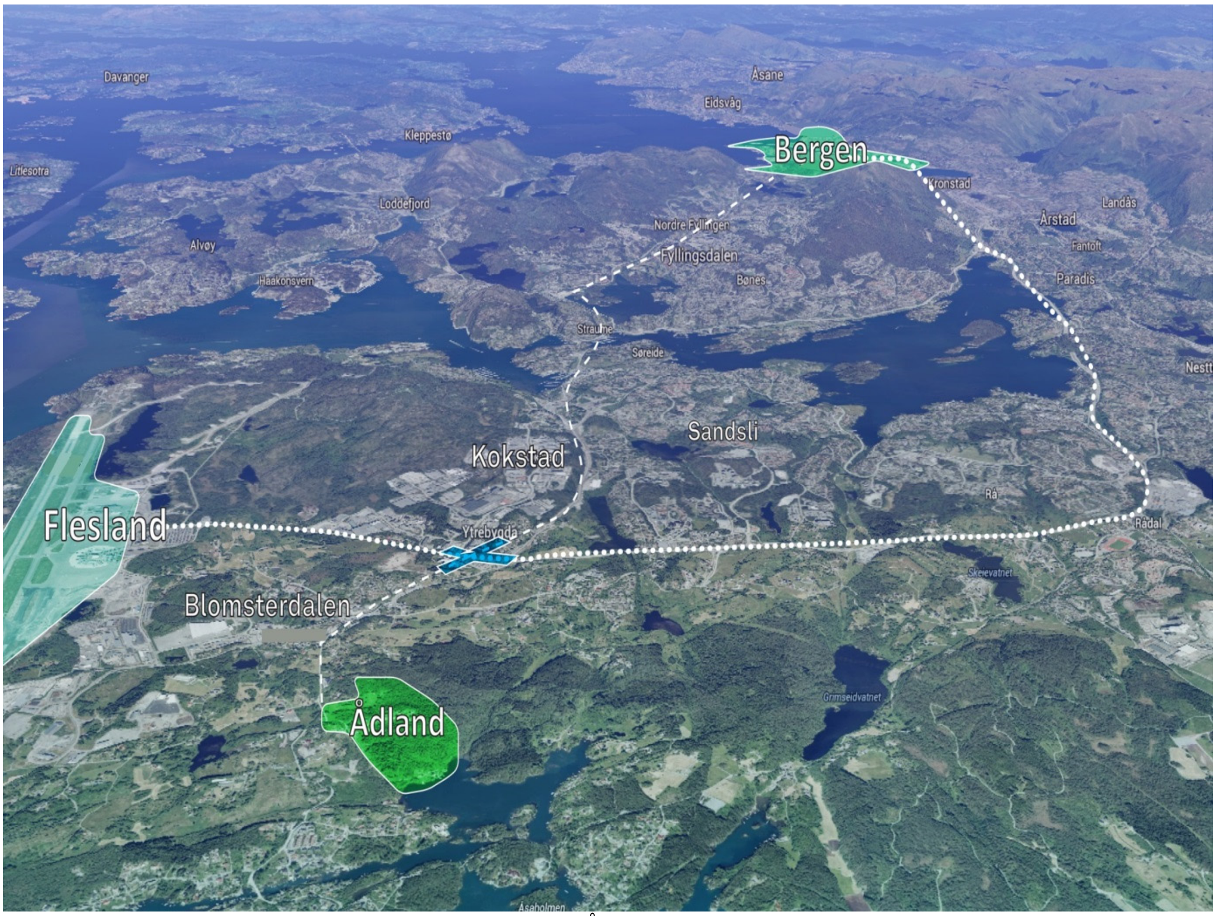


Figure 1.1 The location of Zero Village Bergen at Ådland.

The project is currently in the planning phase and is being developed by the company ByBo AS in close cooperation with the Norwegian Research Centre on Zero Emission Buildings (www.zeb.no) with partners NTNU, SINTEF, Snøhetta, and Multiconsult.

The overall energy ambition of the development is that the greenhouse gas emissions related to the operation of the buildings should be zero on an annual basis. Also, the embodied emissions from construction materials should be accounted for, and for some of the dwellings, the ambition is to also include these in the zero emission balance. Due to the long time scale of the development, different ambition levels were specified for different stages in the duration of the development according to the ZEB definition (see below):

- The area as a whole should reach the ZEB-O level
- The lowest performance level for single buildings should be ZEB-O÷EQ
- Within 2 years of project start, the ambition level should be raised to ZEB-OM
- Within 4 years of project start, the ambition level should be raised to ZEB-COM
- For projects with ZEB-O÷EQ level, there should be minimum requirements with regards to emissions from materials

The ZEB definition is characterized by different ambition levels ranging from the lowest (ZEB-O÷EQ) to the highest (ZEB-COMPLETE) depending on what aspects in the building life cycle that are included. The different ambition levels are defined as (Dokka et al. 2013a, Kristjansdottir et al. 2014):

1. ZEB-O÷EQ: Emissions related to all energy use in operation "O" except energy use for equipment/appliances (EQ) shall be compensated with renewable energy generation.
2. ZEB-O: Emissions related to all operational energy "O" shall be compensated for with renewable energy generation.
3. ZEB-OM: Emissions related to all operational energy "O" use plus embodied emissions from the materials "M" shall be compensated with renewable energy generation. The M includes the product phase of materials A1–A3, and scenarios for the replacement phase, B4 from the standard EN 15804 (2012), see figure 1.2.
4. ZEB-COM: Same as ZEB-OM but also taking into account emissions related to the construction phase "C" are included and need to be compensated for. The phases included in the “C” are A4, transport to building site, and A5, construction installation processes, ref EN 15804 (2012), see figure 1.2.
5. ZEB-COME: Similar to ZEB-COM but emissions related to a scenario for the end-of-life phase “E” have to be included and compensated for C2, transport, and C4, disposal phases from the standard EN 15804 (2012), see figure 1.2.
6. ZEB-COMPLETE: Emissions related to a complete life cycle emission analysis have to be compensated for, namely all the phases, A1–A5, B1–B5, as well as B6- operational energy use and C1–C4, from the standard EN 15804 (2012), see figure 1.2.

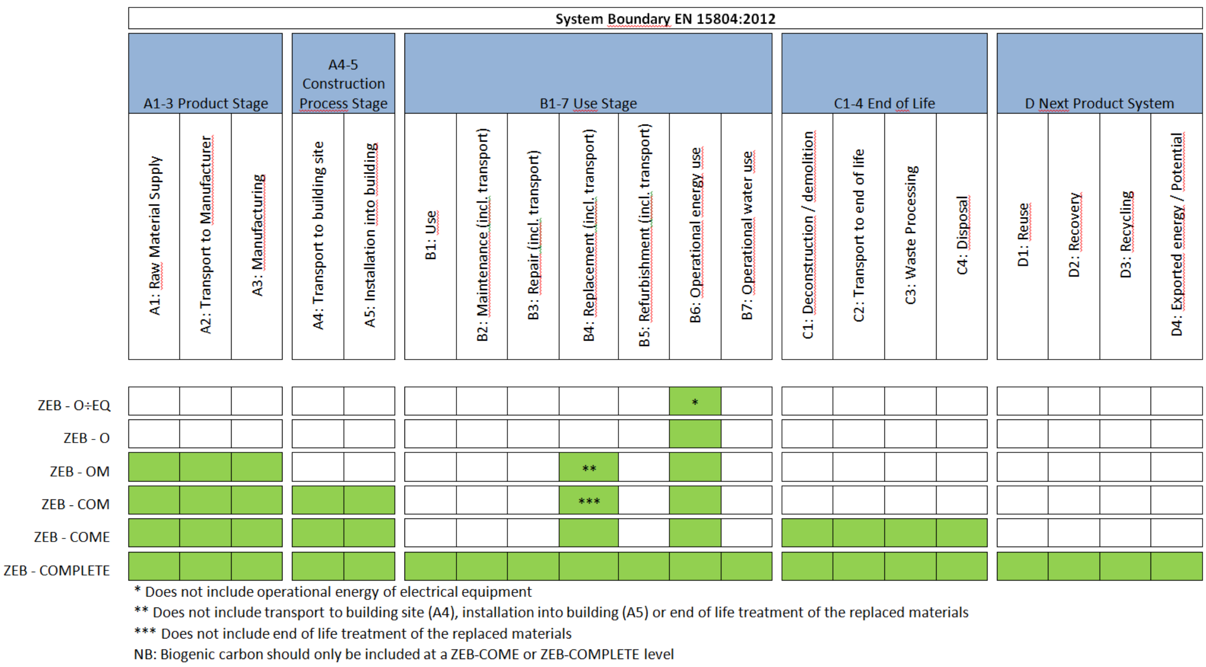


Figure 1.2 Different life cycle phases included in EN 15804 (2012), with indication (green) of which phases are included in the different ZEB ambition levels.

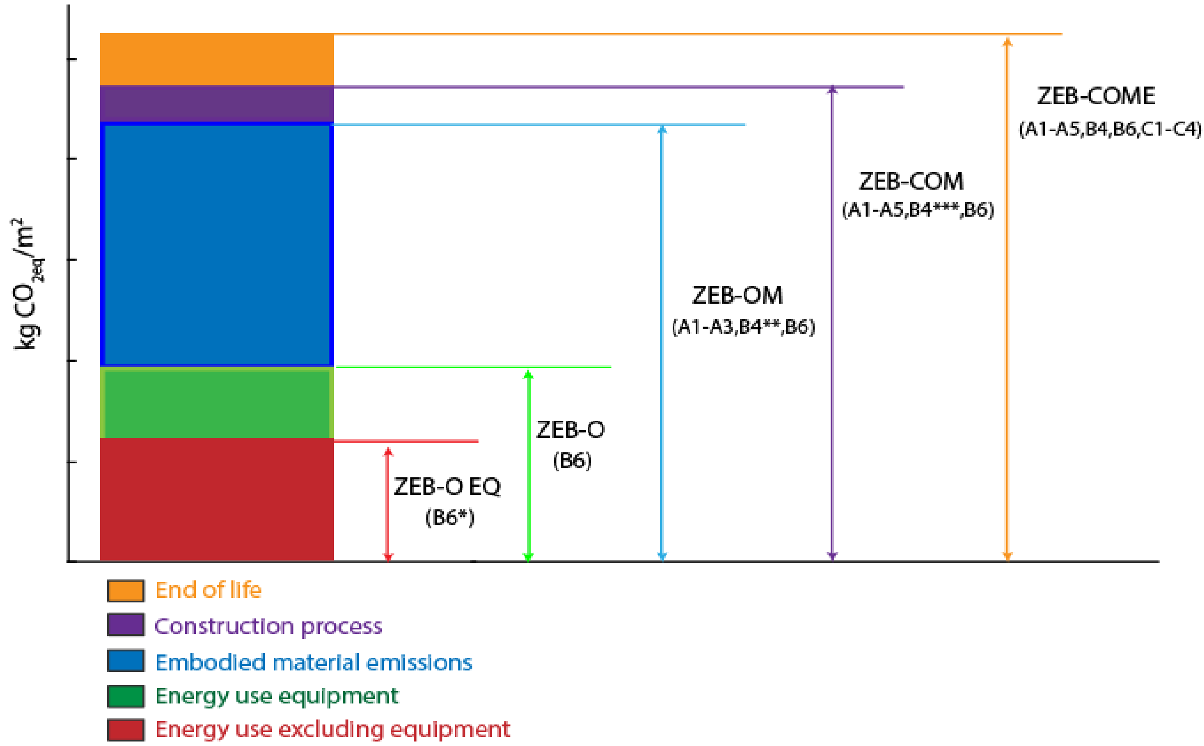


Figure 1.3 Graphical presentation of the ZEB ambition levels.

Figure 1.4 shows the different anticipated construction stages of the development (left), and an indication of the buildings that are designated to reach ZEB-OM level (right).

Figure 1.4 Overview of the Zero Village Bergen development showing left) construction stages and right) the buildings designated to reach ZEB-OM level. Image: Snøhetta.

Previous work has included a preliminary design and analysis of energy concepts for the buildings, as described in Risholt et al (2014). The preliminary design of the dwellings encompass careful location to account for maximum solar and daylight access, and at the same time provide shielding from noise levels from the nearby airport. The building envelopes and HVAC equipment are to be constructed according to the Norwegian passive house standard NS 3700 (2013). Two alternative energy supply systems were explored in the concept design phase: 1) A combination of a central ground source heat pump system and building integrated solar thermal collectors and photovoltaics, and 2) A combination of a centrally located biogas cogeneration machine combined with building integrated photovoltaic systems. See Risholt et al (2014) for a further description.

The energy and load calculations described in Risholt et al (2014) were limited and simplified in several ways:

The utility grid was basically treated as an infinite capacity battery; surplus electricity was assumed to be exported to the grid and re-imported in periods of net demand. In reality, onsite generation and loads have a temporal mismatch both at seasonal level, i.e. PV generation is concentrated in summer, and at hourly level. This mismatch may be considerable, especially in residential building since the peak demand is usually in the evening while PV generation peaks in the central hours of the day.

Furthermore, the aggregation of loads and PV production from several buildings was not studied. The PV installations in several buildings would peak their generation at approximately the same time due to the geographical proximity. In residential neighborhoods this peak typically coincides with the time of minimum building load. The result is an aggregated peak of electricity exported to the distribution grid, which might challenge its limits or cause curtailment of the PV generation (Sartori *et. al.,* 2014).

In order to get a more detailed overview of the amount of PV electricity that may be generated, consumed, or exchanged between the buildings and the grid, a more comprehensive analysis needs to be carried out. The work described in this report includes an investigation of the dynamic loads of all the residential buildings, as well as a detailed analysis of the hourly PV generation profiles. Also the load profiles of the commercial buildings in the neighbourhood have been included in the analysis, in order to consider the export of PV electricity to these buildings.

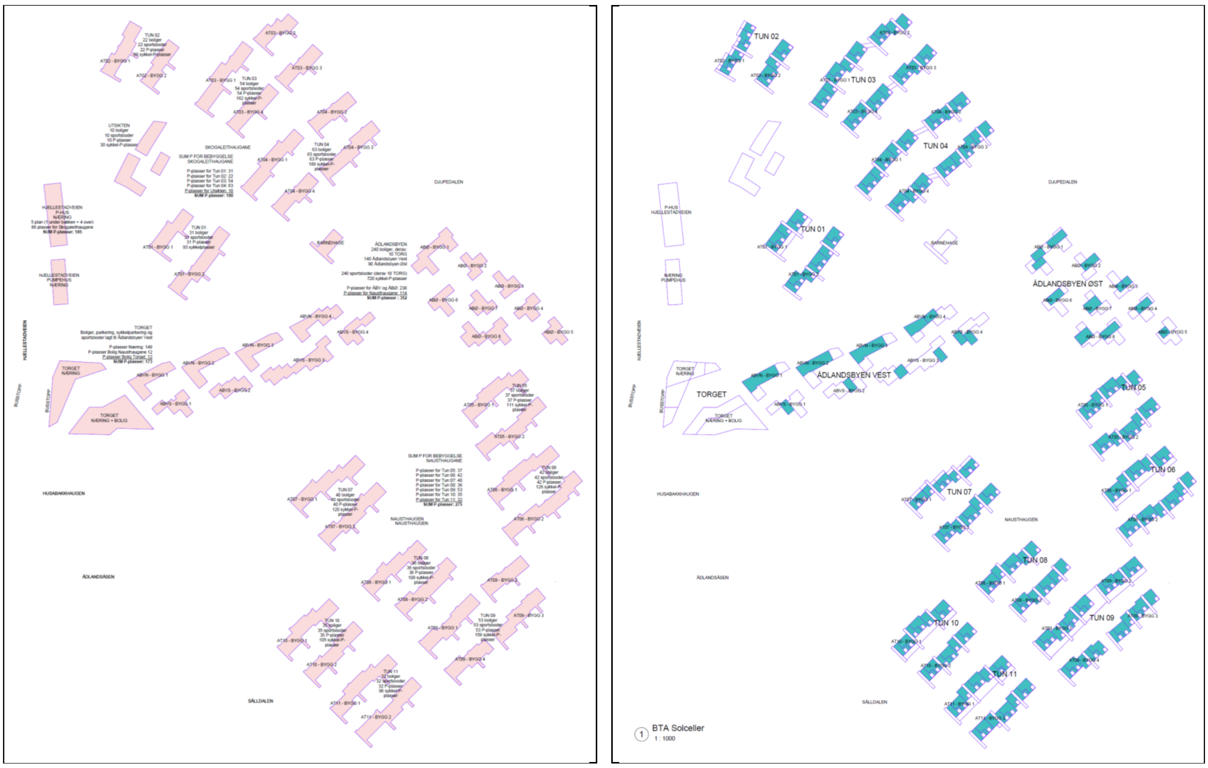


Figure 1.5 Graphical overview of left) floor area of buildings and right) roof area for solar cells. Image: Snøhetta.

2. Aggregated loads

This chapter describes how the aggregated building load profiles for the Zero Village Bergen have been obtained. For residential buildings, stochastic electric profiles are obtained from a Time of Use Data (TUD) methodology as explained in §2.3. The resulting aggregated electric load profiles for lighting and plug loads are normalized per household and used as input in the calculation of the thermal load. The thermal load is calculated by dynamic building energy performance simulations using the software tool IDA ICE. As shown in Figure 2.1, two types of buildings have been simulated: a terraced house and an apartment block. Both buildings have envelope properties that qualify them as passive house buildings according to the Norwegian norm NS3700[4]. In highly insulated buildings the significance of internal gains such as from lighting and equipment is higher than in conventional buildings, and with this approach we aim at considering this effect in a more accurate fashion than applying normative tabulated values for both quantity and timing of such internal gains.

For the non-residential buildings the energy demand has been calculated directly from real measurements of similar buildings. The data collection from hundreds of monitored buildings and further adjustments, e.g. normalization to a typical climatic year and differentiation between conventional and very energy efficient (passive house) buildings, is part of an ongoing PhD work at NTNU[5]. The values presented here are representative averages of very energy efficient buildings, equivalent to passive house buildings.

2.1 Buildings floor area and its modelling for energy simulations

The buildings in Zero Village Bergen can be classified in two major types: terraced houses and apartment blocks. These residential buildings make up 91% of the total utility floor area (UFA); in addition there is also some area dedicated to non-residential purposes such as offices, shops, and a kindergarten. The UFA is calculated by the architect as being 0.96 times the gross floor area (GFA). For energy demand modelling purposes it is assumed, to stay on the safe side, that the heated floor area corresponds to the UFA (while it is normally somewhat less). In this report the terms floor area and heated floor area are used as synonyms, unless differently specified. A summary of the floor areas for different building types is given in Table 2.1.

Table 2.1 Total floor areas in Zero Village Bergen.

Building type	Floor area [m2]	Floor area [%]
Terraced houses	62 136	68 %
Apartment blocks	23 028	25 %
Total residential	*85 164*	93 %
Kindergarten	1 061	1 %
Shop	2 833	3 %
(with food storage)	(1500)	
Office	2 833	3 %
Total ZVB	***91 891***	*100 %*

[4] NS3700:2013 Criteria for passive houses and low energy buildings – Residential buildings, *Standard Norge*. (in Norwegian)

[5] Karen B. Lindberg: "The impact of ZEBs on the overall energy system through smart grid and demand side management" Ongoing PhD thesis at the department of Electric Power Engineering, Norwegian University of Science and Technology (NTNU),

The two major residential building types, terraced house and apartment block, have been modelled with a simplified geometry in order to reduce the computational time of the energy simulations, and their main geometric features are given in Table 2.2. The results of the energy performance simulations in terms of energy intensity (kWh/m^{2}y) have then been multiplied by the total floor area given in Table 2.1 in order to obtain the total loads for residential buildings in ZVB. The non-residential buildings are not modelled directly since their load profiles are taken from other sources, as explained at the beginning of §2.

Table 2.2 Geometric features of the simulated buildings.

Simulated building	Nr. storeys	Footprint [m]	Nr. dwellings	Floor area [m2]
Terraced house	3	67.5 x 10	15	2 025
Apartments block	4	39 x 10	16	1 560

In the terraced house model, each dwelling is treated as a single thermal zone, and in order to reduce considerably the computational time without significantly affecting the accuracy of the simulation, the internal zones are treated as adiabatic. This means that the two external dwellings at each end of the houses row are modelled explicitly, being in thermal contact with the exteriors, while the 13 internal dwellings are modelled implicitly by applying a multiplication factor of 13 to one thermal zone that is thermally adiabatic on two sides, see Figure 2.1.

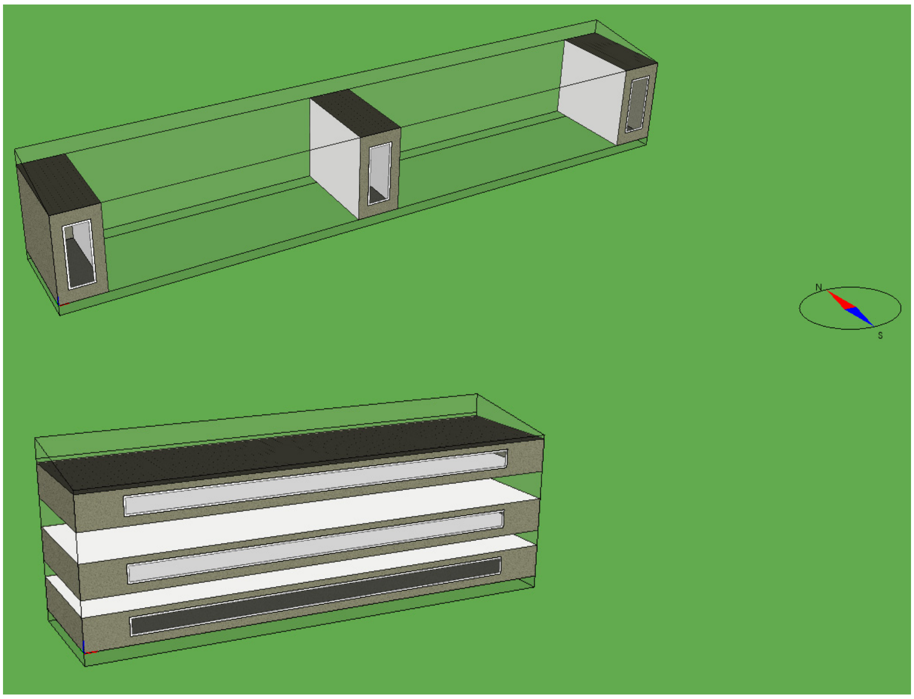


Figure 2.1 3-D view of the building models upper) terraced house and lower) apartments block.

Similarly, in the apartments block model, each floor is treated as a single thermal zone with the ground and top floors modelled explicitly, being in thermal contact with the exteriors. The two intermediate floors are modelled implicitly by applying a multiplication factor of two to one thermal zone whose floor is in thermal contact with its own ceiling, see Figure 2.1 (in this case an adiabatic assumption would have neglected the thermal stratification effect).

In both the terraced house and the apartments block the building is modelled with a slab on ground even though in some cases there is an unheated basement/garage in the underground. However, what matters in terms of energy performance simulation is the equivalent U-value (or more precisely the H-value) for the heat transmission towards the ground, taking into consideration unheated spaces as well as ground properties and average ground temperatures, as specified in the ISO-13370. As long as the equivalent U-value is the same, the results of the calculations will be the same for either a slab on ground or an unheated basement.

2.2 Background: Aggregated Energy Demand

It is a known phenomenon that different residential users do not have a coincident demand of energy, i.e. the peak load of one user does not happen at the exact same time as that of her neighbour. This is known as the coincidence factor, which is always lower than one, and often around 60% for residential users[6], and might be even lower for highly energy efficient house where the consumption depends less on the thermal needs and more on the user appliances. Sartori *et al.* (2014)[7] have studied the aggregated load in the case of a neighbourhood with 200 passive houses with heat pump (all-electric houses), using simulations based on stochastic user profile inputs for occupancy, lighting, and appliances.

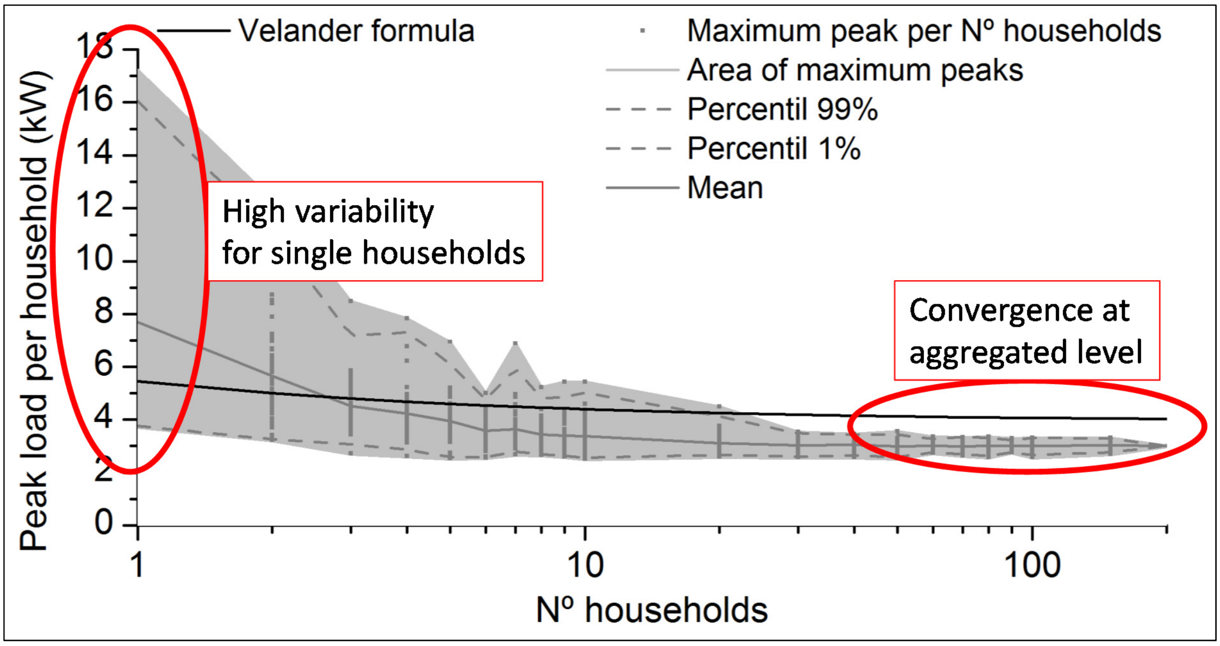


Figure 2.2 Peak load per household (y-axis) for increasing number of households considered (x-axis, logarithmic scale)

Results from that study are shown in Figure 2.2, which give a sense of how the high variability that is observable for single households largely vanish as the demand of more and more households is aggregated. Energy performance simulation results were first obtained for the 200 households separately, with hourly resolution. In post processing, in order to investigate the effect of increasingly large aggregation of households, the results have been grouped by summing up the load from a random selection of households from the full set. For example, for the group of 10 households, 10 single households are chosen randomly and their data series are summed up, hour by hour. Since each single data set is stochastic, load and generation peaks from the subset will not be the same as the sum of the

[6] Ivar Wangensteen (2012) Power System Economics – the Nordic Electricity Market, 2nd Edition, *Tapir Academic Press*, Trondheim, Norway. ISBN: 978-82-519- 2863-2/2856-4 (epub).

[7] Sartori, I., Ortiz, J., Salom, J. and Dar, U.I. (2014) Estimation of load and generation peaks in residential neighbourhoods with BIPV: bottom-up simulations vs. Velander method, *WSB Conference – World Sustainable Buildings*, 28-30 Oct., Barcelona, Spain.

single households composing the subset. Furthermore, such grouping has been repeated 50 times per each subset, i.e. 50 different groups of 10 households have been created. In Figure 2.2 all 50 data points are shown per each aggregation group (grey dots in the graph, vertically aligned).

The loads analysis performed in this study is also based on stochastic user profile input data series. The focus is on the aggregated loads for the entire ZVB, so that the energy performance of single houses has not been analysed and only aggregated results are presented here. However, the results are based on simulations with aggregated stochastic user profiles as explained in the following sub-chapter.

2.3 Electric load

Three types of electric specific loads are considered:

- Ventilation fans
- Lighting
- Plug loads

2.3.1 Ventilation fans

The ventilation system is a Constant Air Volume (CAV) with airflow rates as specified in the NS3031[8] of 1.2 m^3/hm^2 for the terraced house and 1.4 m^3/hm^2 for the apartments block, and the Specific Fan Power (SFP) is assumed to be 1.25 $kW/m^3/s$. This gives an annual consumption of 3.6 kWh/m^2y for the terraced house and 4.2 kWh/m^2y for the apartments block; all data summarized in Table 2.3. It is further assumed that pumps consumption is marginal compared to consumption from ventilation fans, and it is thus neglected here.

Table 2.3 Ventilation system data.

Ventilation Fans	Airflow rate [m^3/hm^2]	SFP [$kW/m^3/s$]	Yearly consumption [kWh/m2y]
Terraced house	1.2	1.25	3.6
Apartments block	1.4	1.25	4.2

2.3.2 Lighting and plug loads

For the lighting and plug loads, the profiles are obtained with a model for generating stochastic profiles based on Time of Use Data (TUD), which are collected by the Norwegian statistics bureau (SSB). The methodology is explained in detail in Rangøy (2013)[9]. The model generates stochastic and statistical representative user profiles for Norwegian households for occupancy at 10-minute resolution, and for lighting and plug loads at 1-minute resolution. The profiles have been calibrated against the best available measurements from various sources, including:

- REMODECE (EU/Norwegian project)
- Eldek (Norwegian project)
- Data from NVE
- SEA (Swedish Energy Agency), only for lighting

The model considers a number of appliances, with respective probability of ownership in Norwegian households, including electric oven and cooking plates, but does not include induction cookers. Ownership of induction cookers increases steadily in Norway, thus it would be worth considering in it in

[8] NS3031:2014 Calculation of energy performance of buildings – Method and data, *Standard Norge*. (in Norwegian)

[9] Rangøy, E. (2013) Validation of user profiles for building energy simulations, *Master thesis at NTNU*, Trodheim.

further work. This aspect is here considered when performing a sensitivity analysis in §2.5. However, it should be noted that while induction cookers have a higher peak power demand, their operating cycle is shorter, therefore limiting the coincidence factor between different household. In other words, though the effect of an induction cooker on the peak power demand of a single household may be significant, it is likely to be rather limited in the case of many households aggregated load, and possibly negligible in the hourly average.

The stochastic profiles for lighting and plug loads are generated for single households, considering different sizes from 1 to 5 or more persons per household, and with 1-minute resolution. Since the purpose of this study is to analyse the aggregated load for the totality of Zero Village Bergen, average profiles have been created for a large aggregation of stochastic profiles, further averaged at hourly resolution. The reason to work with hourly averages is pragmatic: hourly profiles can be used as input to the thermal modelling of the buildings, for which purpose hourly resolution data are accurate enough due to the inertia of thermal phenomena involved.

In order to obtain aggregated profiles, the following method was used. First 250 stochastic profiles have been generated for both lighting and plug loads, 50 per each household size from 1 to 5 (or more) persons. Then a weighted average has been calculated considering the national average household size distribution, which corresponds to 2.21 persons / household, as shown in Table 2.4.

Table 2.4 National average household size distribution. Source: SSB.

Persons / household	Percentage %
1	39.6 %
2	28.1 %
3	12.6 %
4	12.7 %
5 or more	7.0 %
2.21	**Average household size**

The following Figure 2.3 and Figure 2.4 show the resulting aggregated profiles normalized for a single household. For visualization purposes Figure 2.3 shows the average for summer and winter for the lighting load, with a differentiation between weekdays and weekend; the swing seasons' profile lays in between the two.

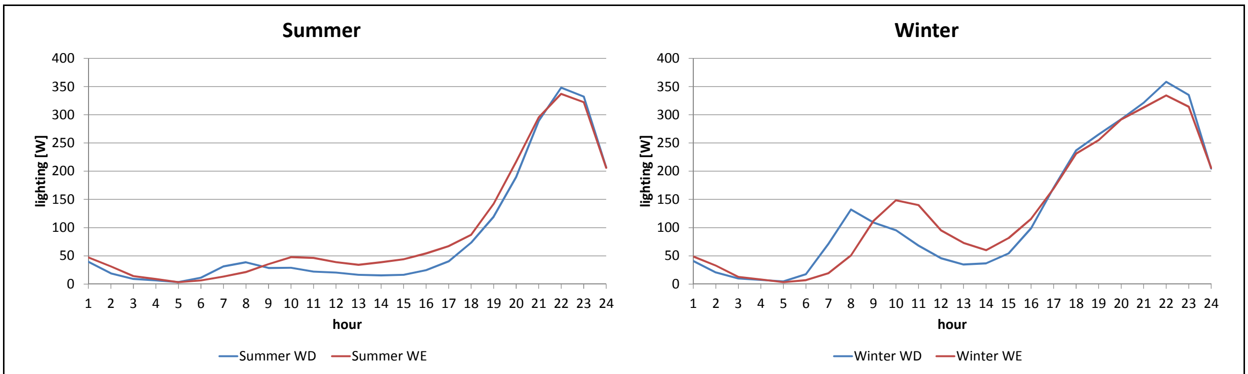


Figure 2.3 Aggregated lighting profile with hourly resolution, left) average summer day and right) average winter day. WD = Weekday; WE = Weekend.

Figure 2.4 shows the average winter profile for the totality of plug loads, with a differentiation between weekdays and weekend. Only the winter average is shown since there is little variability throughout the year. Rather both profiles with hourly and minute resolution are shown. One may expect to see a more substantial difference between the two graphs, hourly and minute, with the minute resolution presenting more pronounced spikes. As discussed in §2.2, the aggregation of several households – already at the level of a few dozens – dampens the spikes notable in single households due to their non-coincidence in time. Since the shown profiles represent the aggregation of a rather large number, 250, of stochastic household profiles and the average over an entire season, ca. 90 days, the spikes are significantly dampened.

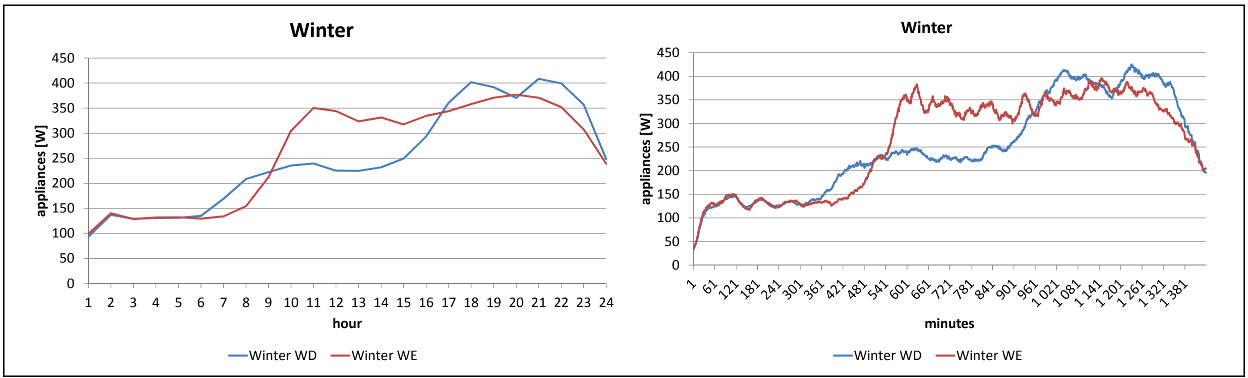


Figure 2.4 Aggregated plug load profile for the average winter day, left) hourly resolutuion and right) minute resolution. WD = Weekday; WE = Weekend.

In Table 2.5 the resulting yearly consumption and the average power[10] are presented, normalized per square metre of floor area, for different sources. The results from the stochastic profiles are shown alongside the normative values tabulated in both NS3031 and NS3700[11] standards, the values previously adopted in the ZEB Project Report 15[12] for ZVB, and the estimates presented in a report by NVE[13] (The Norwegian Directorate for Energy and Water Resources), which in turn summarizes the outcome of different other studies and surveys.

Table 2.5 Comparison of electric loads data from various sources.

Electric load	Stochastic profiles		NS3031/NS3700		ZEB PR-15		NVE*
	Avg. power	Yearly demand	Avg. power	Yearly demand	Avg. power	Yearly demand	Yearly demand
	[W/m²**]	[kWh/m²y]	[W/m²]	[kWh/m²y]	[W/m²]	[kWh/m²y]	[kWh/m²y]
Lighting	1.33	7.7	1.95	11.4	1.5	8.8	8.4
Plug loads	3.20	18.7	3.00	17.5	2.5	14.6	29.4

* Assuming average dwelling size of 119 m2 (SSB). N.B. here Plug loads incl. ventilation fans.
** Equivalent, calculated a posteriori

The values from the stochastic profiles (which are calibrated to the best available measurements data as specified above) do not look too dissimilar from the other sources. It is out of the scope of this work to investigate the differences between various sources, but it can be said that the major differences are seen in the lighting value from NS3031/NS3700 and in the plug loads value from NVE. For the former, the reason may be that the norms tend to adopt somehow conservative values. For the latter, two factors could explain the higher value: the consumption of ventilation fans is here included in the plug loads, and the fact that the same report shows rather low values for the domestic hot water (DHW)

[10] Assuming the standard activity time and flat profile as specified in NS3031.

[11] For NS3700 see footnote 4, for NS3031 see footnote 8.

[12] B. Risholt, J. Thomsen, T. Kristjansdottir, M. Haase, K. Lien and T.H. Dokka (2014) Energikonsepter for Ådland boligområde, *ZEB project report 15-2014,* Trondheim. (in Norwegian)

[13] NVE (2013) Energy consumption 2012 – Household energy consumption, *NVE report 16-2013*, Oslo.

consumption compared to other sources. Since the large majority of hot water heaters in Norway are electric, it is possible that the given split between plug loads and hot water is inaccurate, considering that the sum of the two is not so different from that in other sources.

2.3.3 Non-residential buildings

For the non-residential buildings the energy demand has been calculated directly from real measurements of similar buildings, as explained at the beginning of §2. Representative average profiles for the total electric load are shown in Figure 2.5 for the total of kindergarten, office and shop floor area[14]. It should be noted that the load for the shop area is representative of shops that do not have food storage, e.g. supermarkets. As shown in Table 2.1, out of ca. 2 800 m², ca. 1 500 m² will be dedicated to shops with food storage, thus consuming significantly more electricity due to the refrigeration load. This energy consumption is process related and not building related, and therefore it is normally not accounted for when looking at the energy performance of buildings. Consequently it is not included in the definition of the ZEB balance and target. Nevertheless it will be necessary to take into consideration also the refrigeration load when looking at the energy system solution.

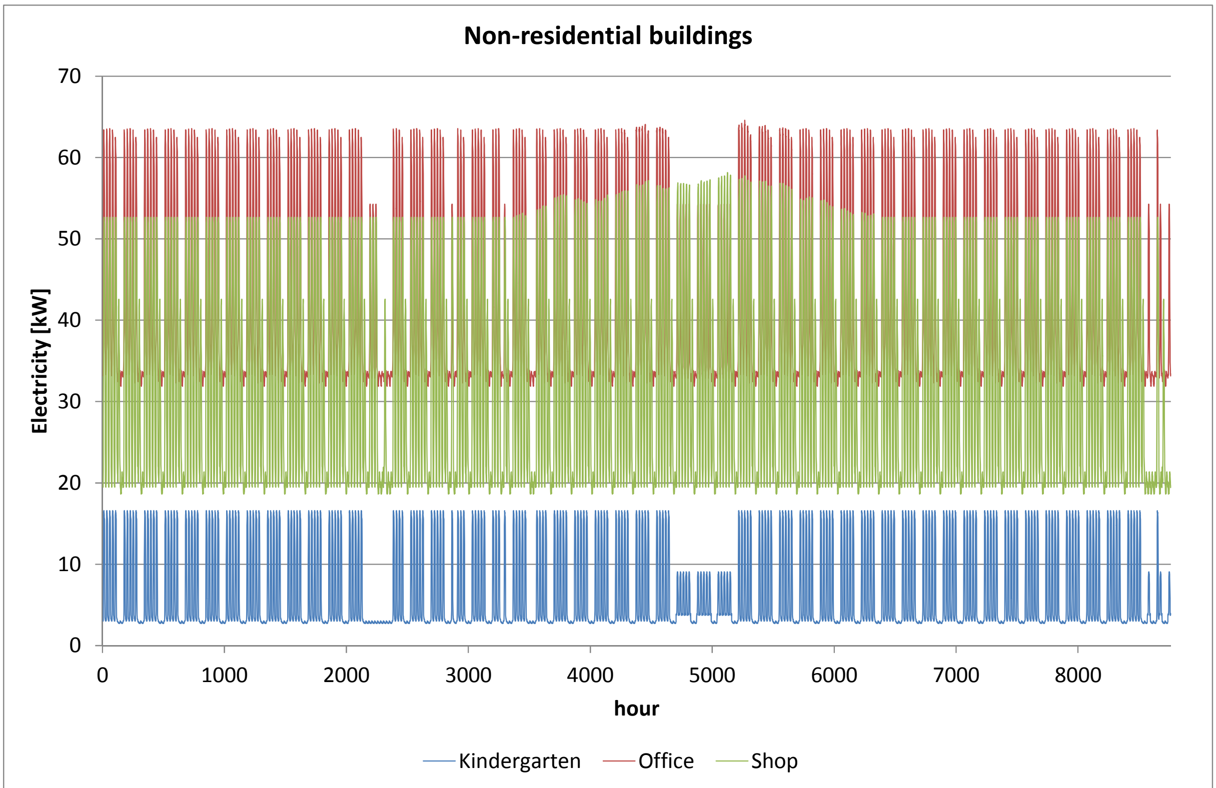


Figure 2.5 Total electric load profile for the non-residential spaces: Kindergarten, Office and Shop. The weeks with markedly reduced consumption are due to Easter, summer and Christmas vacations.

2.3.4 Results

The overall results for the electric load in ZVB are shown in Table 2.6. For residential buildings, the difference between terraced houses and apartment blocks is merely due to the different floor area since the same aggregated profiles have been assumed for the whole neighbourhood, as explained above. For non-residential buildings it is worth noting how high their electric specific demand is (per m²) compared to residential buildings. Even though non-residential buildings only represent 7% of the total floor area in ZVB, they contribute to 21% of the total electric yearly demand.

[14] See footnote 5.

Table 2.6 Summary of the aggregated electric load.

Electric load	Energy [kWh/y]	Energy [kWh/m²y]	Peak Power* [kW]	Peak Power* [W/m²]
Terraced houses	1 849 000	29.8	449	7.2
Apartment blocks	704 000	30.6	169	7.3
Total residential	***2 553 000***		*619*	
Non-residential (sum)	705 000	104.8	138	20.5
Total ZVB	***3 257 000***		*684*	

* Hourly average, without food storage in shop area.

The value that needs to be considered for the ZEB balance of the entire ZVB is approximately 3.3 GWh/y (2.6 GWh/y for the residential buildings only), while the peak load to be considered for dimensioning of the energy system is approximately 0.7 MW. Both values are excluding the refrigeration load in the supermarket area and eventually the electric load deriving from charging of electric vehicles.

2.4 Thermal load

2.4.1 Simulation set up

The thermal load has been calculated using IDA ICE, a software tool for dynamic building energy performance simulations. The two typologies of residential buildings, terraced house and apartments block, have been modelled in thermal zones as discussed in §2.1 and as shown in Figure 2.1, and lighting and plug load profiles from §2.3 were used as input.

The following Figures 2.6, 2.7, and 2.8 show a schematic representation of the building model in IDA ICE.

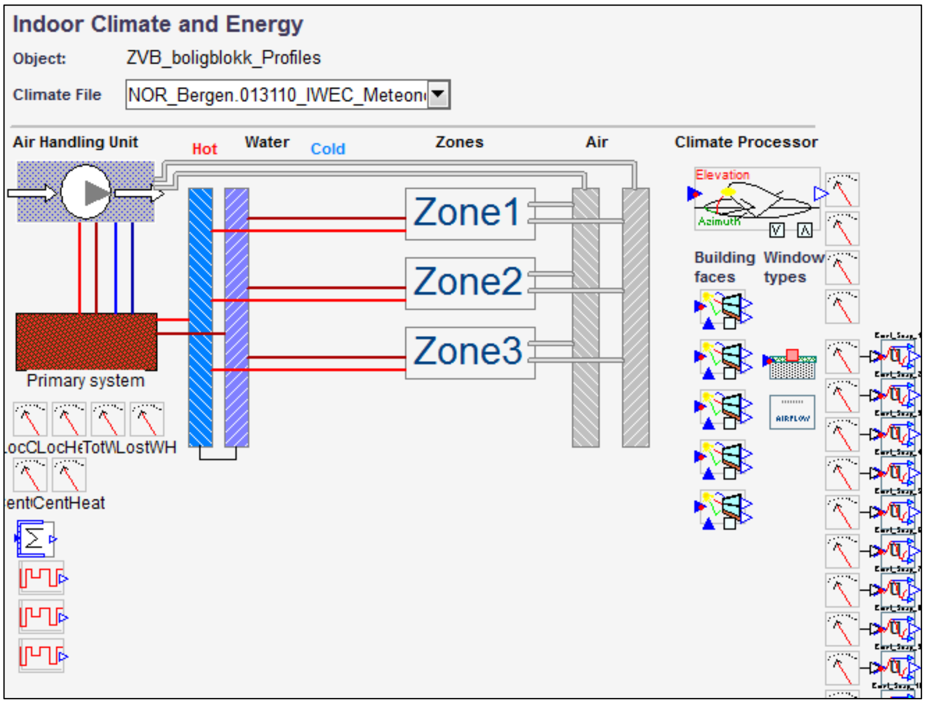


Figure 2.6 Schematic of the connections between thermal zones and the plant (primary system) and the AHU (Air Handling Unit) in IDA ICE.

Figure 2.6 shows how the thermal zones are served by the plant (primary system) for heating and cooling purposes, and by the AHU (Air Handling Unit) for ventilation. As explained in §2.1 the three thermal zones represent the four floors in the average apartments block and the 15 dwellings in the average terraced house, with Zone 2 representative of the intermediate floors/units. Each zone is equipped with a generic heating panel served by the primary system, thus simulating a hydronic heating system with low temperature radiators or a hydronic floor heating system.

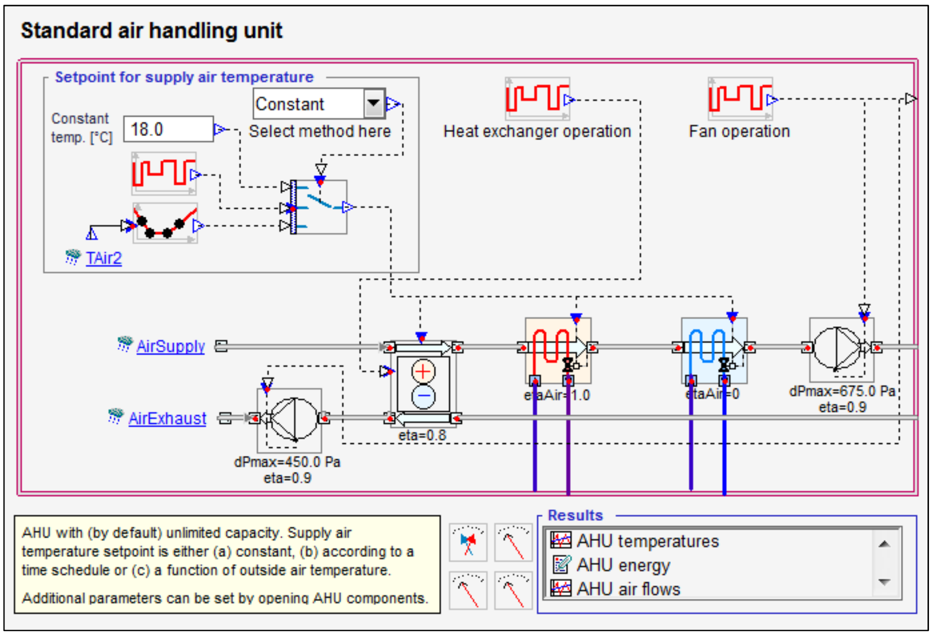


Figure 2.7 Schematic of the Air Handling Unit, AHU, in IDA ICE.

Figure 2.7 shows the main structure of the AHU, with the fans, the heat exchanger and the heating and cooling coils (cooling coil not used in these simulations). The ventilation is a Constant Air Volume (CAV) system that supplies fresh air to the zones at 18°C throughout the year; a typical ventilation system in Norwegian new built residential units. Since there is no active cooling, the supply temperature may exceed 18°C in summer.

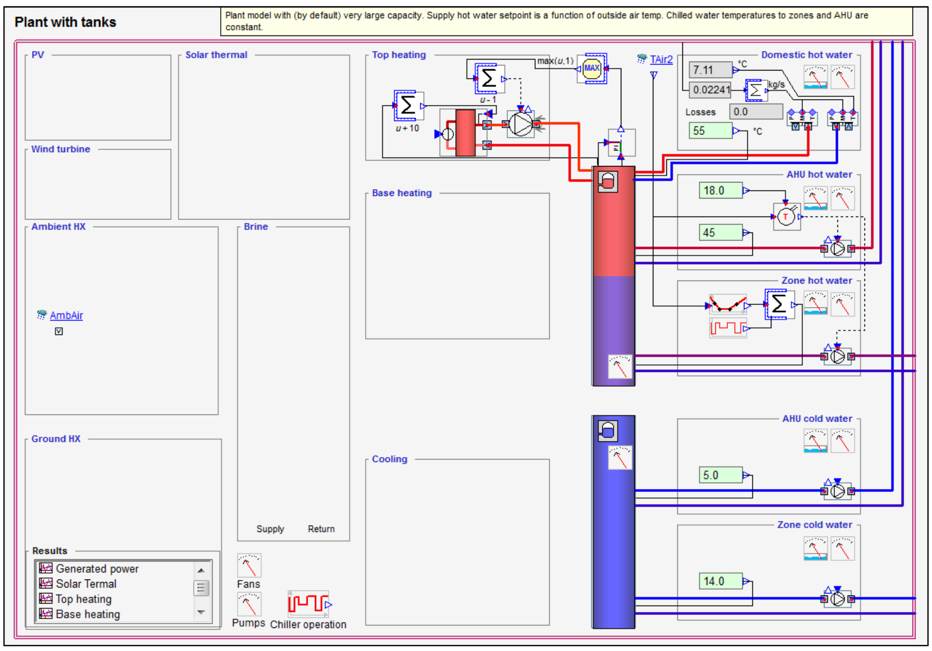


Figure 2.8 Schematic of the plant in IDA ICE.

Figure 2.8 shows the main components of the plant, or primary system, in IDA ICE. These simulations are meant to estimate the heating need of the buildings regardless of which system will be used to actually supply the demand – which is a task for future work. Therefore, the plant is reduced to a generic boiler (top heating unit) supplying heat to various purposes: hot water, ventilation heating and space heating at the respective design temperatures which are: 55°C, 45°C, and 45°C (maximum, when outdoor temperature is -20°C), respectively. The heating tank is only virtual (it is a required component in the IDA ICE plant structure but has no volume in this case) since its dimensioning and use – and thus its thermal losses too – will depend on the heat generator chosen, e.g. heat pump, boiler or district heating, and its properties are therefore part of the heating system and not part of the heating need. Furthermore, a general 10% heating losses have been considered for the distribution losses.

2.4.2 Indoor thermal comfort

The following Figures 2.9 and 2.10 are useful to get a graphical impression of the indoor thermal environment in the simulated buildings.

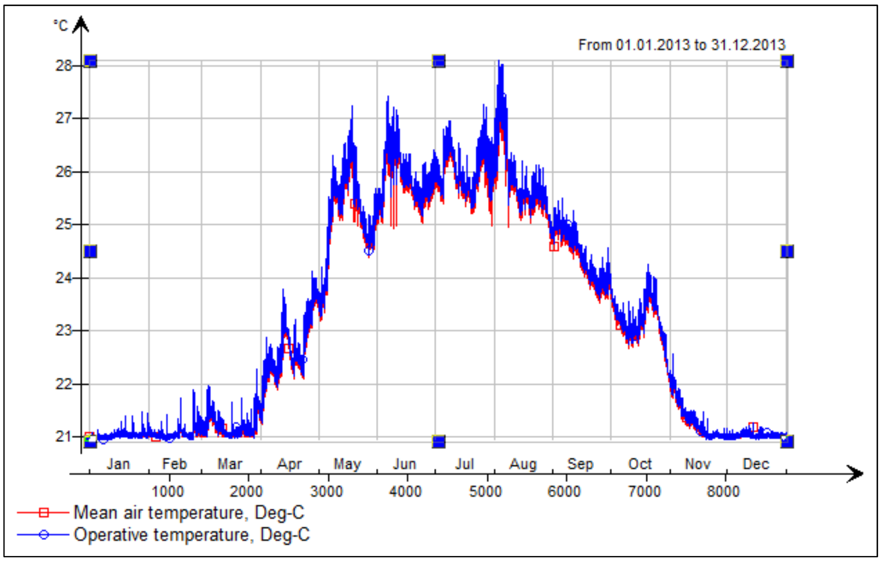


Figure 2.9 Overview of indoor temperatures in Zone 2 of the apartment block throughout the simulation year (the most sensible to possible overheating).

Figure 2.9 shows indoor temperatures in Zone 2 of the apartment block, the one most sensible to possible overheating. In winter the constant heating setpoint controls the air temperature and force it at 21°C. In summer the indoor temperature is floating since there is no active cooling. It should be noted that these simulations are not aimed at studying the indoor thermal comfort of the building, for which purpose a more detailed modelling of the thermal zone would be necessary. The purpose here is to estimate the energy demand, for which purpose it is commonly accepted practice to simulate entire dwellings or floors as a single thermal zone because the accuracy in estimating the energy demand is not significantly affected by this assumption. Note that this thermal zoning is in any case more accurate than what is required by the standard NS3031[15], according to which a single thermal zone is normally sufficient for the entire building in the case of residential buildings.

Nevertheless, it is important to simulate an indoor thermal environment that is realistic, though approximated. In particular, it would be misleading to focus only on the winter condition because cooling is assumed not necessary a priori. Rather, this assumption should be verified because there might be the risk of overheating in highly insulated and air-tight buildings, and passive cooling measures should

[15] See footnote 8.

be considered – also in the simulations – that prevent overheating. This is explained in relation to Figure 2.10.

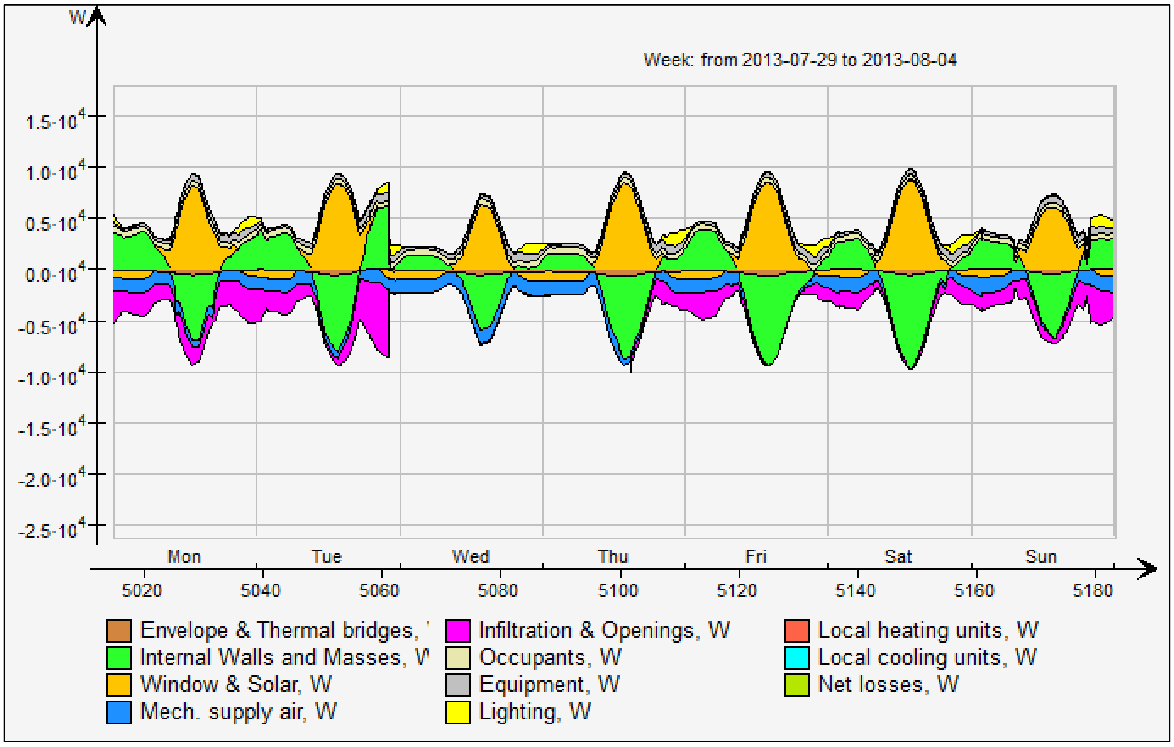


Figure 2.10 Overview of the energy balance in Zone 2 of the apartment block in one summer week.

Two typical passive cooling measures to consider are the use of solar shading devices such as Venetian blinds, both internal and/or external, and natural ventilation, i.e. the manual opening of windows. In the performed simulations no solar shading was considered but natural ventilation was considered. In particular, it is assumed that occupants open the windows when the indoor air temperature rises above 26°C in an attempt to cool it down. It is also assumed that such a 'control' is purely proportional and therefore inherently inaccurate and delayed (as opposed to a proportional-integrative control that would rather simulate the behaviour of an automatic control of natural ventilation). Furthermore, the amount of fresh air intake by natural ventilation is limited so that it never exceeds realistic values, such as 5 to 6 air changes per hour.

Figure 2.10 shows the energy balance in Zone 2 of the apartment block in one summer week, and illustrates how the natural ventilation is simulated. Note, for example, that while the daily peaks represent the effect of solar gains (positive) and its accumulation in the internal thermal mass (negative), the second peak occurring on Tuesday afternoon is due to natural ventilation. As the indoor air temperature rises above 26°C, windows are opened, and when the temperature drops again below 26°C (due to a combination of less solar gains and cooler outdoor air as evening comes) there is a sudden change in the energy balance due to the closing of windows. The behaviour of the indoor air temperature in the period with opened windows is dependent on the actual conditions of solar radiation, outdoor air temperature, wind speed, as well as the internal thermal mass properties and internal gains. For these reasons the summer temperature is never perfectly controlled and may rise above 26°C, as is to be expected in the absence of active mechanical cooling. Nevertheless, as Figure 2.10 shows, indoor temperatures above 28°C are not expected, even without solar shading devices; this is considered both an acceptable temperature condition and a reasonable margin of safety. It should be reminded again that this is with respect to the purpose of estimating the energy demand of the building, not the indoor thermal comfort conditions, for which a more detailed thermal zone modelling would be necessary.

2.4.3 Thermal envelope and ventilation parameters

The following Table 2.7 summarizes the main parameters of the envelope and of the ventilation system, which qualify the buildings as passive houses according to the Norwegian standard NS3700[16].

Table 2.7 Main parameters of the buildings' envelope and ventilation system.

Parameter	Value	Unit	Note
U-Value walls	0.14	W/m²K	350mm insulation
U-Value roof	0.09	W/m²K	350mm insulation lightweight
U-Value ground	0.11	W/m²K	Equivalent U-value for ground transmission
U-Value windows (glass)	0.8 (0.7)	W/m²K	20% insulated wood frame
% window area/BRA	20	%	60% South, 40% North
Air-tightness	n_{50} = 0.5	ach	
Thermal bridges	0.03	W/m²K	
Ventilation airflow	1.2 / 1.4	m³/hm²	Fresh air supply for terraced house / apartments block
Ventilation heat recovery η	80	%	Min. exhaust T = 5°C
SFP (Specific Fan Power)	1.25	kW/(m³/s)	
Low temperature system	45	°C	Dimensioning T space heating @ -20°C T_{supply} ventilation heating battery

2.4.4 Domestic Hot Water (DHW)

In very well insulated buildings the space heating need is so low that it is lower than the Domestic Hot Water (DHW) need. A passive house has by definition a heating need < 15 kWh/m²y (NS3700) while the normative value for DHW is 30 kWh/m²y (NS3031)[17]. However, there are some differences behind these numbers. The value for space heating is expressed as a need[18], therefore not considering the efficiency and losses of the heating system; furthermore, it is a thoroughly grounded number resulting from the application of the passive house concept: highly insulating envelope, air tightness, maximization of solar gains, ventilative heating. The DHW value, on the other hand, is expressed as delivered energy, so considering the efficiency of the heat generation system and the storage losses[19]. Furthermore, there are reasons to believe that the DHW normative value may be an overestimate, perhaps useful for labelling purposes but not as an estimate of real consumption. Substantially different values are found in literature, and it is possible to use simple calculations, as shown in Table 2.8 and by applying Equation 1.

Table 2.8 DHW values from different sources.

Domestic Hot Water load	NS3031/NS3700	NVE[20]	Sweden – 1300 dwellings[21]	Finland – 180 dwellings[22]
Metrics and unit	Delivered energy [kW/m²y]	Delivered energy [kW/m²y]	Water flow need [m³/m²y]	Water flow need [m³/m²y]
Value	30	22*	0.41	0.29*
Unit			[l/pers.day]	[l/pers.day]
Value			61*	43

* Assuming Norwegian average dwelling size of 119 m² and 2.2 pers/dwelling (SSB)
Note: there can be significant differences in the choice of reference floor area between countries

[16] See footnote 4.

[17] For NS3700 see footnote 4, for NS3031 see footnote 8.

[18] Assuming a balanced ventilation system with heat recovery is in place, therefore seeing it as a passive measure, not as a heating supply system.

[19] Typically in Norway DHW is prepared with an electric heater immersed in a hot water storage tank.

[20] See footnote 13.

[21] Bagge H., Johansson D. and Lindstrii L. (2015) Brukarrelaterad energianvändning: Mätning och analys av husållsel och tappvarmvatten, *Lågan Rapport*, Lund, Sweden.

[22] Ahmed K., Pylsy P. and Kurnitski J. (2015) Monthly domestic hot water profiles for energy calculation in Finnish apartment buildings, *Energy and Buildings*, (97) 77-85.

The values shown in Tabke 2.8 from Sweden and Finland refer to measurement campaigns on large samples of dwellings: approximately 1300 and 180, respectively. In these reports physical quantities of water flows were measured, but since different units of measurement were used, the conversion between them is made assuming the average size of Norwegian dwellings (119 m^2) and households (2.2 pers/dwelling), according to the Statistics Bureau (SSB). This may partly explain the difference in the numbers from Sweden and Finland, since the actual conversion between units should have been made using dwelling and household size data from each country. However, it shall also be noted that there can be significant differences in the choice of reference floor area between countries (e.g. net, gross, useful, utility floor area), thus making any conversion between different datasets somewhat imprecise. The value from NVE seems rather lower than the one from the norms NS3031 and 3700, and also lower than the results from simulations, see Table 2.9, and from application of Equation 1, see below. However, it is interesting to note that while NVE numbers – not coming from direct measurements but from a review of existing reports and datasets – seems to underestimate the DHW demand, they also seem to overestimate the plug loads demand, see Table 2.5. It is likely that the two things are correlated, since DHW preparation is done predominantly via electric boilers, and so it is often measured together with the other plug loads, and it may then be difficult to properly distinguish between the two parts of the total.

The following Equation 1 is useful to get an understanding of what the DHW demand is likely to be, given some approximation. In particular, if we consider that the physical properties of water can be taken as constant in the relevant temperature range, such as its thermal capacity c_p and its density – water is indeed an incompressible fluid with a density of, by definition, 1000 litres per m^3 – the only assumptions we need to make are on the mass flow rate and the temperatures. Assuming an average mass flow rate m of 0.41 m^3/m^2y as from the Swedish study (which had the largest sample, see Table 2.8) and an average temperature difference ΔT of 45°C (e.g. average storage/supply T = 55°C and water from the mains at T = 10°C) we obtain the energy need Q equal to ca. 21.5 kWh/m^2y, as shown below:

$$Q = m \cdot c_p \cdot \Delta T \qquad \text{Equation 1}$$

$$m = 0.41\, m^3/m^2y = 410\, kg/m^2y$$
$$c_p = 4.2\, kJ/kgK = 4.2/3600\, kWh/kgK$$
$$\Delta T \cong 45°C$$

$$Q \cong 21.5\, kWh/m^2y$$

This value represents a pure need; losses from generation, storage and distribution have to be added on top. This is why the value from NVE reported in Table 2.8 appears to be rather low, being given as delivered energy. In the simulations performed with IDA ICE the temperature of the water from the mains varies from month to month according to the ground temperature, and the average level of supply/storage is assumed to be 55°C. Additional distribution losses are added (as an input data in IDA ICE) based on values form the EU-project TABULA[23]:

- Terraced house = 1 kWh / m^2y
- Apartments block = 3 kWh / m^2y

[23] TABULA (2013) TABULA Calculation Method – Energy Use for Heating and Domestic Hot Water, *TABULA project team*, see www.building-typology.eu.

The relatively large value for the apartments block is due to the DHW recirculation system always necessary in large buildings. The losses due to heat generation and storage are not considered, since it depends on the heating system to be chosen (e.g. district heating or heat pump) and its dimensioning and configuration.

The results from the whole building energy performance dynamic simulations in IDA ICE are shown in Table 2.9. The values for space heating and DHW represent energy needs, though not strictly meant (as in NS3031) since the numbers already include, as mentioned earlier in this chapter, distribution losses of 10% for the heating part and the fixed values shown above for DHW.

Table 2.9 Results of the simulations in IDA ICE.

Energy service	**Terraced house [kWh/m²y]**	**Apartments block [kWh/m²y]**
Heating	11.8	10.2
Space	9.9	8.2
Ventilation	1.9	2.1
DHW	24.8	26.8
Fans and pumps	3.6	4.2
Lightning	7.6	7.7
Plug loads	18.5	18.6
Total	**66.3**	**67.5**

It is interesting to note that the resulting overall energy demand, 66-68 kWh/m²y which is about half that of a conventional new building built according to the current TEK10 requirements, is more or less the same for both types of houses, allowing for some uncertainty on the given numbers. In §2.5 a sensitivity analysis is carried out for those parameters and input values that might significantly affect the results. However, concerning the distinction between terraced houses and apartment blocks, it should be noted that some parameters are held constant (per m² of floor area) between the two dwelling types while there is no certainty that this is the case; this concerns lighting, plug loads, and DHW flows. Nevertheless, this is common practice and the normative values in NS3031, though different from those used here, are also constant for any type of residential building. With this given, we obtain a figure for space heating need that is lower in the apartment block than in the terraced house, as expected due to the unfavourable surface-to-volume ratio of the latter. However, since the space heating need is so small in absolute, the difference between the two is small enough to be counterbalanced by the higher energy needs in the apartment block for DHW (circulation losses) and ventilation (higher fresh air requirement).

A final remark is worthwhile concerning DHW: while all other energy needs are treated with hourly profiles (whether deterministic or stochastic) the DHW flow is treated as a constant flow throughout the year, i.e. the same flow is assumed for every hour of the year, see Table 2.8. This is only partly due to the fact that data on water flow are scarce, yet to some extent available such as in the Finnish study mentioned in footnote 22, and in standardized form (deterministic, always repeating the same pattern for every single day) also in some norms[24].

There are two main reasons for considering a constant DHW. First, there is always a hot water storage tank (since we are not considering instantaneous boilers) so that energy use for DHW and actual hot water withdrawals are strongly decoupled. Second and most important, preparation of domestic hot water requires different temperature levels and different sanitary attention than hot water for space heating. Therefore it is convenient to have a clear distinction of which part of the thermal load is due to space heating and which to DHW, so that one can clearly see what is the relative importance of the two

[24] See for example EN 15316-3-3:2007. Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies. Part 3-1: domes-tic hot water systems, characterization of needs (tapping requirements), 2007.

in terms of energy and power demand and have this in mind when addressing the choice and the dimensioning of the heating system. In other words, in old buildings the DHW demand is always a fraction of space heating demand and may be neglected in the first analysis; but the situation is reversed in new highly energy efficient buildings, as noted. It is important to clearly visualize this aspect, and plotting the DHW demand as a flat value throughout the year helps distinguishing it from the hourly ups and downs (and seasonal drift) of the space heating demand.

2.4.5 Non-residential buildings

For the non-residential buildings, the energy demand has been calculated directly from real measurements of similar buildings, as explained at the beginning of §2. Representative average profiles for the total thermal load are shown in Figure 2.11 for the total of kindergarten, office and shop floor areas[25].

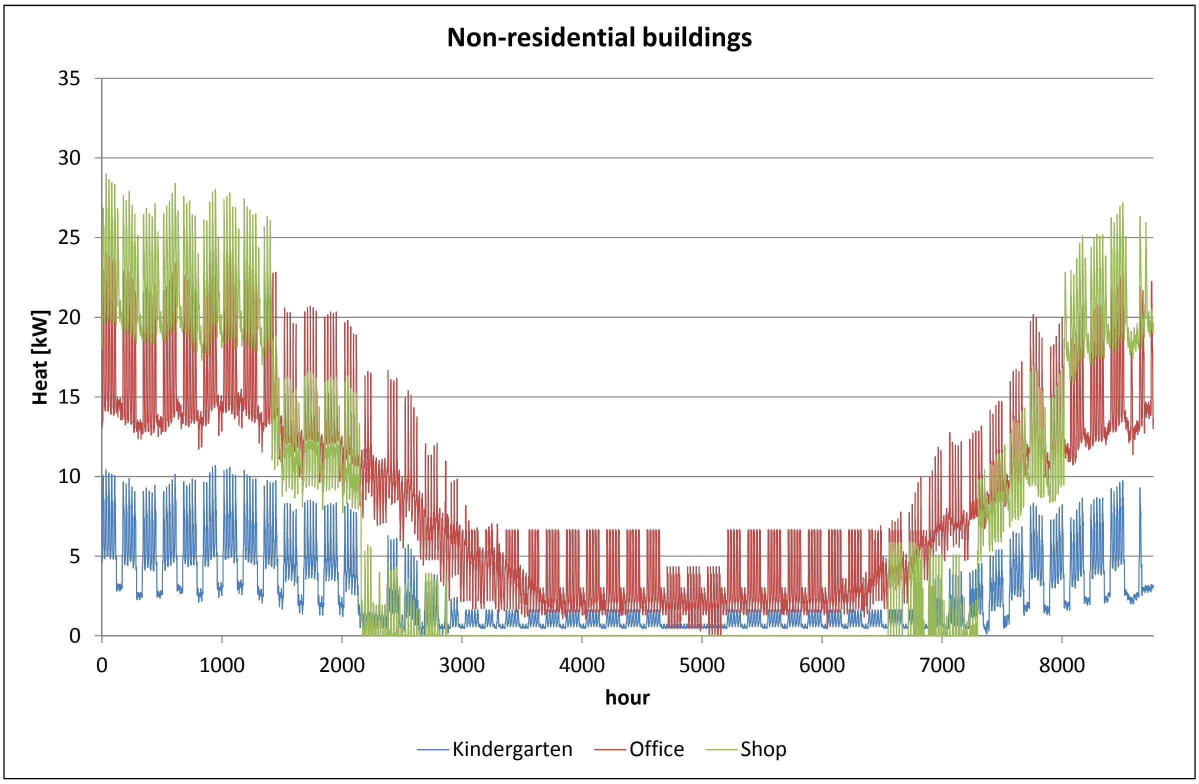


Figure 2.11 Total thermal load profile for the non-residential spaces: Kindergarten, Office and Shop. The weeks with markedly reduced consumption are due to Easter, summer and Christmas vacations.

2.4.6 Results

The overall results for the thermal load of Zero Village Bergen are shown graphically in Figure 2.12 – Figure 2.14 and summarized in Table 2.10. Figure 2.12 shows the aggregated hourly profile and its duration curve superimposed; the flat values during the summer, as well as in general the bottom constant part of the load is due to the DHW demand, while the oscillating values above this constant minimum are due to space heating (both ventilation heating and room heating).

[25] See footnote 5.

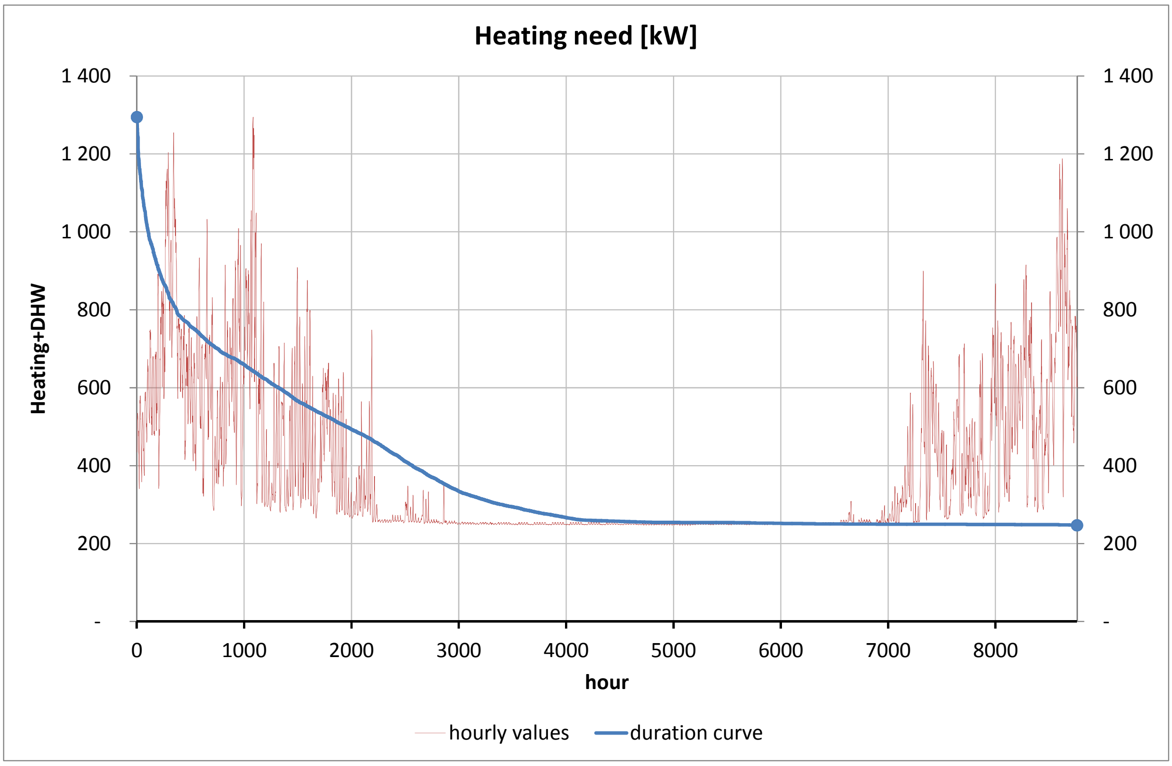


Figure 2.12 Hourly profile (red) and duration curve (bold blue) of the total thermal load for the Zero Village Bergen.

Figure 2.13 shows the load duration curve and the corresponding energy coverage curve in percentage values on the first *y*-axis, together with a duration curve of the outdoor temperature on the second *y*-axis, used as a reference for the climatic conditions. The graph should be read as in the following example, and it provides an answer to the question:

> *How much energy demand y [%] do I cover with a (base) heating system dimensioned to cover x [%] of the dimensioning load?*

The answer is given by a cross-reading of the values in the load and energy curves. For example, set the value of load coverage at 50% on the *y*-axis, move horizontally to intercept the red (load) curve and thereafter move vertically to intercept the black (energy) curve. Move again horizontally to read the value on the *y*-axis, which is ca. 95%. This means that a base heating system dimensioned to supply 50% of the dimensioning load would cover ca. 95% of the annual energy demand, leaving barely 5% to be covered by the top (back-up) heating system.

Knowledge of such values is important when designing the heating system because it affects its cost and performance. The investment cost normally increases proportionally with the installed capacity (higher capacity = higher cost) while the part load efficiency normally decreases inversely proportional to the installed capacity, and with it the operational cost goes up (higher capacity = lower part-load efficiency = higher operational cost). It is therefore convenient to under-dimension the main heating generator (the base heater, e.g. the heat pump) in order to have it operating closer to its nominal capacity and thus reduce both investment and operational costs. On the other hand, the top heater (e.g. electric immersion resistance) is normally chosen to be significantly cheaper in installation cost, but the price to pay for it is that its operational performance is also poorer. Therefore, a minimization of the global cost (investment and operation and maintenance) for the entire heating system (base and top heaters) is to be sought as a balance between a low base-heating dimensioning and a low top-heating operation.

As a rule of thumb – for example for heat pumps, though similar considerations are valid also for boilers and CHP units – it is often good practice to dimension the base heating system to cover about 40-60% of the maximum load. Nevertheless, the shape of the load duration curve in highly energy efficient buildings is substantially different than in conventional buildings. Furthermore, the storage will also play an important role in hedging between nominal and part-load efficiencies, at the cost of some storage losses. The proper dimensioning of the heating system is a task for future work, for which the graphs shown here will be the main input.

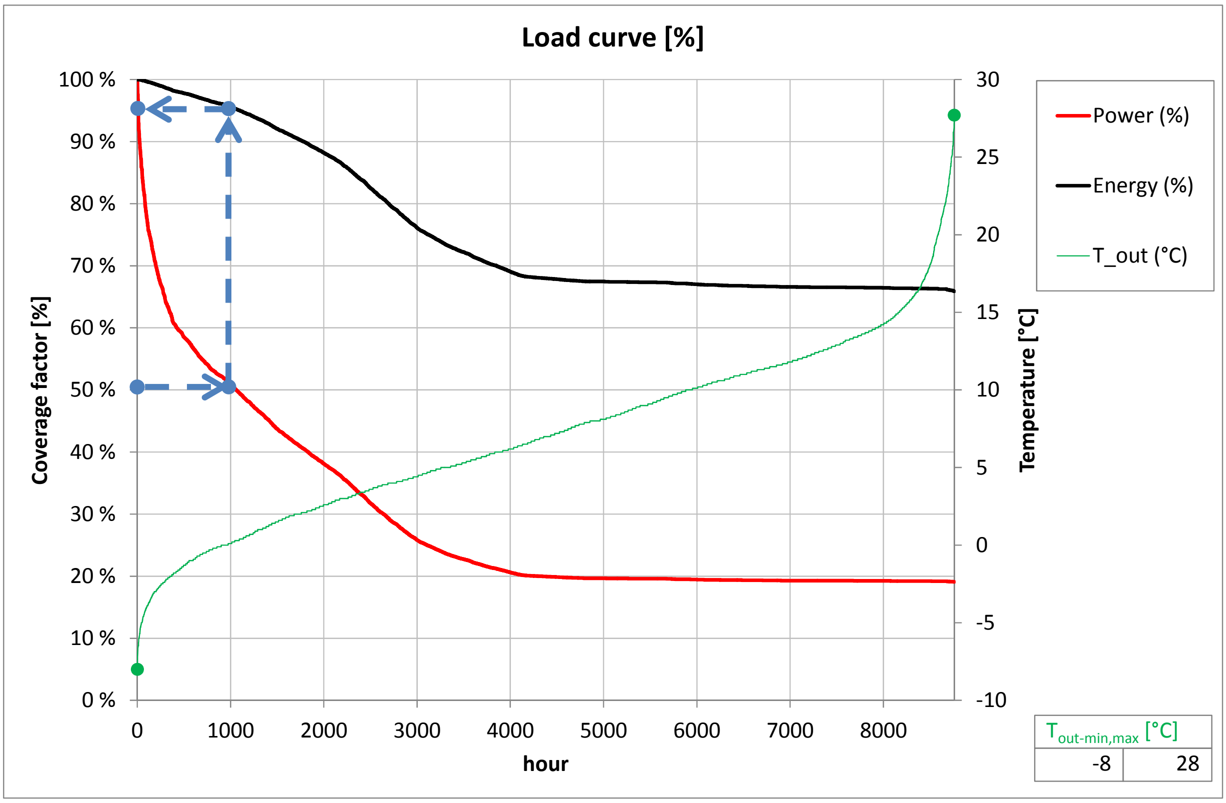


Figure 2.13 Percentage values of load duration curve (red), energy coverage curve (black) and temperature duration curve (thin green) for the total thermal load for the Zero Village Bergen. The bold blue line shows an example of how to read the graph.

Figure 2.14 shows substantially the same data, but not including the temperature curve, in absolute scale. Applying the same example as above, we see that choosing a base heating system with a capacity of 600 kW (less than 50% of the dimensioning load) would cover more than 3.0 GWh of yearly energy demand (i.e. more than 90% of the total).

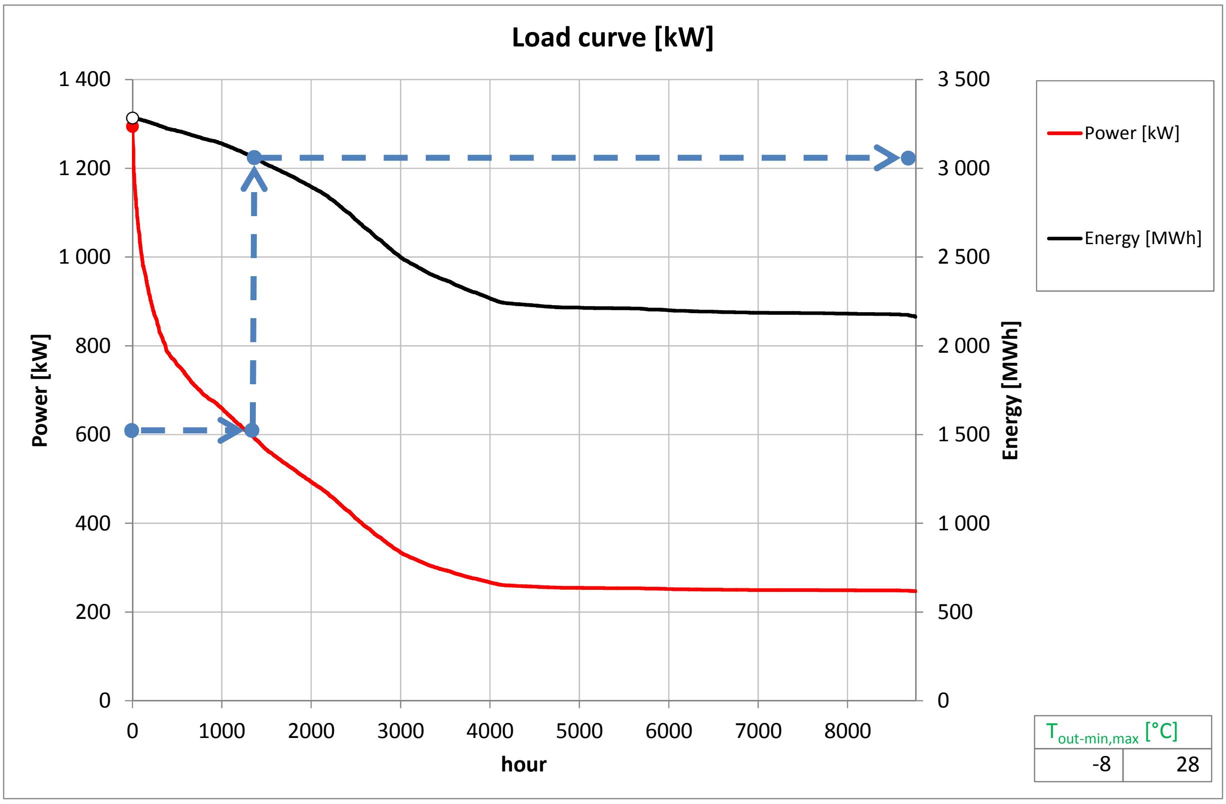


Figure 2.14 Absolute values of load duration curve (red) and energy coverage curve (black) for the total thermal load for the Zero Village Bergen. The bold blue line shows an example of how to read the graph.

Finally, the aggregated results for the thermal load are shown in Table 2.10. Terraced houses and apartment blocks have similar intensity values (per m²) for both energy and peak power demand, though in the totals the impact of terraced houses is dominant because of their larger floor area. The non-residential buildings, on average, have thermal requirements that are more modest than for residential buildings (contrary to what happens with the electric load, see Table 2.6), and their impact is small on both the total energy demand and the peak power demand.

Table 2.10 Summary of the aggregated thermal load.

Thermal load	Energy		Peak Power*	
	[kWh/y]	[kWh/m²y]	[kW]	[W/m²]
Terraced houses	2 272 000	36.3	901	14.4
Apartment blocks	852 000	37.0	361	15.4
Total residential	***3 124 000***		*1 262*	
Non-residential (sum)	160 000	23.8	63	9.4
Total ZVB	***3 283 000***		*1 300*	

* Hourly average.

The value that need to be considered for the ZEB balance of the entire ZVB is approximately 3.3 GWh/y (3.1 GWh/y for the residential buildings only), while the peak load to be considered for dimensioning of the energy system is approximately 1.3 MW.

2.5 Sensitivity analysis: loads

The aim of this sensitivity analysis is to gain a sense of the magnitude by which the results may change depending on the possible changes in some key inputs and parameters. In this sensitivity analysis, different input values and parameters are considered, especially those whose assumed value is most uncertain, in order to evaluate their impact on the final results in terms of both energy demand and peak power.

For the residential buildings, the assumed values of the identified inputs and parameters are changed within a certain range. The uncertainty range is not defined a priori, e.g. ± 15% of the central value; rather, the boundary conditions and the different data sources are considered as alternative input and parameter values. Furthermore, the effect of every single variation will be evaluated in itself, and no cumulative effect will be considered since it is not possible to say a priori how they correlate. In other words, if variation A gives an effect (for example on total energy demand or peak power) of + 3% and variation B also gives and effect of + 3%, we cannot conclude that the combined effect of A+B will be + 6%. Likewise, if the variation B had an effect of - 3% we could not conclude that A and B neutralize each other giving a net zero effect. We simply do not know how these variations correlate to each other in a complex system such as the one under analysis (we could know it if it were merely about adding, multiplying or performing other simple mathematical operations between different variables; then we would know also how to treat mathematically the combination of the error probabilities and error intervals of each single variable).

For the non-residential buildings, since the load is taken here as an input, we consider a possible variation of ± 50% on the hourly values, while keeping the same temporal profile.

2.5.1 Electric load

Four alternative inputs can be considered when looking at the electric load: using the values tabulated in NS3031, considering less efficient ventilation fans, looking at the values with 1-minute resolution, and the use of induction cookers. The results of the sensitivity analysis on these four inputs are shown in percentage values in Table 2.11. First the variation in the four inputs is presented (in % over their reference value), while the last row shows the resulting variation on the total ZVB electric load (in % over its reference value).

Table 2.11 Results of the sensitivity analysis of the electric load.

	Residential								**Non-residential**	
% variation of input	NS3031 values		Worse SFP		1-minute resolution*		1-minute resolution* & induction cooker		± 50 %	
	Energy	**Peak Power**	**Energy**	**Peak Power**	**Energy**	**Peak Power**	**Energy**	**Peak Power**	**Energy**	**Peak Power**
Lighting	+48%	n.a.	-	-	-	+7%	-	+7%		
Plug loads	-6%	n.a.	-	-	-	+16%	-	+29%		
Ventilation fans	-	-	±20%	±20%	-	-	-	-		
Total non-residential load									±50%	±50%
% variation of ZVB electric total	+7%	n.a.	±2%	±2%	-	+7%	-	+12%	±11%	±5%

* For residential buildings only.

Considering the tabulated values in NS3031 for lighting and plug loads is an obvious choice, since those are the values that would normally be used in common practice. For total energy demand, the variation in the input values looks significant for the lighting (+48%) and moderate for the plug loads (-6%). However, due to the relatively low importance of lighting on the total ZVB electric load, the net effect is an increase of + 7%. Regarding the peak power, nothing can be said in this case because the NS3031 prescribes a flat value to be applied for 16 hours a day; the resulting value, however meaningless, would be lower than the estimate we get by using stochastic user profiles.

Another obvious variation is to consider ventilation fans that are more or less efficient. The assumed SFP is 1.25 kW/(m^3/s), which is not at the frontier of the best possible values (SFP <= 1.0 kW/(m^3/s)) but is still better than the requirement in NS3700 for passive house standard (SFP = 1.5 kW/(m^3/s)). Since the ventilation in the residential buildings is a CAV system (Constant Air Volume), this corresponds to a ± 20% variation in both energy demand and peak power for the ventilation fans. The effect on the overall ZVB total is nevertheless rather small, being ± 2% for both energy demand and peak power.

N.B. These values, though small, are the only ones that can certainly have a direct additive effect on top of the other uncertainties, since the CAV ventilation system means that the fans are always in operation and with a flat power profile.

Using the input data with a 1-minute resolution does not change the total energy demand, but does affect the peak power, which increases by + 7% and + 16% for lighting and plug loads, respectively. The overall effect on the total ZVB peak load is no more than + 7%, mainly because of the non-coincidence of the 1-minute peaks.

An attempt was made also to estimate what might be the effect of using induction cookers instead of conventional ceramic electric cookers. This result should be considered with care, since the method for generating stochastic user profiles[26] does not contain a modelling of the induction cooker based on direct observations. What has been done to attempt an estimate is to modify the parameters of the conventional cooking cycle, increasing threefold the average power (from 1 to 3 kW) and decreasing threefold the average time (from 27 to 9 minutes), so that the average energy per cooking cycle (a calibrated parameter) would remain the same. The adaptation is somewhat artificial because it does not contain an observed profile of the power variation during the cooking cycle with induction cookers, but it does address the fact that a higher power demand is accompanied by a shorter cooking time, therefore reducing the coincidence factor between households. The increase in peak power thus result less pronounced than one might imagine. Furthermore, the effect would nearly disappear on the hourly resolution and it is then presented for the 1-minute resolution. An increase in peak power of + 29% for the plug loads caused by the simulation of an induction cooker, turns into an overall ZVB peak power increase of + 12%.

Finally, the electric load for the non-residential buildings has been considered with variations of ± 50% for safety's sake. Though the values come from real measurements of dozens or hundreds of buildings per each building type[27], the spread around the average is generally rather high and the small amount of non-residential floor area in the ZVB is by no means guaranteed to behave as the average of a much larger sample. The variation affects both the energy demand and the peak power (being applied on the hourly values), resulting in an overall variation of ± 11% in energy demand and ± 5% in peak power for the entire ZVB.

[26] See footnote 9.

[27] See footnnote 5.

In conclusion, it appears reasonable to consider intervals of confidence for energy demand and peak power as shown in Table 2.12. This interval is obtained by simply taking the largest variations caused by a single input, as from Table 2.11 (see also initial remarks in §2.5). It shall be reminded that one must be more cautious with the peak power because it is an instantaneous value and therefore subject to extreme variations, while the energy demand is a more robust estimate being the sum of an entire year's data series where over- and under-estimations on single data points may balance each other off to some extent.

Table 2.12 Summary of the aggregated electric load considering the sensitivity analysis.

Electric load	**Energy demand [GWh/y]**	**Peak Power* [MW]**
Total ZVB	*3.3 (±11%)*	*0.7 (-5% / +12%)*

* 1-minute resolution.

It shall be once more reminded that the data in Table 2.12 do not consider the energy demand and peak power related to neither the refrigeration load in the shops area nor the charging of electric vehicles.

2.5.2 Thermal load

Several alternative inputs have been considered when looking at the thermal load, as shown in Table 2.13 that reports the results of the sensitivity analysis in percentage values. The inputs considered are: weather file (IWEC instead of Meteonorm), heating and DHW loads as NS3700, higher indoor temperature, better/worse VHR (ventilation heat recovery), night setback, less thermal mass in floors/ceilings/internal walls (now concrete). Variations on the U-value of various envelope components and/or on the amount of window area (within reasonable values, and still guaranteeing for the classification as passive house) have not been considered explicitly. However, adopting the NS3700 values for heating loads represents the limit for a passive house denomination, and increasing the indoor temperature gives similar effects, even amplified. Table 2.13 shows only the resulting variation on the total ZVB thermal load (in % over its reference value), while the variations of the inputs are discussed below.

Table 2.13 Results of the sensitivity analysis of the thermal load.

	variation of input	**% variation of ZVB total**	
		Energy	**Peak Power**
Residential	Weather file: IWEC	+7%	-12%
	NS3700 values for heating loads	+22%	n.a.
	T_indoor = 24°C	+30%	+12%
	VHR* 70%	+6%	±0%
	VHR* 90%	-1%	±0%
	Night setback @19°C	±0%	+51%
	Low thermal mass	+1%	-2%
Non-residential	Total load ±50%	±3%	±1%

* Ventilation Heat Recovery

Concerning the energy needs, the high end of the sensitivity analysis is marked by the increased indoor temperature (+30% at 24°C instead of 21°C), while the bottom is marked by a variation of the expected thermal load from the non-residential buildings. It is worth noticing that the increased indoor temperature effect on just the space heating of residential buildings is +107% (from 10-11 to 22-23 kWh/m^{2}y, see Table 2.9). This is consistent with the knowledge that thermal losses vary approximately linearly with the delta-T (difference in temperature between indoor and outdoor). Indeed, when simulating without any heating source (neither space nor ventilation heating – though keeping the ventilation heat recovery) the free floating temperature turns out to be ca. 17°C on average in the heating season (Oct-Mar). Considering in addition that the heating season becomes longer when trying to keep 24°C indoor temperature, it looks reasonable that increasing the indoor temperature from 21°C to 24°C (delta-T = 3°C) requires about the same energy – actually slightly more – as keeping it at 21°C (delta-T ~= 3°C compared to the free floating temperature). However, since the DHW need is dominant (see Table 2.9) the overall effect on the ZVB aggregated thermal load is about 30%.

It can also be noticed that the effect of a better or worse ventilation heat recovery (VHR), over a reference efficiency of 80%, is asymmetrical. When increased to 90% it results in energy savings of -1% and reduced peak power of -1%. When decreased to 70% it results in additional energy use of +6% and peak power of +1%. The reason is that higher efficiency is not always used: when the ventilation T-supply reaches 18°C the VHR stops its function of saving energy, and it may rather contribute to overheating in summer, unless bypassed. Lower efficiency, instead, affects the entire duration of the heating season.

Concerning the peak power, the high end of the sensitivity analysis is marked by the night setback (+51% at 2°C setback delta), while the bottom is marked by a different climate file (-12% with IWEC instead of Meteonorm). It is worth noticing that the large increase in peak power due to night setback is not justified by any decrease in the energy need. This is because the energy need for heating in the residential buildings is already very small, so that reducing it a few % gives negligible results in the overall total thermal need of Zero Village Bergen, which is dominated by the DHW need. Finally, the difference given by using another climate file is interesting because it results in a substantial decrease in peak power (-12%) while resulting in a substantial increase in the energy need (+7%). This, of course, depends on the outdoor temperature profiles contained in the weather files. It is worth noticing that the IWEC weather file is the standard choice for energy performance simulations of buildings, while the Meteonorm weather file was here chosen as the reference one in order to have consistent hourly profiles with the PVsyst simulations, see §3.1.2.

Table 2.14 Summary of the aggregated thermal load considering the sensitivity analysis.

Thermal load		**Energy demand [GWh/y]**	**Peak Power* [MW]**
	Total ZVB	*3.3 (+30% / -3%)*	*1.3 (+51% / -12%)*

* hourly values.

In conclusion, it appears reasonable to consider intervals of confidence for energy demand and peak power as shown in Table 2.14. This interval is obtained by simply taking the largest variations caused by a single input, as from Table 2.13 (see also initial remarks in §2.5). It shall be reminded that one must be more cautious with the peak power because it is an instantaneous value and therefore subject to extreme variations, while the energy demand is a more robust estimate, being the sum of an entire year's data series where over- and under-estimations on single data points may balance each other off to some extent.

2.6 Summary: loads

The summary of the Zero Village Bergen electric and thermal loads is presented in Table 2.15, including the range of the sensitivity analysis.

Table 2.15 Summary of electric and thermal loads.

Total ZVB load	Energy [GWh/y]	Peak Power [MW]
Electric load	3.3	0.7 *
	(±11%)	*(-5% / +12%)*
Thermal load	3.3	1.3 **
	(-1% / +30%)	*(-12% +52%)*

* Hourly average, without food storage in shop area.
** Hourly average.

3. Aggregated PV generation

3.1 Preconditions for the analysis

Photovoltaic (PV) panels are the preferred power supply for on-site power production for this project. The power output of PV panels is highly dependent on the amount of solar irradiation, surface area, efficiency, and orientation of the panels. Thus, this study includes an assessment of the local solar irradiation in combination with power yield estimations based on the available roof area reserved for PV by the architect.

The software PVSyst (version 6) has been used to estimate the photovoltaic production in this project. PVSyst has been developed at the University of Genève (Switzerland) from 1992 and has a large database of existing PV components to use in the simulations. PVSyst is among the most recognized simulation tool and is widely used for both system design and technical/economical evaluation of solar power plants, it is one of the few software accepted by banks around the world for yield analysis. The software includes advanced features for simulation of all losses that may occur in a photovoltaic power plant, including a 3D tool for near shadings simulation.

3.1.1 Available roof area

The available roof area is calculated based on the gross floor area (GFA) of the buildings given by the architect. Knowing that the roof tilt will be approximately 19-20°, we apply the factor $\frac{1}{\cos 19} = 1{,}057$ to the GFA in order to obtain the area of the tilted surface.

<u>Example:</u>

$$m^2\ GFA\ \times \frac{1}{\cos 19} = m^2\ tilted\ roof$$
$$762\ m^2 \times 1{,}057 = 805\ m^2$$

Figure 3.1 below shows the identification of the different sites considered in this study.

Figure 3.1 Zero Village Bergen. Identification of the sites. The numbers indicate the order of the different construction phases.

An overview of the roof areas is shown in Table 3.1 below.

Table 3.1: Overview of the available roof areas.

Site	Name	GFA [m²]	Available roof area [m²]
1	Tun 04	2 404	2 541
2	Tun 03	2 205	2 331
3	Tun 01	1 243	1 314
5	Ådlands-byen vest	1 974	2 087
6	Ådlands-byen øst	1 389	1 468
7	Tun 07	1 322	1 397
8	Tun 10	1 357	1 434
9	Tun 08	1 357	1 434
10	Tun 11	1 537	1 625
11	Tun 09	2 236	2 363
12	Tun 06	1 642	1 736
13	Tun 05	1 445	1 527
14	Tun 02	896	947
15	Utsikten		1000
Sum		**21 007**	**23 204**

The available roof area of the building "Utsikten" has been assessed to be approximately 1 000 m². Because of slightly different roof orientations (azimuth), every site has been divided into different roof areas/buildings for the PV production. An overview is shown in Table 3.2 below.

The cover ratio of each roof ($\frac{m^2\ PV}{m^2\ roof}$) is normally very dependent on its own form (dimensions) and on the dimensions of the chosen PV module for an optimal pattern layout. We assumed a cover ratio of 95% for these calculations (meaning that PV covers 95% of the available roof area). This value is generally high, but we assessed that at an early stage the roofs can be designed according to the chosen module, and then the pattern layout and the cover ratio may be optimized.

NB: the building identification (for example "1 (N)") follows a numbering by a line from west to east. The letter indicates the line (north or south). This system regroups buildings with the same azimuth. Example with site 2:

Figure 3.2 Building identification

Table 3.2 Overview of the PV areas

Site	Name	Building	Azimuth [°/S]	Tilt roof [°]	Available roof area [m²]	PV area [m²]
1	Tun 04	1 (N)	-48	20	805	765
		2 (N)	-40	20	508	483
		3 (S)	-48	20	720	684
		4 (S)	-40	20	508	483
2	Tun 03	1 (N)	-53	20	805	765
		2 (N) + 3 (S) + 4 (S)	-48	20	1 525	1 449
3	Tun 01	1 (N) + 2 (S)	-53	20	1 314	1 248
5	Ådlands-byen vest	N	-29	20	1 462	1 389
		S	-40	20	625	593
6	Ådlands-byen øst	All	-40	20	1 468	1 395
7	Tun 07	1 (N) + 2 (S)	-45	20	1 397	1 327
8	Tun 10	1 (N) + 2 (S)	-45	20	1 434	1 363
9	Tun 08	1 (N) + 2 (S)	-45	20	1 434	1 363
10	Tun 11	1 (N) + 2 (S)	-45	20	1 625	1 543
11	Tun 09	1 (N) + 3 (S)	-45	20	1 182	1 123
		2 (N) + 4 (S)	-40	20	1 182	1 123
12	Tun 06	1 (N) + 2 (S)	-40	20	1 736	1 649
13	Tun 05	1 (N) + 2 (S)	-40	20	1 527	1 451
14	Tun 02	1 (N)	-60	20	474	450
		2 (S)	-53	20	474	450
15	Utsikten	All	-60	20	1 000	950
Sum					**23 205**	**22 045**

The commercial buildings (called "Torget") has not been considered in this study for PV production. In solar energy studies, the azimuth is always given with 0 being oriented toward the solar noon (south in the northern hemisphere). +90° corresponds to an orientation toward west, and -90° toward east.

3.1.2 Meteorological data

Power generation of a PV system is largely dependent on local solar radiation and on the angle between the modules and the sun. Other factors, such as temperature, wind, and snow, also have great influence on the power plant's performance.

Solar radiation data of good quality is limited in Norway. There are few meteorological stations for which the quality of the measured solar radiation has been cross-checked by ground measurements; one must therefore largely rely on satellite data. Figure 3.3 below shows the meteorological stations included in the software Meteonorm (four in Norway: Oslo, Bergen, Trondheim and Tromsø).

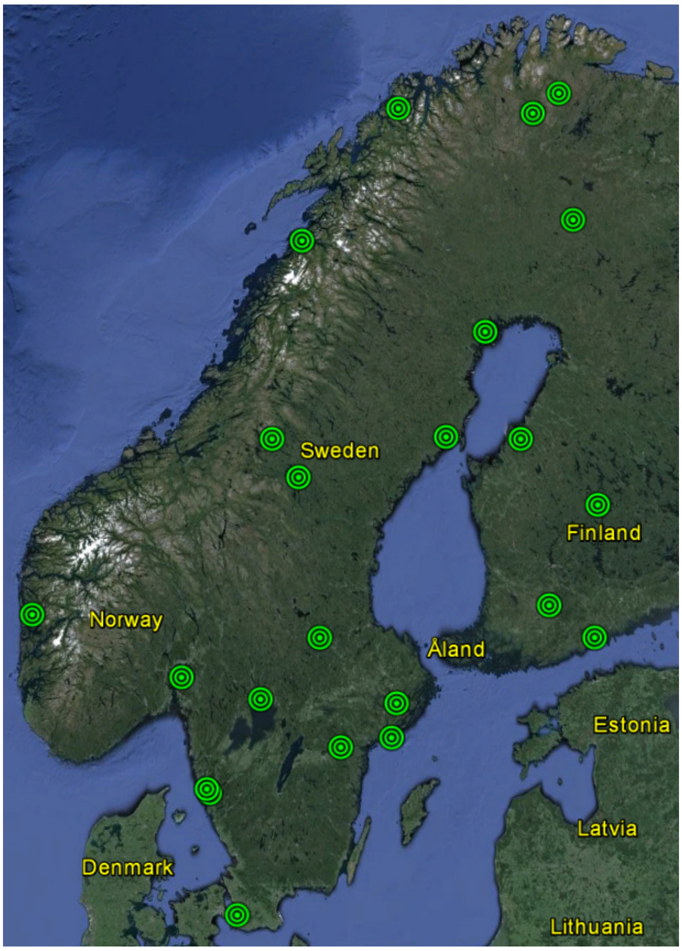


Figure 3.3 Meteorological stations with certified radiation data in the North. Source: Meteonorm / Google Earth.

Six different datasets have been considered in this study:

- Meteonorm 6: old data from Meteonorm. Meteonorm is a software used to generate weather statistics by interpolation of the closest stations and eventually satellite data.
- Meteonorm 7: new data from Meteonorm.
- Nasa-SSE: free service available online for global meteorology and solar climatology. It generates weather data from the Nasa satellites on a resolution of 1° x 1° (110 km x 110 km x cos(Lat)).
- PVGIS Classic: free service available online, based on the results of an EU project. Data is based on satellite data.
- S@tel-Light: free service data available online. Data is based on Meteosat satellites (ESA, measurements every half hour).
- Geophysical Institute (UiB): time-based measurements from the University of Bergen (Florida).

Monthly values and yearly sum are summarized in Table 3.3 and Figure 3.4 below.

Table 3.3: Summary of soalr radiation data (global horizontal) per month from different sources.

kWh/m².mth	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Des.	Year
Meteonorm 6	5,8	19,3	48,5	89,7	135,3	136,4	128,6	100,3	59,5	27,7	9,4	3,9	764,4
Meteonorm 7	6,1	19,5	50,1	91,2	138,5	139,4	128,2	100,5	60,2	28,6	9,6	4,0	775,9
Nasa-SSE	9,0	26,3	61,1	108,6	162,8	164,7	152,8	122,5	74,7	36,9	13,8	5,3	938,5
PVGIS Classic	5,6	18,6	53,0	96,0	135,5	155,7	139,5	101,1	60,6	26,4	7,7	3,5	803,2
S@tel-Light	7,9	17,3	51,0	94,2	149,4	138,6	130,1	113,8	63,4	30,4	11,0	5,6	812,7
Geophysical Institute (UiB)	6,8	21,7	53,1	94,8	137,6	145,9	131,4	102,4	55,7	31,7	10,0	4,2	795,2
Average	**6,9**	**20,5**	**52,8**	**95,8**	**143,2**	**146,8**	**135,1**	**106,8**	**62,3**	**30,3**	**10,2**	**4,4**	815,0

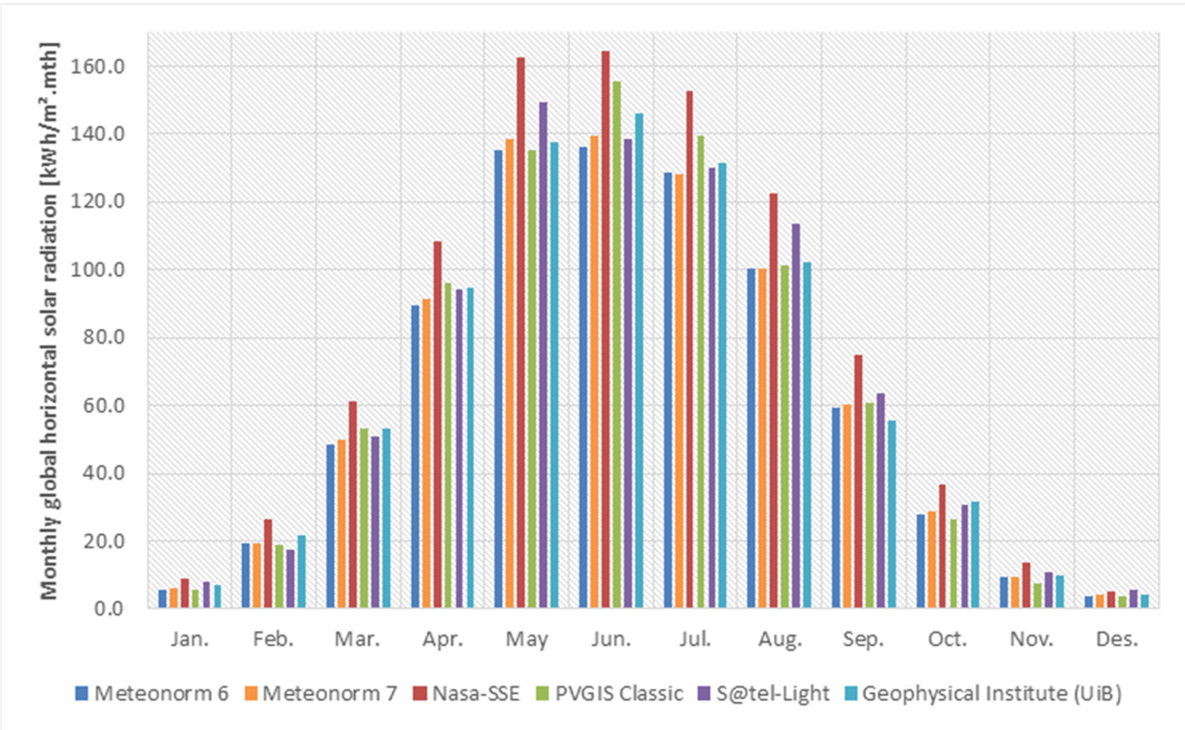
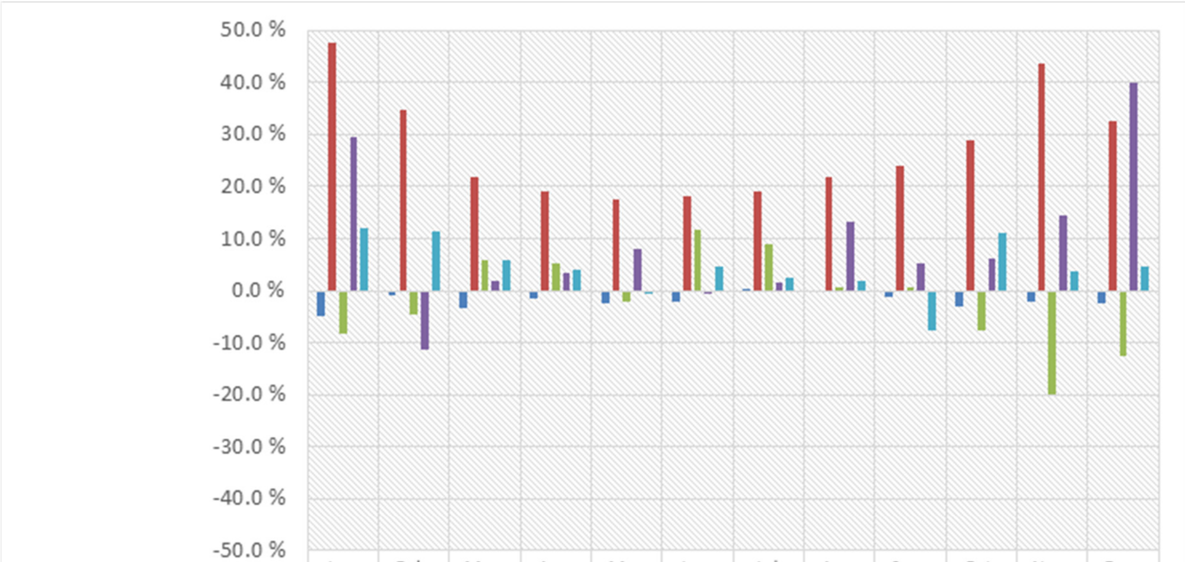


Figure 3.4 Summary solar radiation data per month from different sources.

The dataset from Nasa-SSE shows clearly higher radiation than the others all year round, while PVGIS shows higher values during some of the best months of the year, such as June and July. S@tel-Light shows another profile with higher radiations during May, August and September.

The datasets from Meteonorm come from the weather station Bergen/Florida, operated by the Norwegian Meteorological Institute since 1949. Radiation data has been certified and corrected (missing data) by both the Norwegian Meteorological Institute and Meteonorm (normal procedure before the integration of any dataset in the software). Since Meteonorm use actual local data and combines it with satellites data, the dataset from Meteonorm 7 is considered to be the most relevant for this study. The results of a relative percentage difference study are shown in Figure 3.5 below.



	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Des.
Meteonorm 6	-4.9 %	-1.0 %	-3.2 %	-1.6 %	-2.3 %	-2.2 %	0.3 %	-0.2 %	-1.2 %	-3.1 %	-2.1 %	-2.5 %
Nasa-SSE	47.5 %	34.9 %	22.0 %	19.1 %	17.5 %	18.1 %	19.2 %	21.9 %	24.1 %	29.0 %	43.8 %	32.5 %
PVGIS Classic	-8.2 %	-4.6 %	5.8 %	5.3 %	-2.2 %	11.7 %	8.8 %	0.6 %	0.7 %	-7.7 %	-19.8 %	-12.5 %
S@tel-Light	29.5 %	-11.3 %	1.8 %	3.3 %	7.9 %	-0.6 %	1.5 %	13.2 %	5.3 %	6.3 %	14.6 %	40.0 %
Geophysical Institute (UiB)	12.0 %	11.4 %	5.9 %	4.0 %	-0.6 %	4.6 %	2.5 %	1.9 %	-7.5 %	11.0 %	3.7 %	4.6 %

Figure 3.5 Relative percentage difference between Meteonorm 7 and the other datasets.

Except the dataset from Nasa-SSE, which is generally higher, the figure shows a relative difference with S@tel-Light and PVGIS globally high during winter months. This difference is high in percentage but relates to small numbers in radiation. For example in December, S@tel-Light is 40% higher than Meteonorm 7 but the difference in radiation is only of 1,6 kWh/m² during the month. Otherwise, the monthly relative difference is lower than approximately + 10%, Meteonorm 7 showing lower results. The dataset from Meteonorm is thus also considered generally conservative compared to the other datasets studied here.

It should be mentioned that neighbours to the location of the project site claim that there is “more sun” at the project site than in central Bergen where the measurement station Florida is situated. This is a qualitative observation which has not been proven, but it does indicate that the weather data used in this study may be conservative. As a consequence of this observation, a new ground measurement station has been installed at the Flesland Airport nearby. It is expected that the measurements from this station with time will enable a quantitative assessment of the difference in solar irradiation between the two stations, and that might give new inputs to our analysis.

3.1.3 PV system efficiency and losses

The efficiency of a PV plant relies on the chosen components but also on various system factors, detailed in the sections below.

Components

The choice of the components plays a significant role in the results of the simulations, with different technologies leading to different efficiencies. PV modules and inverters must be chosen and designed carefully.

In the calculation we have supposed PV modules from LG Solar, model LG NeON 2 Black 300 (LG 300 N1). The LG 300 N1 is a 60-cells monocrystalline silicon module with a rated power of 300 Wp and an efficiency of 18,3 % (183 Wp/m²). It is also completely black (cells, back sheet and frame).

Figure 3.6 PV module LG 300 N1

Inverters used in the simulations are from the German supplier SMA. SMA has long experience in inverter technology (company founded in 1981) and is known for the quality of their products. SMA is one of the largest suppliers on the world's market today and they have the broadest range of products. The efficiency of SMA's inverters is generally between 97 and 98%.

Figure 3.7 Inverters type SMA Sunny Tripower

Thermal parameters

The thermal behaviour of the PV field strongly influences the electrical performances.

The Field Thermal Loss Factor used in the simulation is determined by an energy balance between ambient temperature and heating upof the cells due to incident irradiance. It is characterised by a thermal loss factor designed here by U-value, which can be split into a constant component Uc and a factor proportional to the wind velocity Uv. These factors depend on the mounting mode of the modules (sheds, roof, facade, etc...).

It is natural to integrate the PV solar plants into new constructions (BIPV – "Building Integrated PhotoVoltaics"). The PV plant then becomes the roof itself, and one can save the cost of a traditional roof cover.

Table 3.4: Thermal loss factor

Thermal Loss Factor U [W/m².K]	**15 (integration with fully insulated back)**

Ohmic losses

Ohmic losses are the losses in the cables. The calculation of the direct current (DC) circuit losses leads to the wiring's sizing. In the case of a preliminary estimation, though, the default value of 1,5 % at STC ("Standard Test Condition") is a good estimation. These losses can easily be optimized in the electrical design by changing the cable cross-section. Losses in alternating current (AC), between the output of the inverter and the injection point, are normally negligible but should be considered if the distance is remarkably long.

Table 3.5: Ohmic losses

Ohmic losses [%]	**1,5 (at STC)**

Module quality

The Module quality loss is a parameter that expresses one's own confidence in the real module's performance, in relation to the manufacturer's specifications. One can set this parameter at any value that is found suitable (for example to express the long-term losses, or keeping some reserve on the production warranty, etc).

In the past, it was well-known that most of PV modules series didn't match the manufacturer nominal specifications. The real behaviour of modules with respect to the specifications was one of the most significant uncertainties in the PV system performance evaluation. Now, with "guaranteed" power assertions and increasing availability of independent certifications, the uncertainty is decreasing. Module series are sold with a given tolerance, final flash-test assertions, and actual powers usually may lie below the nominal specified power, but still stay within the tolerance.

We have chosen to use positive-rated modules (LG 300 N1), meaning that the real capacity (according to final flash-test) is certified to be higher than the rated capacity (here 300 Wp). We may then use a "negative loss" to simulate the gain.

Table 3.6: Module quality

Module quality [%]	**-0,8**

LID

LID (Light Induced Degradation) is a loss of performances arising in the very first hours of exposure to the sun, with crystalline modules. It may affect the real performance of the panels, and is tested by some PV module providers with respect to the final factory flash tests data The LID loss is related to the quality of the wafer manufacturing, and may be of the order of 1 % to 3 % (or even more). It is due to traces of Oxygen included in the molten Silicon during the Czochralski process (a method of crystal growth used to obtain single crystals of semiconductors).

NB: The LID effect only arises with conventional p-type boron-doped wafers. Unconventional technologies using n-type doped wafers are not affected.

It is very difficult to obtain data about the LID effect on a given module sample. This is rarely referenced by the manufacturers. It depends on the origin of the Silicon wafers, and may vary from product to product, but it may also depend on batches of a given production.

In this assessment we have used high-quality PV modules, considered LID-free.

Table 3.7: LID

LID [%]	**0**

Mismatch losses
The "Mismatch loss" is mainly due to the fact that in a string of modules (or cells), the lowest current drives the current of the whole string. When installing real modules in the field, the characteristics of each module are never rigorously identical.

The default value of 1 % of power loss at MPP (maximum power point) is generally used in simulations.

Table 3.8: Mismatch losses

Mismatch losses [%]	**1 (at MPP)**

IAM losses
The incidence effect (the designated term is IAM, for "Incidence Angle Modifier") corresponds to the decrease of the irradiance really reaching the PV cells' surface, with respect to irradiance under normal incidence, due to light reflecting increasing with the incidence angle.

In practice, it is often approached using a parameterization called "ASHRAE"[28] (as it has become a standard in this American norm), depending on one only parameter *bo*.

For single-glazed thermal solar modules, the usually accepted value for bo is of the order of 0,1. But in a PV module, the lower interface, in contact with the cell, presents a high refraction index and specific measurements on real crystalline modules actually indicate a value of *bo* = 0,05.

Table 3.9: IAM losses

IAM losses (*bo*)	**0,05**

Shadings
The chosen software to simulate the PV power plant - PVsyst - enables the construction of a 3D model of the buildings and the PV arrays in order to simulate the losses associated with shading.

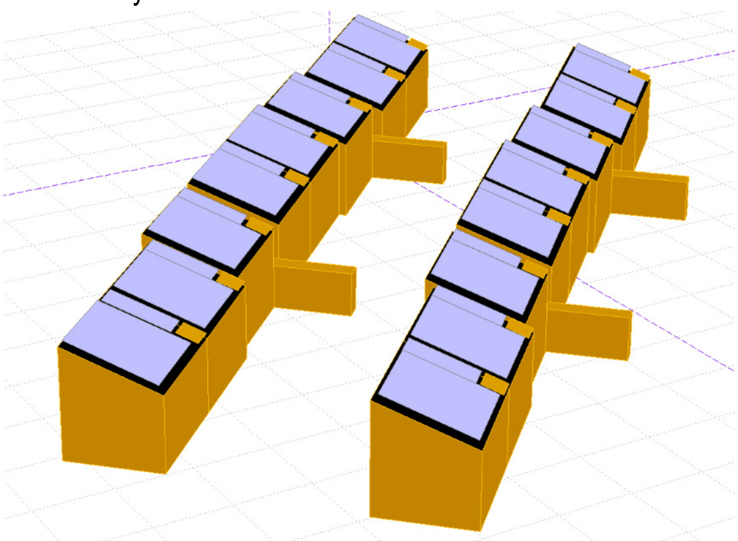


Figure 3.8 3D model for shading analysis. Source: PVsyst.

[28] D. Yogi Goswami, Frank Kreith and Jan F. Kreider (2000) *Principles of Solar Engineering*, Taylor & Francis.

The tool includes the simulation of the so-called "shading electrical effect" that causes loss of power when only a part of a string is shaded. A PV panel is made up of a number of individual cells, and a typical crystalline PV panel produces roughly 25-30 Volts. In order to reduce system losses and ensure efficient operation of inverters, inverters are often connected to several panels in series (one "string"). A PV panel with shading on even a small portion of its area can have significantly reduced output. The shade may come from for example building elements or vegetation. The output from a PV module is directly related to the amount of light that the module is exposed to. In the event of shading, the output is reduced accordingly. When the modules are connected in strings, the current in the string is reduced to the current produced by the shaded module. This happens according to "Kirchoff's law" in the electronics field. That loss, called "shading electrical effect", is illustrated in Figure 3.9 below.

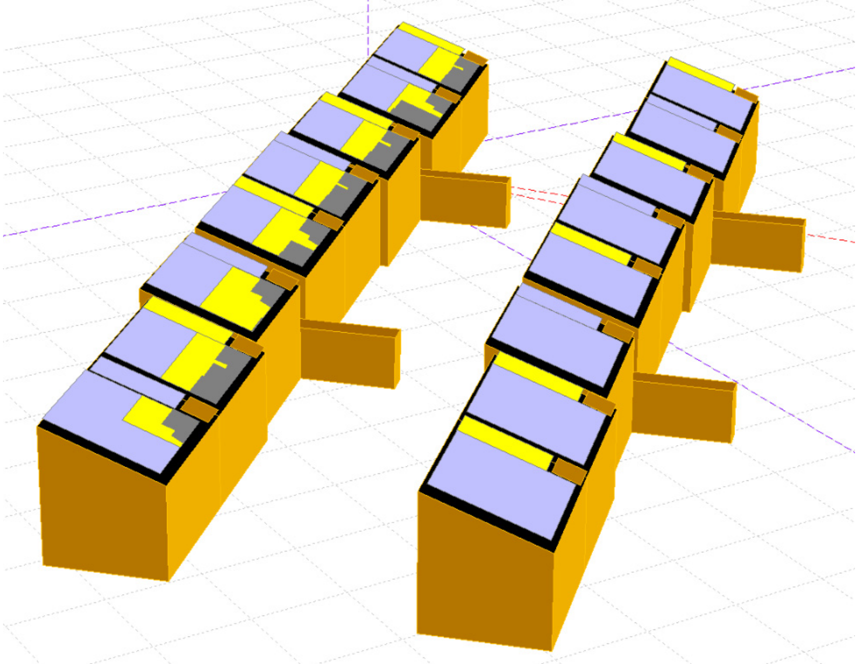


Figure 3.9 Example of shading electrical effect (21st of December, 10:30 am). Blue: PV not shaded. Grey: shading. Yellow: strings impacted by shading. Source: PVsyst.

Snow and albedo

The presence of snow in winter might lead to higher shading losses (snow covering the PV field) and higher shading electrical effect (when the snow covers only partially a module or part of a string), but also higher albedo (ratio of reflected radiation from the surface to incident radiation upon it).

Snow losses are the most complicated factor to simulate because of the combination of direct shading and mismatch losses. Snow might also melt quickly when not covering the entire PV array, because of the "hot-spot" effect (hot-spot heating occurs when a large number of series connected cells cause a large reverse bias across a shaded cell, leading to large dissipation of power in the poor cell). On the meteorological side, it is also difficult to assess precisely both the amount of snowfall and how long it will stay before melting.

The most accurate way to simulate snow in our calculation tool is to set a percentage of "soiling losses", meaning that the related amount of radiation will never be collected by the PV module. 2 % is a default value to simulate dust, leaves, and other things that can land on the modules.

In the winter months, a higher percentage is chosen, to represent the effect of snow cover (on the PV modules).

Table 3.10: Soiling losses

Jan.	Feb.	Mar.	Apr.	Mai	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
10%	20%	10%	2%	2%	2%	2%	2%	2%	2%	2%	15%

The albedo's dimensionless nature lets it be expressed as a percentage and is measured on a scale from 0 for no reflection of a perfectly black surface to 1 for perfect reflection of a white surface, as shown in Figure 3.10 below.

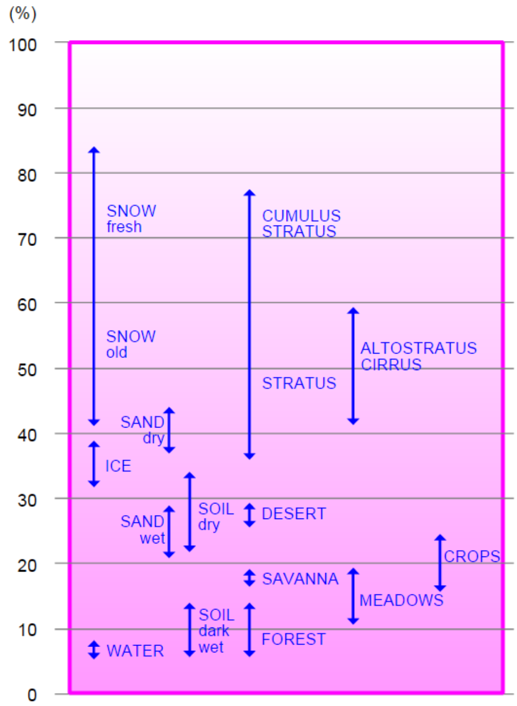


Figure 3.10 Albedo, various surface conditions. Source: Hannes Grobe, Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany (under Creative Commons).

The albedo value for a large area composed of various surfaces is of course complicated to calculate without a full diffuse light test, but it is assumed that the value will at least be higher in winter months because of the snow cover. 20 % is the default value.

Table 3.11: Albedo

Jan.	Feb.	Mar.	Apr.	Mai	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
25%	50%	20%	20%	20%	20%	20%	20%	20%	20%	20%	25%

3.2 PV generation profiles

The installed capacity per building has been calculated with the PV area and the chosen module's efficiency as follows:

$$P\ [Wp] = \frac{\eta\ [\frac{Wp}{m^2}]}{PV\ area\ [m^2]}$$

Where η is the PV module's efficiency (183 Wp/m²).

An overview of the installed capacity is shown in Table 3.13.

The preliminary phase of the project is designed with roofs oriented toward six different orientations (-29°, -40°, -45°, -48°, -53° and -60°). A specific PV production (production per m² of PV) has been calculated for these six azimuths. This specific production has then been multiplied by the PV area of each building in order to obtain the total production per building. The results of specific production simulations per azimuth are shown in Table 3.12 below.

Table 3.12: Specific PV production for each azimuth.

Azimuth [°/S]	Specific PV production [kWh/m².year]
-29	136,16
-40	134,41
-45	133,45
-48	132,81
-53	131,67
-60	129,94

The variance of the PV power plant's efficiency according to azimuth and tilt is not linear and follows the graph shown in Figure 3.11 below. For example for an azimuth of -60°/S, the optimal tilt will be between 15° and 45°.

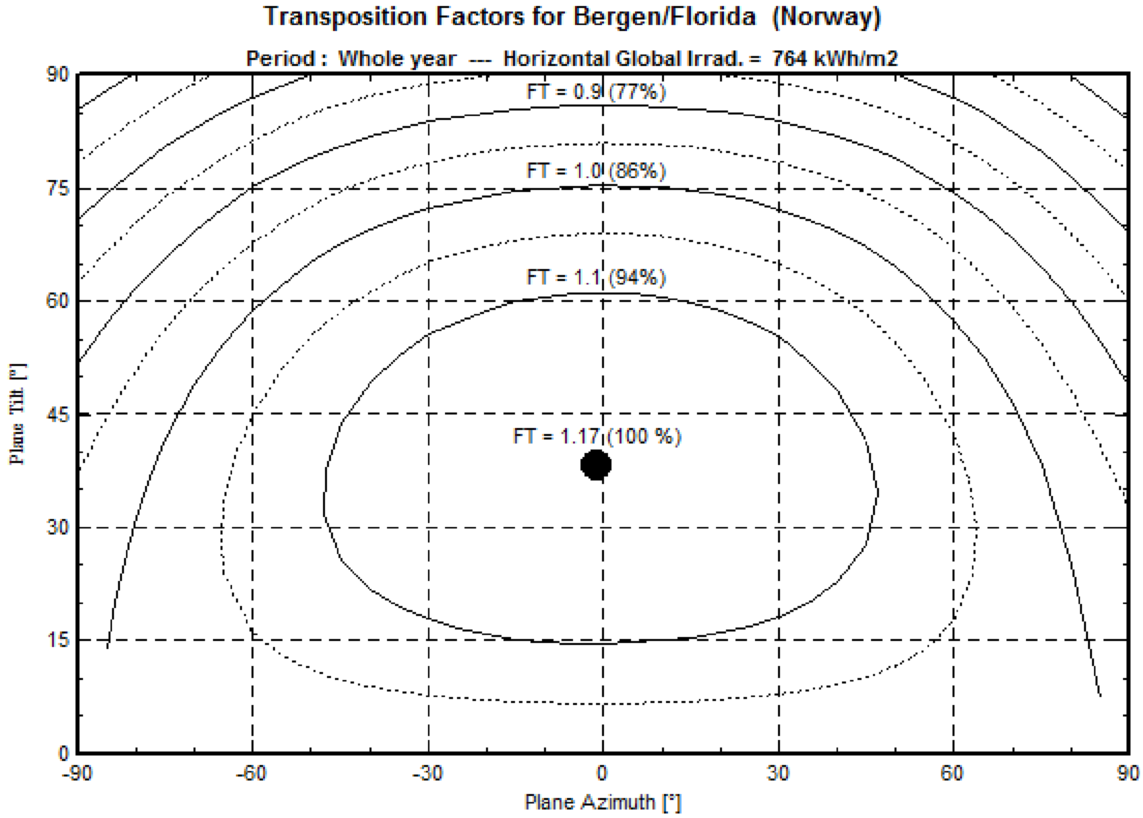


Figure 3.11 Efficiency according to azimuth and tilt. Bergen. Source: PVsyst.

An overview of the PV power and production per building is shown in Table 3.13 below.

Table 3.13: Overview of the installed capacity and PV production.

Site	Name	Building	PV area [m²]	Installed capacity [kWp]	Azimuth [°/S]	Specific PV production [kWh/m².year]	PV production [kWh/year]	Sum production per site [kWh/year]	Specific production [kWh/kWp.year]
1	Tun 04	1 (N)	765	140,1	-48	132,81	101 621	322 279	726
		2 (N)	483	88,4	-40	134,41	64 920		735
		3 (S)	684	125,2	-48	132,81	90 819		726
		4 (S)	483	88,4	-40	134,41	64 920		735
2	Tun 03	1 (N)	765	140,1	-53	131,67	100 749	293 189	720
		2 (N) + 3 (S) + 4 (S)	1 449	265,3	-48	132,81	192 440		726
3	Tun 01	1 (N) + 2 (S)	1 248	228,5	-53	131,67	164 345	164 345	720
5	Ådlands-byen vest	N	1 389	254,3	-29	136,16	189 091	268 857	744
		S	593	108,7	-40	134,41	79 766		735
6	Ådlands-byen øst	Alle	1 395	255,4	-40	134,41	187 470	187 470	735
7	Tun 07	1 (N) + 2 (S)	1 327	243,1	-45	133,45	177 153	177 153	730
8	Tun 10	1 (N) + 2 (S)	1 363	249,5	-45	133,45	181 843	181 843	730
9	Tun 08	1 (N) + 2 (S)	1 363	249,5	-45	133,45	181 843	181 843	730
10	Tun 11	1 (N) + 2 (S)	1 543	282,6	-45	133,45	205 964	205 964	730
11	Tun 09	1 (N) + 3 (S)	1 123	205,6	-45	133,45	149 816	300 710	730
		2 (N) + 4 (S)	1 123	205,6	-40	134,41	150 894		735
12	Tun 06	1 (N) + 2 (S)	1 649	301,9	-40	134,41	221 617	221 617	735
13	Tun 05	1 (N) + 2 (S)	1 451	265,7	-40	134,41	195 028	195 028	735
14	Tun 02	1 (N)	450	82,4	-60	129,94	58 455	117 688	710
		2 (S)	450	82,4	-53	131,67	59 233		720
	Utsikten		950	174	-60	129,94	123 443	123 443	710
SUM			**22 045**	**4 037**			**2 941 430**	**2 941 430**	

The total estimated installed power is 4 MWp, which produces approximately 2. 9 GWh/year.

Due to different azimuths (orientation toward the sun), the different solar PV plants will not produce energy at the same time. Figure 3.12 shows for example the production during two “typical good days”, one in summer and one in winter. The figure shows a time shift between PV plants with different azimuths. This will lead to a flatter global energy production curve.

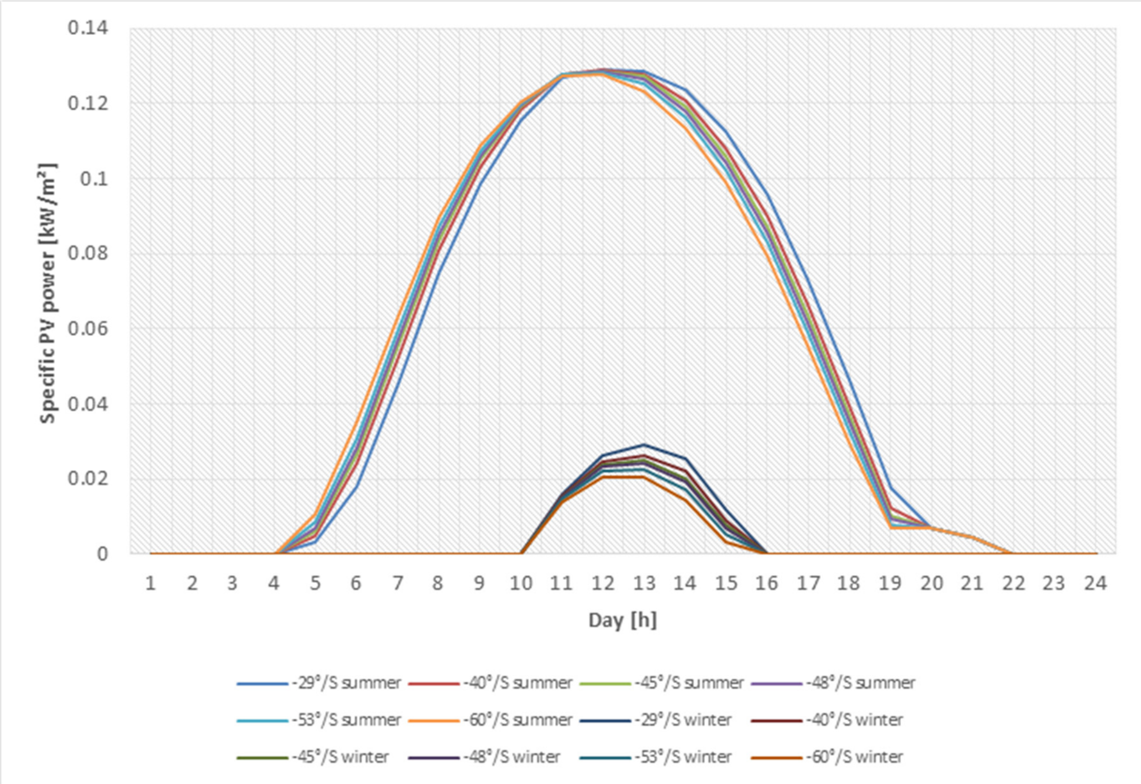


Figure 3.12 Example "typical good day", summer and winter, different orientations

The PV production is low during winter months (November, December, January and February), because of short days, low irradiance, and snow losses. The best month is May with a total power production of 513 MWh. This is due to longer days and good irradiance. We can see in Chapter 3.1.2 that the solar radiation is approximately the same during May and June. The fact that the production is better in May is mainly due to lower temperatures.

The PV power generation per month is shown in Figure 3.13 below.

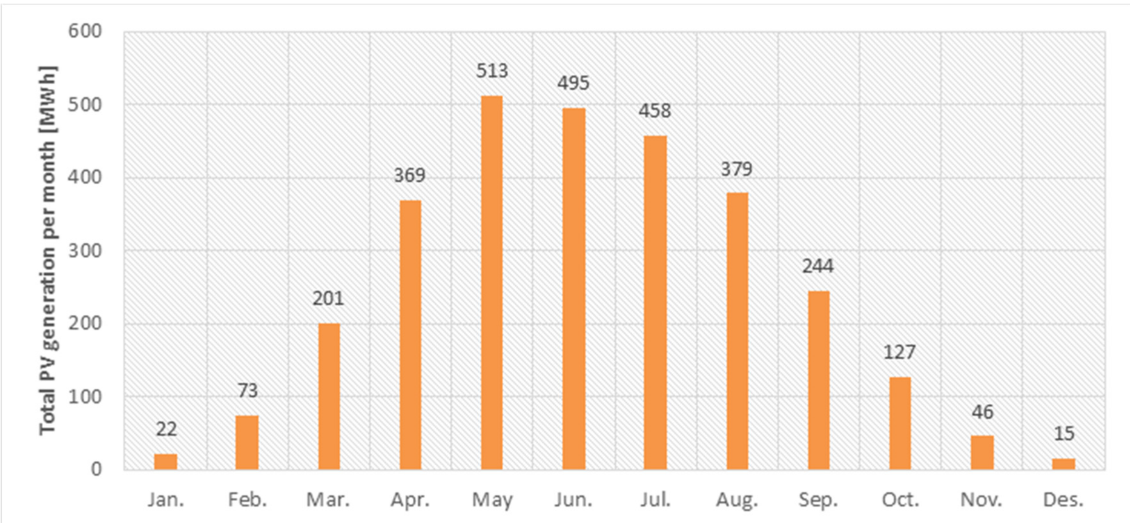


Figure 3.13 Total PV generation per month.

In the context of matching produced energy with electricity consumption without any buffer (storage), it is particularly important to analyse the values on an hourly basis.

An overview of the total power hourly values is shown in Figure 3.14 below.

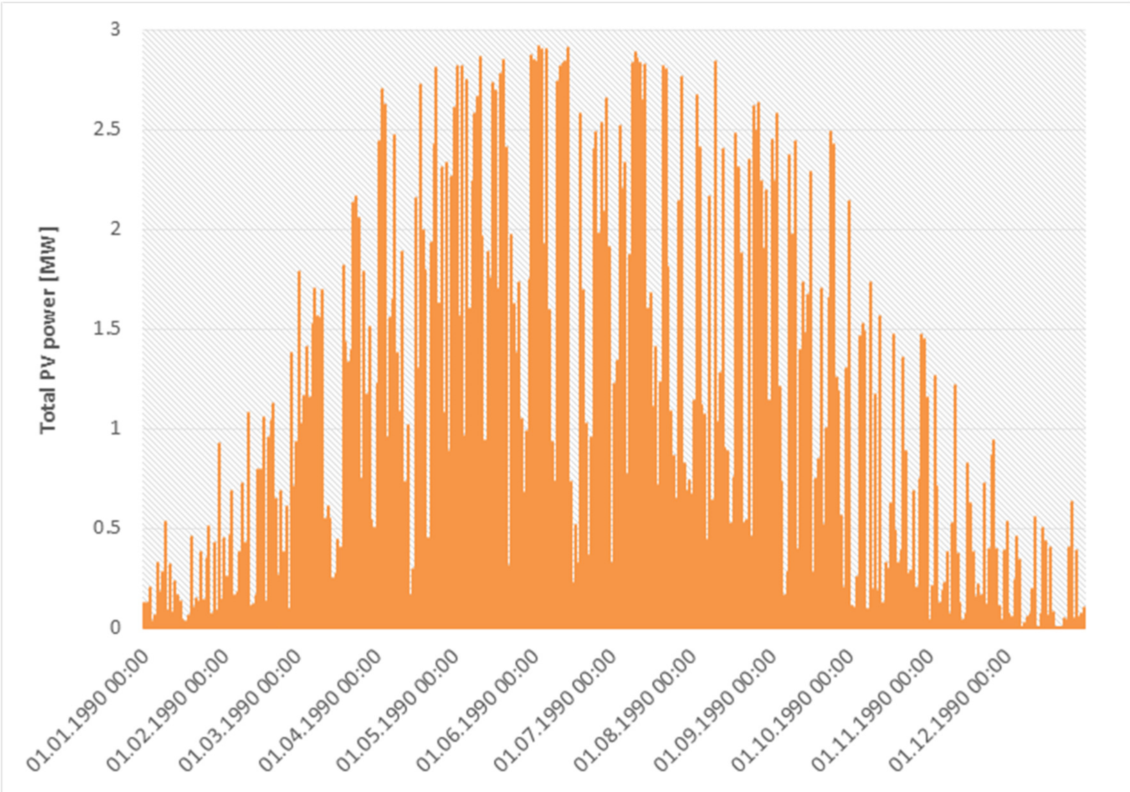


Figure 3.14 Total PV power, hourly values.

Figure 3.14 shows that the produced power never gets higher than approximately 3 MW (the actual simulated value being 2 916 kW).

Because of the poor details readability in Figure 3.14 above, hourly values detailed per month for May (highest production) and December (lowest production) are shown in Figures 3.15 and 3.16 below. Figures for the other months of the year can be found in Appendix 1.

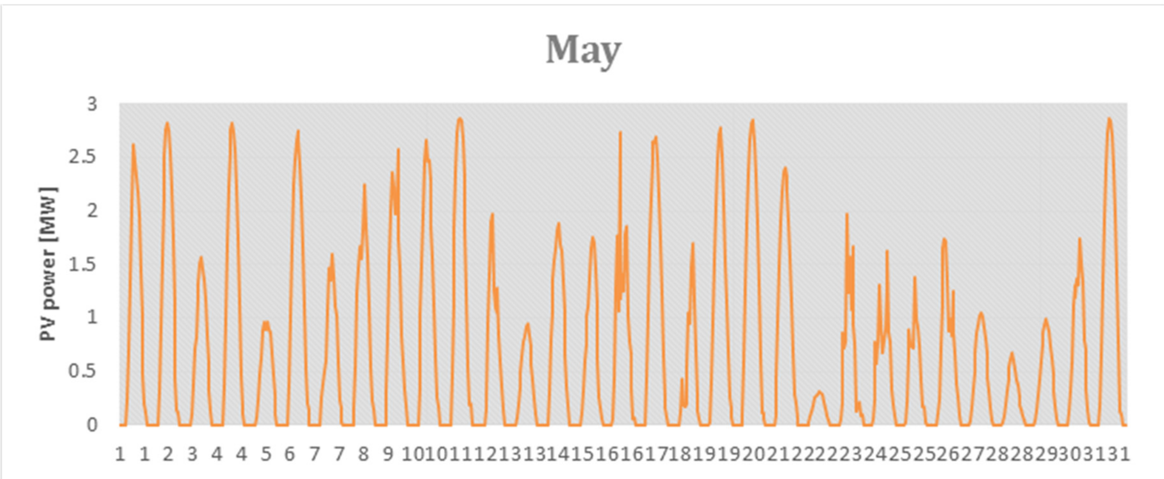


Figure 3.15 PV generation profile, May.

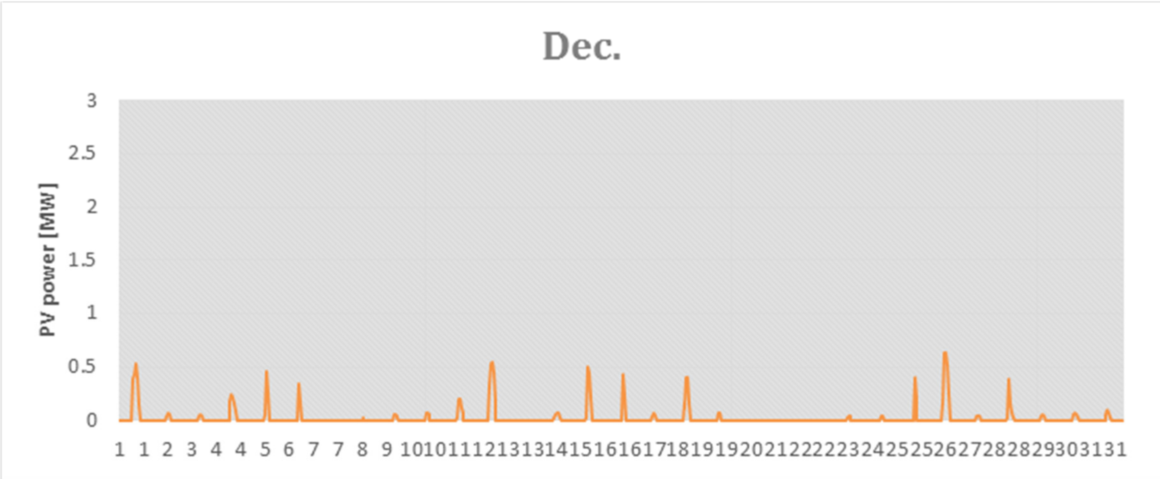


Figure 3.16 PV generation profile, December.

In order to summarize the total amount of hours at different power, a power duration curve is shown in Figure 3.17 below.

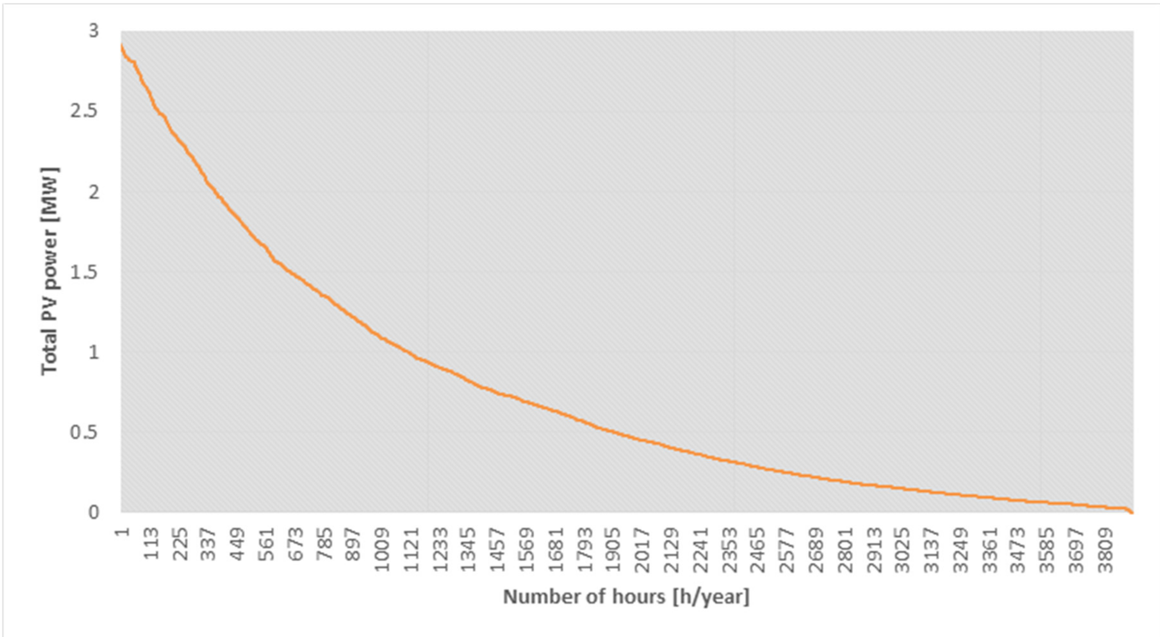


Figure 3.17 PV power duration.

3.3 Sensitivity analysis: PV generation

3.3.1 Available roof area

The calculation of the total available roof area is explained in Chapter 3.1.1. Table 3.14 below gives an overview of the PV production according to less and more available PV area.

The PV production here is directly proportional to the PV area, i.e. with 5 % more PV area the PV plant will produce 5 % more energy per year.

Table 3.14: PV production sensitivity to available roof area.

	Not favorable	Base-case	Favorable
PV area [m²]	-5%	22 045	+5%
PV prod. [MWh/year]	2 794	2 941	3 088
PV area [m²]	-10%	22 045	+10%
PV prod. [MWh/year]	2 647	2 941	3 235
PV area [m²]	-15%	22 045	+15%
PV prod. [MWh/year]	2 500	2 941	3 382

3.3.2 PV system efficiency

The design of the PV system can eventually be subject to changes in order to fulfil production requirements.

Table 3.15: PV production sensitivity To PV system specifications.

	Not favorable	Base-case	Favorable
Module efficiency [%]	16,0	18,3	20,0
PV power [kWp]	3 527	4 037	4 409
Module efficiency [%]	16,0	18,3	20,0
PV prod. [MWh/year]	2 570	2 941	3 212
Azimuth [°/S]	-70	-60	-50
PV prod. [MWh/year]	2 883	2 941	2 999

Table 3.15 above shows that increasing the PV module efficiency from 18,3 % to 20 % allows the installation of an additional 17 Wp/m². This may increase the total PV production by more than 9 %. The best PV modules in the market as of today have an efficiency of 21,5 %. Of course, production gains have to be compared with additional technology costs.

Factors other than efficiency can influence the production of a PV module, e.g. the characteristics of the front glass, which change the IAM (cf. chapter 3.1.3). This has not been considered in this sensitivity analysis.

A global azimuth oriented 10° more toward the south (from -60°/S to -50°/S, for example) would allow a 2 % higher PV production.

3.3.3 Meteorological data

It is important to understand and consider the uncertainties related to the meteorological data.

The PV production here is considered directly proportional to the global horizontal solar radiation, i.e. with 5 % more kWh/m² solar radiation the PV plant will produce 5 % more energy per year.

Table 3.16: PV production sensitivity to meteorological data.

	Not favourable	Base-case	Favourable
Global horizontal solar radiation [kWh/m².år]	-5 %	775,9	5 %
PV prod. [MWh/year]	2 794	2 941	3 088
Global horizontal solar radiation [kWh/m².år]	-10 %	775,9	10 %
PV prod. [MWh/year]	2 647	2 647	3 235

3.4 Summary: PV generation

Chapter 3 gives an overview of the on-site PV energy production for the project Zero Village Bergen. The 15 sites put together have an available roof area of 23 204 m² which, with a PV cover ratio of 95 %, gives a total PV area of 22 045 m². Using a PV module of 18,3 % efficiency (LG NeON 2 Black 300) for the calculations allows to install a total capacity of 4 MWp. These 4 MWp will produce 2,9 GWh per year (with the assumed meteorological data and PV system efficiency detailed in chapters 3.1.2 and 3.1.3).

Table 3.17: PV generation. Summary values.

Available roof area [m²]	23 204
PV area [m²]	22 045
Installed capacity [MWp]	4
Yearly electricity production [GWh]	2.9

There is several ways to increase the total production:

- Increase the available roof area (directly proportional to the production)
- Adjust the azimuth and roof tilt (optimal production: oriented south with a tilt of approximately 45°, the optimal tilt vary according to the orientation, cf. Figure 3.11)
- Use a PV module with higher efficiency (more installed capacity in the same area)

Beyond the total production per year, it is particularly important to analyse the values on an hourly basis in this context of matching produced energy with electricity consumption without any buffer (storage). The profiles presented in Chapter 3.2 confirm that the production is very low during winter (due to short days, low solar radiation, and snow). Most of the on-site use of the solar electricity production will then happen during summer. Furthermore, the fact that every PV area assessed in this project is oriented toward southeast (because of acoustic protection) can create an unfavourable matching of production/consumption during evenings all through the year.

Other surfaces than rooftops can also be considered in order to increase the total PV production. Carports, for example, are a smart solution for combining:

- PV production
- Charging of electric vehicles
- Protection of the vehicles against inclement weather
- Collection and recirculation of rainwater (which can eventually be used for car washing, for example)

PV carports are less dependent on acoustic engineering and architectural concerns and can then be oriented and designed for optimal PV production.

4. Summary

4.1 Mismatch of loads and generation profiles

The aggregated results for the whole Zero Village Bergen are summarized in Table 4.1, showing the total thermal load, the total electric load, and the total PV generation, all three accompanied by the variation range resulting from the sensitivity analysis. At the aggregated level, Zero Village Bergen has a total thermal need of 3.3 (GWh/y) with a peak load of 1.3 (MW) and an electric need of 3.3 (GWh/y) with a peak load of 0.7 (MW). The PV system generates in total 2.9 (GWh/y) with a generation peak of 2.9 (MW).

Table 4.1 Summary of loads and PV generation.

Total ZVB load	Energy [GWh/y]	Peak Power [MW]
Thermal load	3.3	1.3 *
	(-1% +30%)	(-12% +52%)
Electric load	3.3	0.7 **
	(±11%)	(-5% +12%)
PV generation	2.9	2.9 *
	(±15%)	(±15%)

* Hourly average.
** Hourly average, without food storage in shop area.

The discussion of the sensitivity analysis is found in §2.5 and §3.3 for the loads and PV generation, respectively. The results are shown graphically in Figures 4.1 and 4.2, offering at a glance the powerful visual impression that while the PV generation struggles to cover just the electric load, the peak power due to the PV generation is by far higher than the electric peak load, and even higher than both the thermal and electric peak loads together.

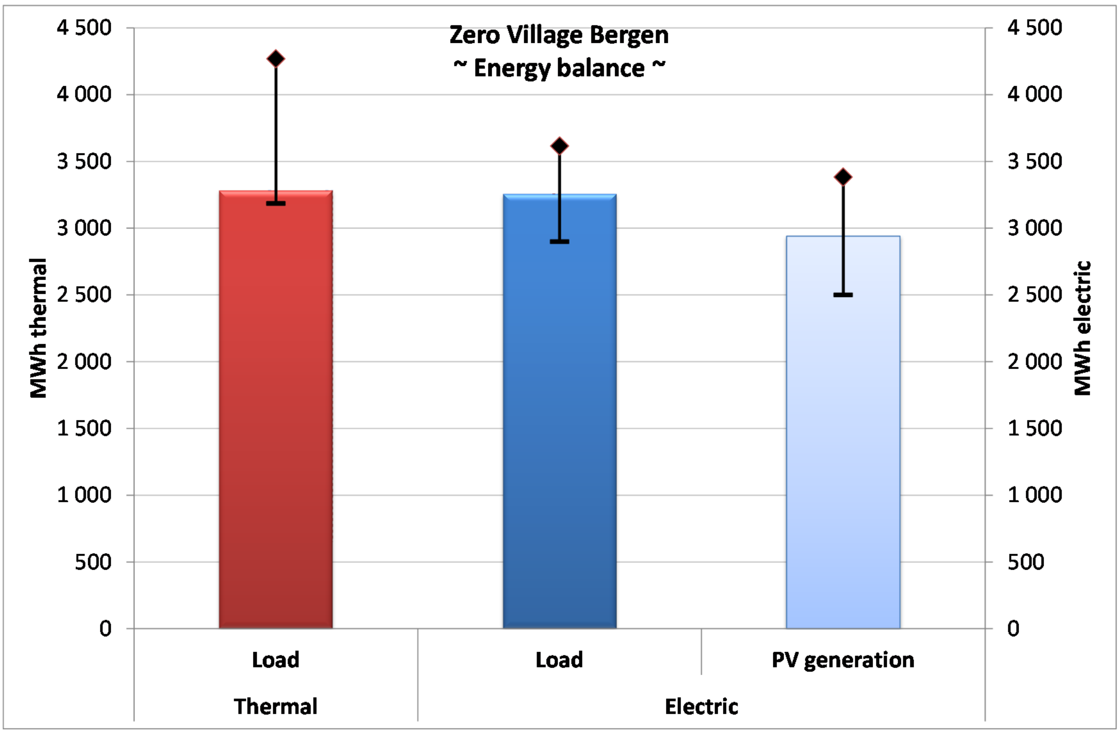


Figure 4.1 Aggregated energy balance, showing the thermal and electric loads and the PV generation with min-max markers from the sensitivity analysis.

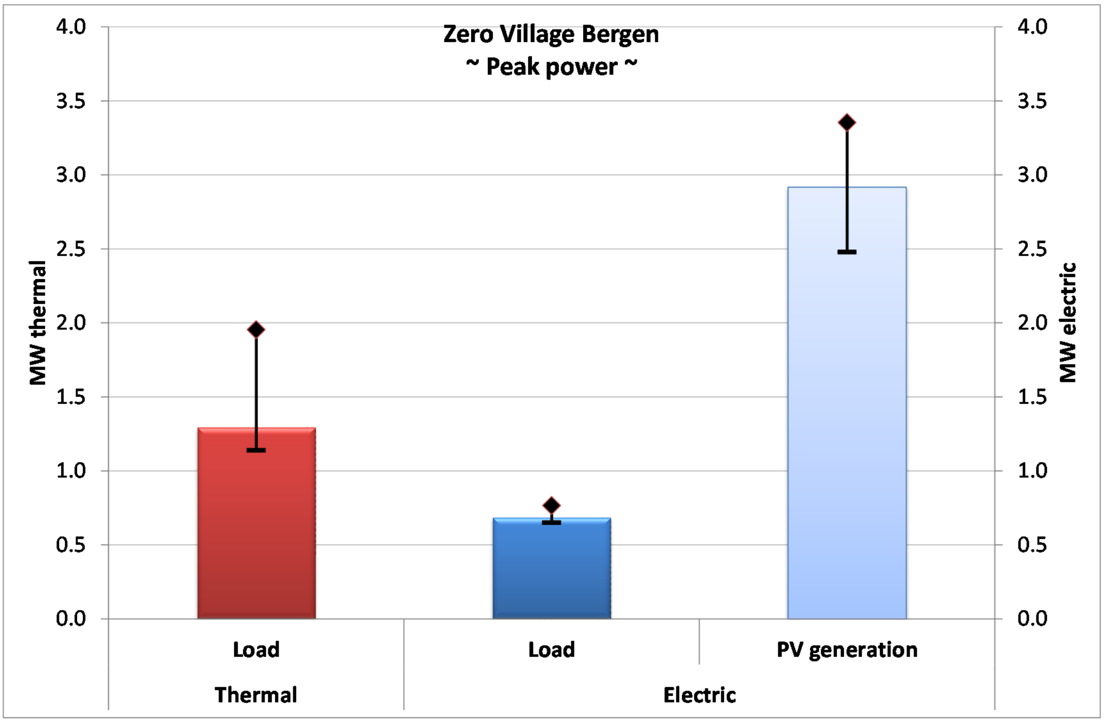


Figure 4.2 Aggregated peak power, showing the thermal and electric loads and the PV generation with min-max markers from the sensitivity analysis.

Since it is not yet decided which energy carrier will be used in the Zero Village Bergen to cover the thermal load, it makes sense for the time being to analyse the mismatch between the electric specific load and the PV generation. The two can be plotted in the same graphs as in Figures 4.3 and 4.4, showing the monthly profiles and the hourly net delivered electricity to the Zero Village Bergen, respectively. In Figure 4.4, negative values mean net export to the grid; here the mismatch between electric load and PV generation is evident: there is a large export to the grid in all seasons but winter, while there is still a net import (in the evenings) throughout the whole summer.

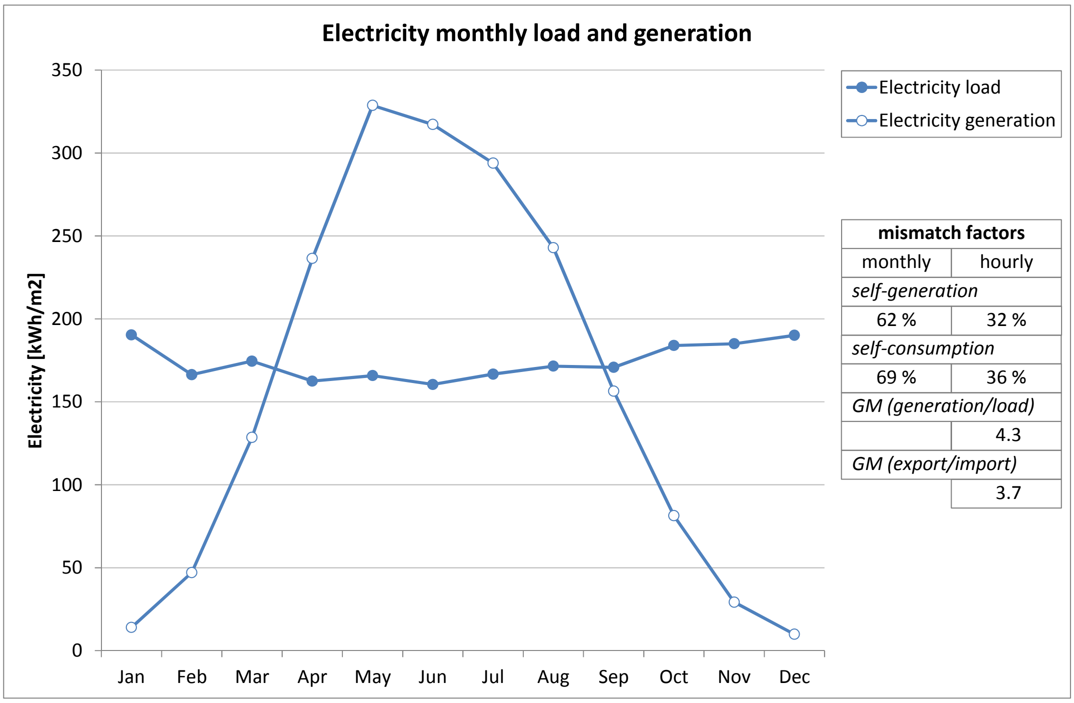


Figure 4.3 Monthly profiles of electric load (filled dots) and PV generation (hollow dots).

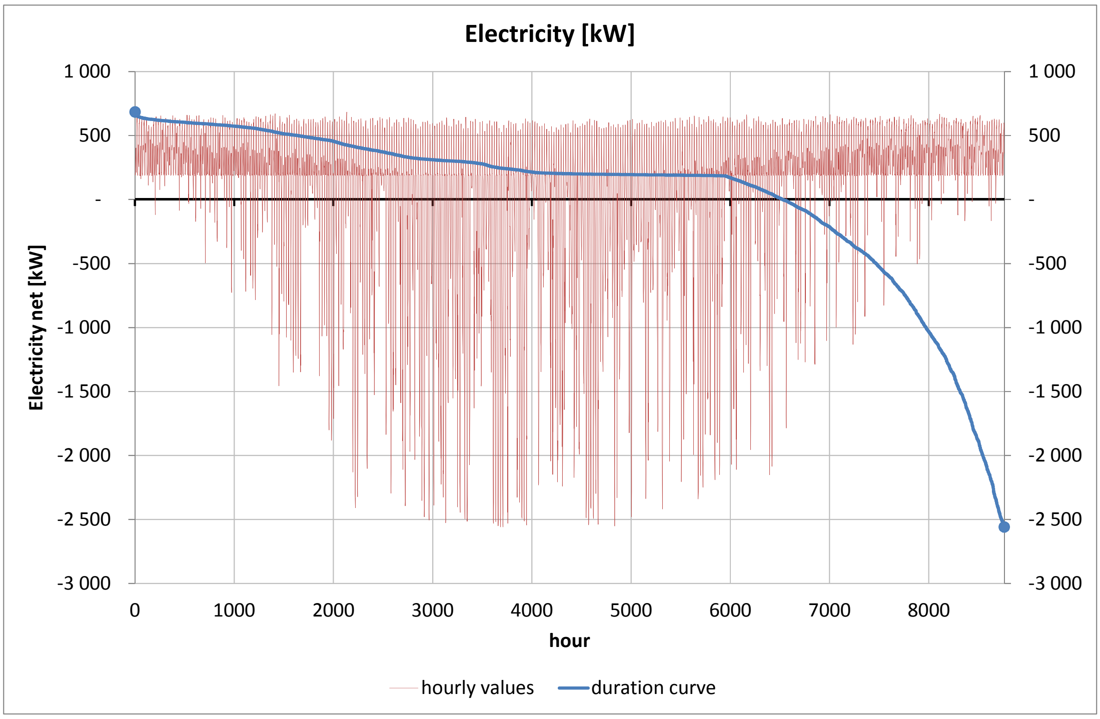


Figure 4.4 Net delivered electricity hourly profile (red) and duration curve (blue).

Table 4.2 summarizes the mismatch numerically, using mismatch indicators suggested in literature[29]. The coverage factor tells how much of the total annual load is covered by the onsite generation. For the Zero Village Bergen the coverage factor is 90%, and this can be seen graphically by comparing the electric load and PV generation bars in Figure 4.1.

Table 4.2 Mismatch indicators between the electric load and PV generation.

	Electric load [MWh/y]	PV generation [MWh/y]	Coverage	Self-Generation	Self-consumption	Peak Power from PV [kW], *(GM* [-])*	
						Generation	Export
Total ZVB	3 257	2 941	90 %	32 %	36 %	2 916 *(GM 4.3)*	2 559 *(GM 3.7)*

* GM = Generation Multiple

Self-generation and self-consumption tell how much energy is exchanged with the grid, while the generation multiple (GM) tells the required peak power capacity of the grid's connection. These indicators can better be understood graphically, as shown in Figure 4.5.

[29] J. Salom et al. (2014) Analysis of Load Match and Grid Interaction Indicators in net Zero Energy Buildings with simulated and monitored data, *Applied Energy*, vol. 136, pp. 119–131.

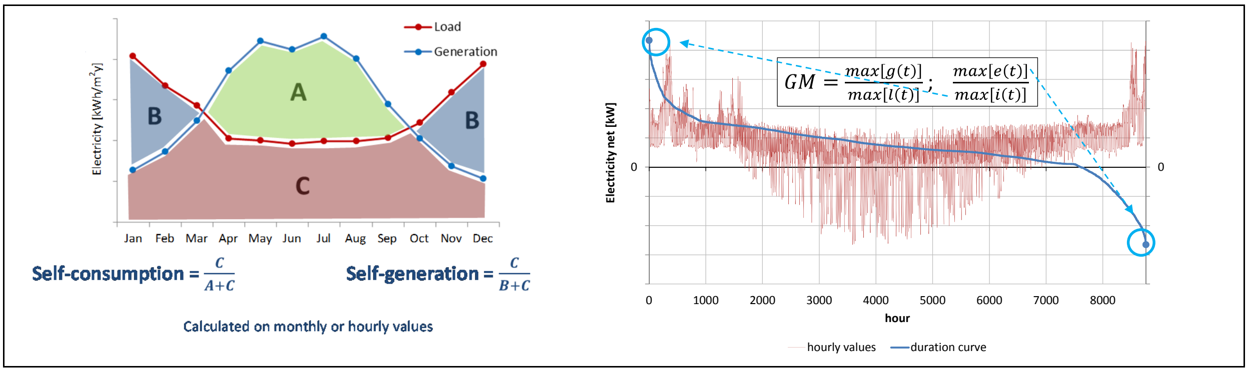


Figure 4.5 Graphical representation of self-generation and self-consumption (left) and generation multiple, GM (right).

For the Zero Village Bergen the self-generation calculated on an hourly basis is 32%, meaning that 32% of the load is directly covered by the PV generation and the rest is taken from the grid. The self-consumption, on the other hand, is 36%, meaning that 36% of all PV generation is instantaneously matched by the electric load and the rest is exported to the grid. If self-generation and self-consumption are calculated on monthly values, the resulting values are significantly higher, as can be graphically estimated in Figure 4.3 (see also table inside the figure).

The Generation Multiple (GM) tells what the required grid connection capacity is due to the PV system compared to what it would be due to the load alone. The GM calculated as the ratio between peak generation and peak load is 4.3; this is the worst case since it does not consider the instantaneous match between the two quantities. Calculating the GM as the ratio of peak export over peak import gives a value of 3.7, as can be graphically estimated by comparing the two extremes of the duration curve (in blue) in Figure 4.4. Either way, the requirement for dimensioning the grid connection capacity is about four times higher with the PV system than it would be without. This means that the power distribution grid should be dimensioned for the local PV generation capacity, not for the load as is usual (at least for what concerns the buildings; load due to electric vehicles is not considered here).

4.2 Meeting ZEB energy targets

The analysis of the mismatch between loads and PV generation offers useful insights for the next step in the design phase: the heating system for the Zero Village Bergen, which is not yet decided. The two most probable options on the design table are either an all-electric solution (with heat pumps in the buildings or at a local district heating station) or a thermal-carrier solution with a local district system (whether or not connected to the city district heating).

The first reflection goes to the energy balance and the feasibility of achieving the ZEB goal in the Zero Village Bergen. First of all, it shall be noticed that the goal of balancing the entire energy use is highly ambitious. In comparison, the definition of "nearly ZEB" in the EPBD and related EN norms only requires to "nearly" balance the delivered energy that goes to cover the thermal load of all buildings plus the lighting for non-residential buildings only[30]. Assuming the all-electric solution one avoids the need for any primary energy or carbon emission conversion factor. In this case, even with a seasonal COP of just 2 the Zero Village Bergen would appear as a "Plus Energy" neighbourhood according to the EPBD, see Figure 4.1.

Setting the balance goal on the total delivered energy makes things more challenging. The thermal and electric loads happen to be about the same, but the electric load has always to be balanced on a one-

[30] ISO 5200-1/EN 15603 (2015) Energy performance of buildings - Overarching EPB assessment, *Draft version*.

to-one basis by the renewable electricity generated onsite or nearby. The thermal load may be easier to balance thanks to favourable conversion factors, as for example in the case of carbon emission factors (or non-renewable part of primary energy) for biomass that are often in the range of 10-70 (gCO_2/kWh) while they are in the range 150-600 (gCO_2/kWh) for electricity[31]. In that case the equivalent thermal load to be covered – after applying the carbon emission factors – would be *de facto* just a small fraction of what is shown in Figure 4.1. This seems to suggest that connecting the buildings to a local district heating system with biomass based cogeneration would provide at the same time a small additional thermal load – counted in carbon emissions – and extra electricity generation, so that the overall ZEB goal may actually be reached. This will depend on the specific conversion factors used for biomass and electricity.

The second reflection goes to the peak power and the mismatch between the load and the PV generation. In case of the all-electric solution one may argue that even if the heat pump seasonal COP was rather high, e.g. 4.0, the peak thermal load in the coldest days might be almost the same as what shown in Figure 4.2 due to poor operating conditions (low source temperature), frosting on the evaporator side, and the need to resource a top heater (electric), which all contribute to a poor COP, in the worst case of just about 1. In this case the ZEB balance would not be reached (at least not by the PV system alone) but the GM would get significantly reduced to about 1.5 because of the increased peak electric load due to the heat pump system. This means that the local electric grid does not need to be largely over dimensioned due to the PV system: something that might normally be regarded as a positive feature.

In case of local district heating, on top of achieving the ZEB balance more easily, the cogeneration would complement well the PV system because it generates electricity mainly in winter, and because it is possible to modulate its generation during the daily cycle, altogether improving the interaction with the grid. In this case though, the GM would be about 4 as analysed here, see Table 4.2. However, this needs not to be regarded as a negative feature. If one considers the need for charging electric vehicles – particularly relevant in Norway already today – having a high GM might even be an advantage. It simply means that the dimensioning of the grid connection is based on the PV peak production in summer, but that capacity is free overnight all year round to be used for charging e-vehicles.

4.3 Further work needed

The heating system for the Zero Village Bergen is not yet decided. The two most probable options on the design table are either an all-electric solution with heat pumps in the buildings, or a local district heating system since a city district heating is not available in the area. The analysis of the mismatch between loads and PV generation offers useful insights for the next step in the design phase.

The analysis of alternative solutions for the Zero Village Bergen heating system will be performed in future work, as well as the analysis of the e-vehicles charging load considering different scenarios of e-vehicles penetration. The analysis of the mismatch between aggregated electric load and PV generation presented in this paper provide useful insights on how to proceed in the next design step for this pilot project.

[31] Sartori, I., Napolitano, A. and Voss, K. (2012) Net Zero Energy Buildings: A Consistent Definition Framework, *Energy and Buildings*, vol. 48, pp. 220-232.

APPENDICES

A. Appendix 1: Monthly PV generation profiles

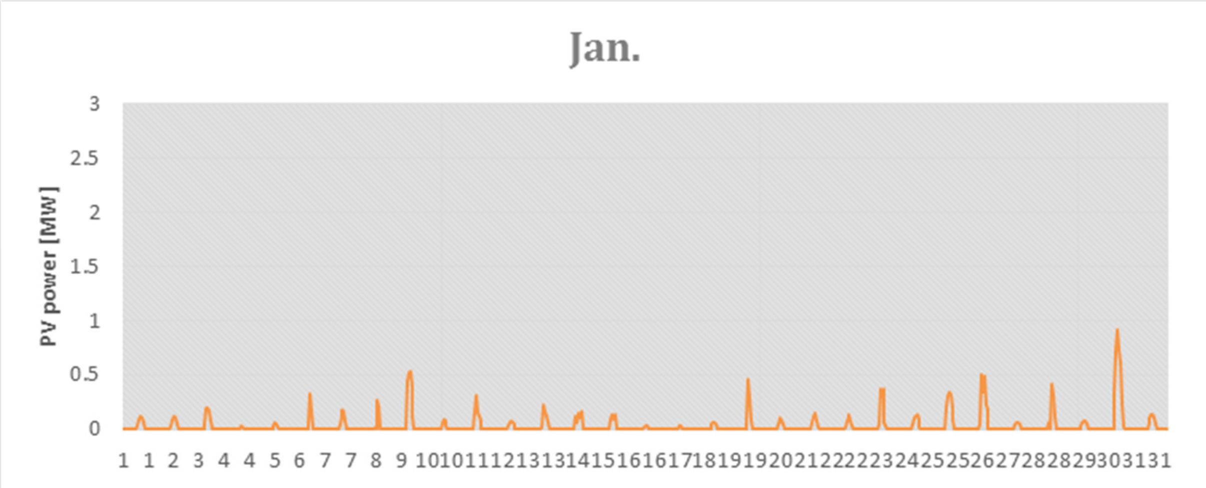


Figure A.1 PV generation profile, January.

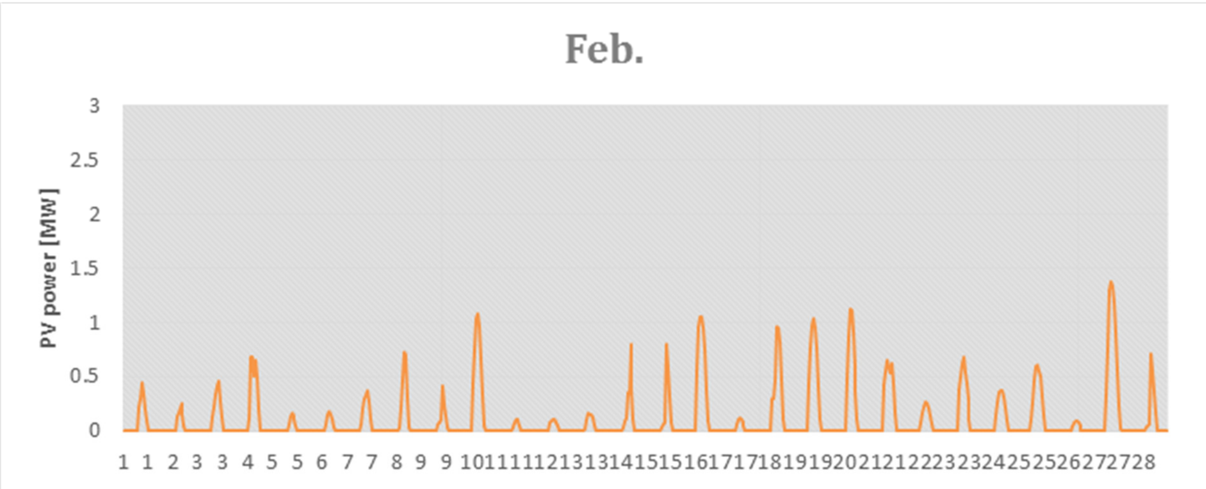


Figure A.2 PV generation profile, February.

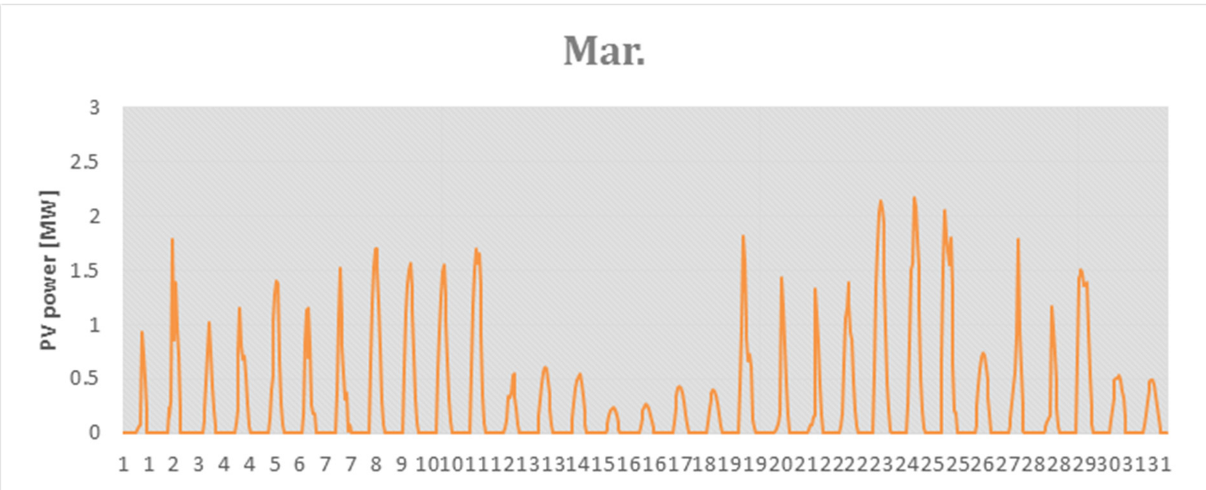


Figure A.3 PV generation profile, March.

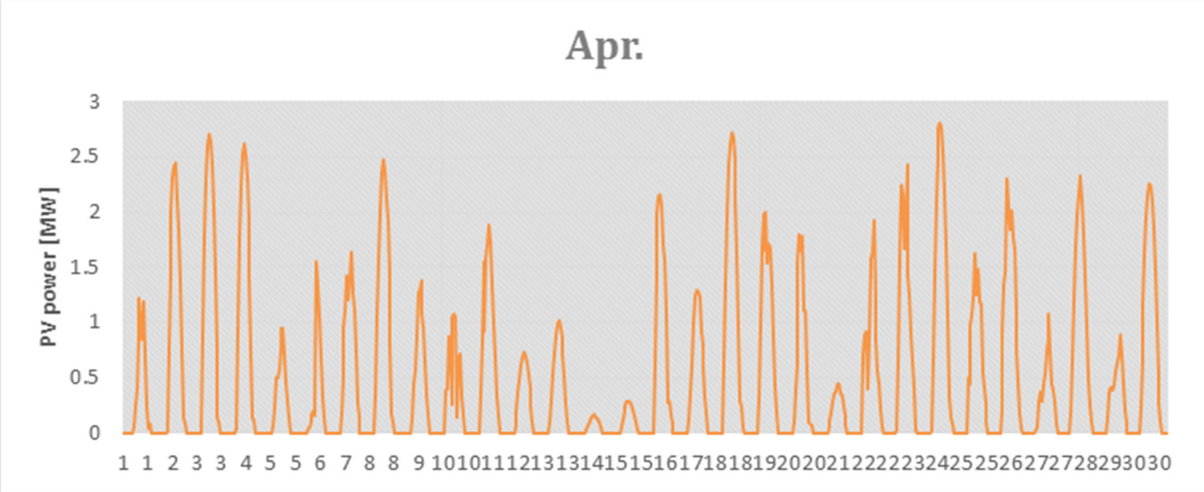


Figure A.4 PV generation profile, April.

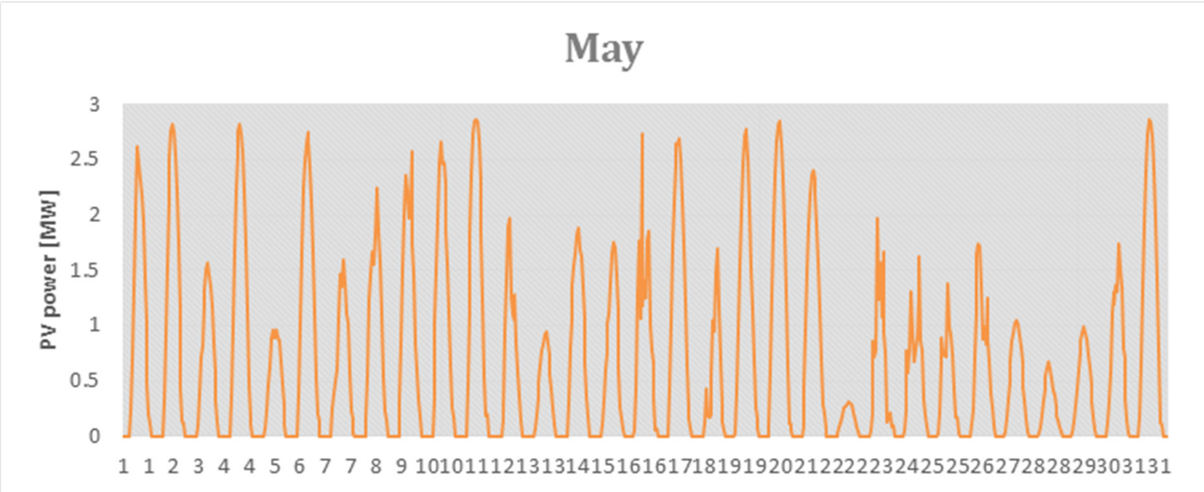


Figure A.5 PV generation profile, May.

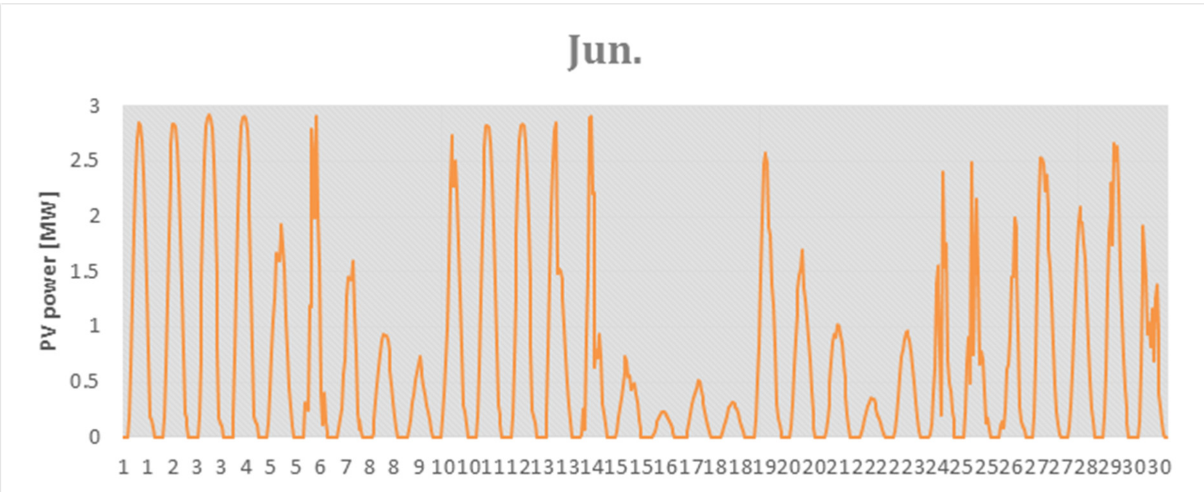


Figure A.6 PV generation profile, June.

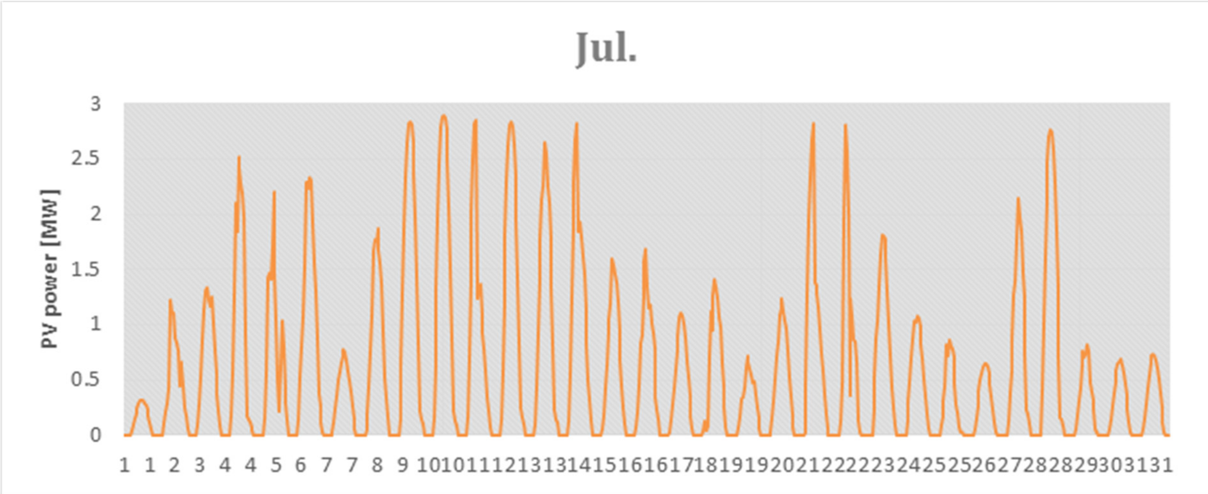


Figure A.7 PV generation profile, July.

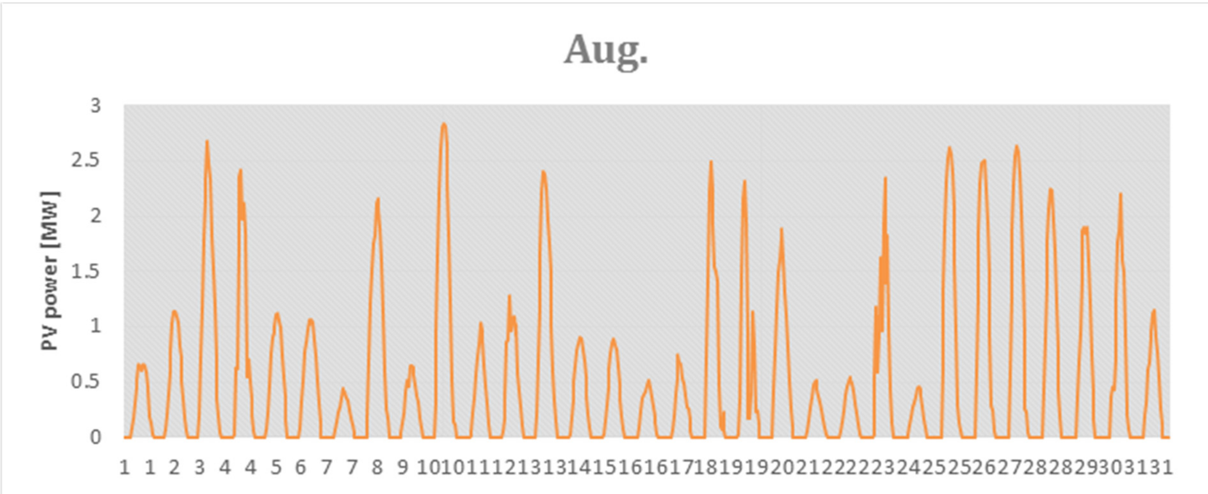


Figure A.8 PV generation profile, August.

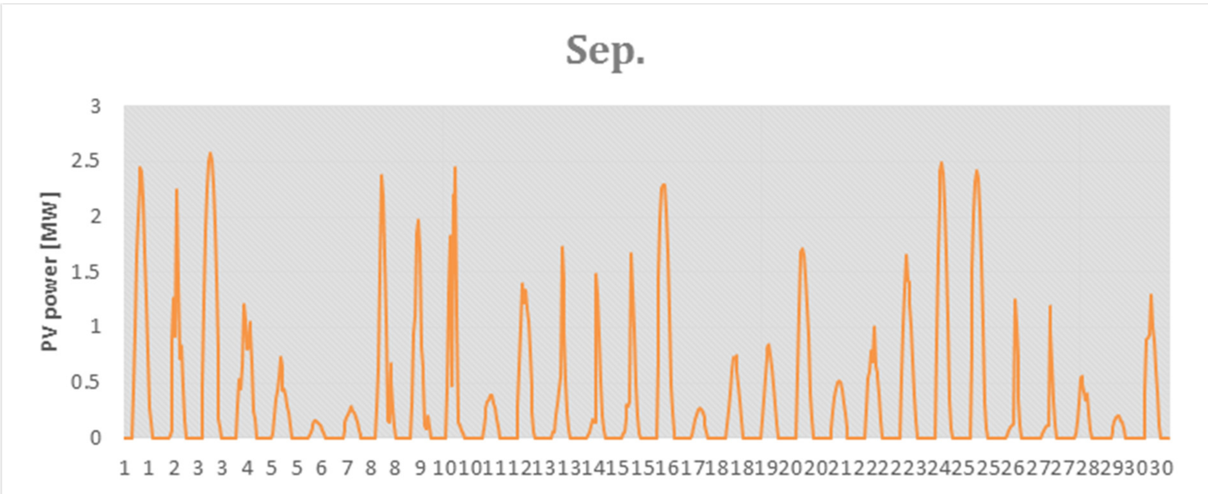


Figure A.9 PV generation profile, September.

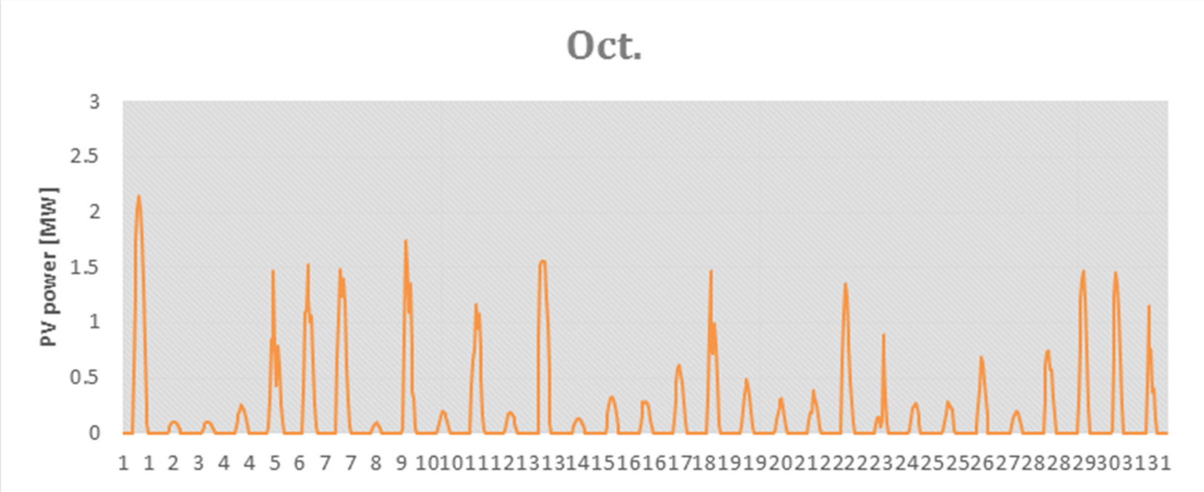


Figure A.10 PV generation profile, October.

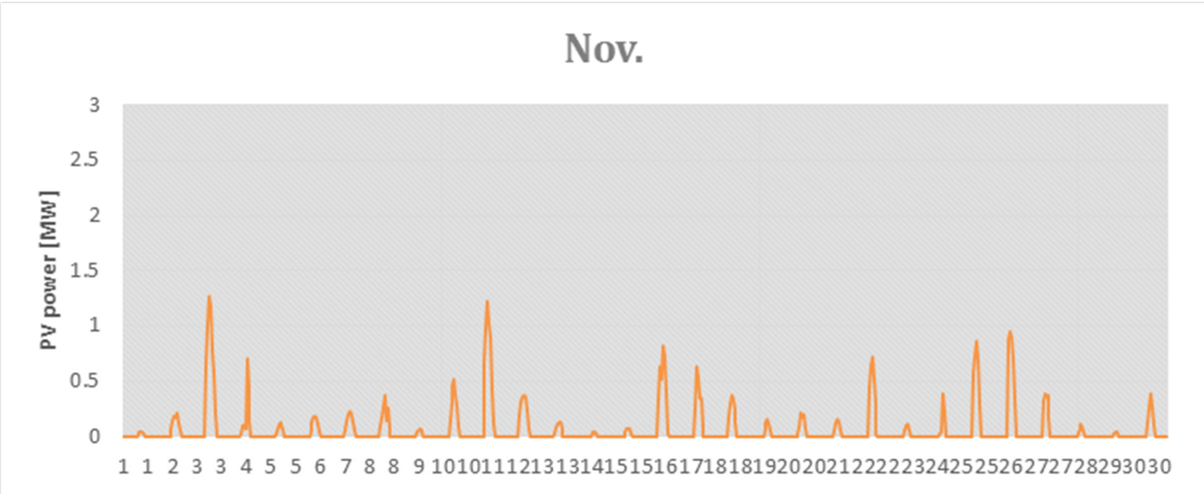


Figure A.11 PV generation profile, November.

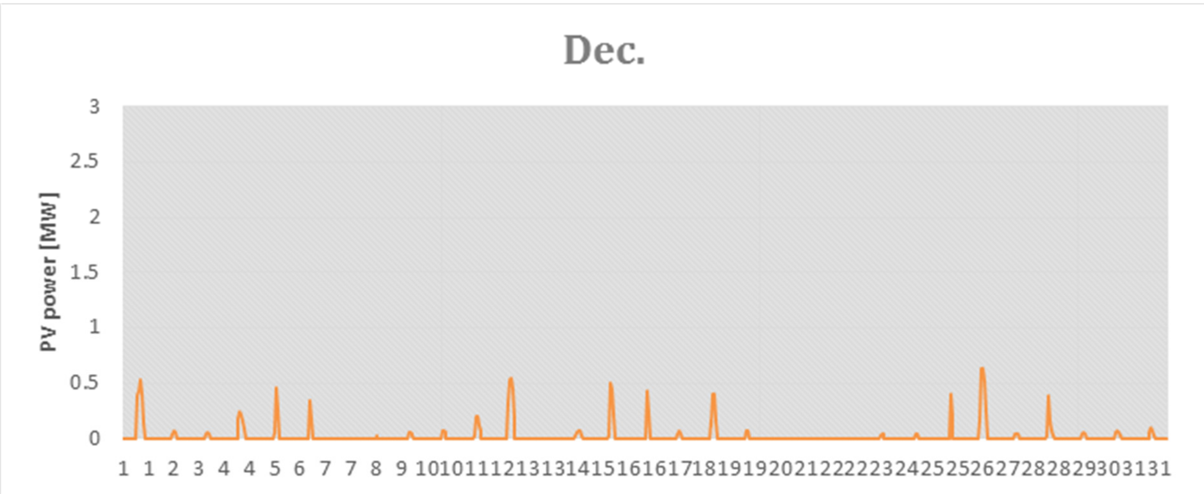


Figure A.12 PV generation profile, December.

The Research Centre on Zero emission Buildings (ZEB)

The main objective of ZEB is to develop competitive products and solutions for existing and new buildings that will lead to market penetration of buildings that have zero emissions of greenhouse gases related to their production, operation and demolition. The Centre will encompass both residential and commercial buildings, as well as public buildings.

NTNU – Trondheim
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SINTEF

ZEB The Research Centre on Zero Emission Buildings

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