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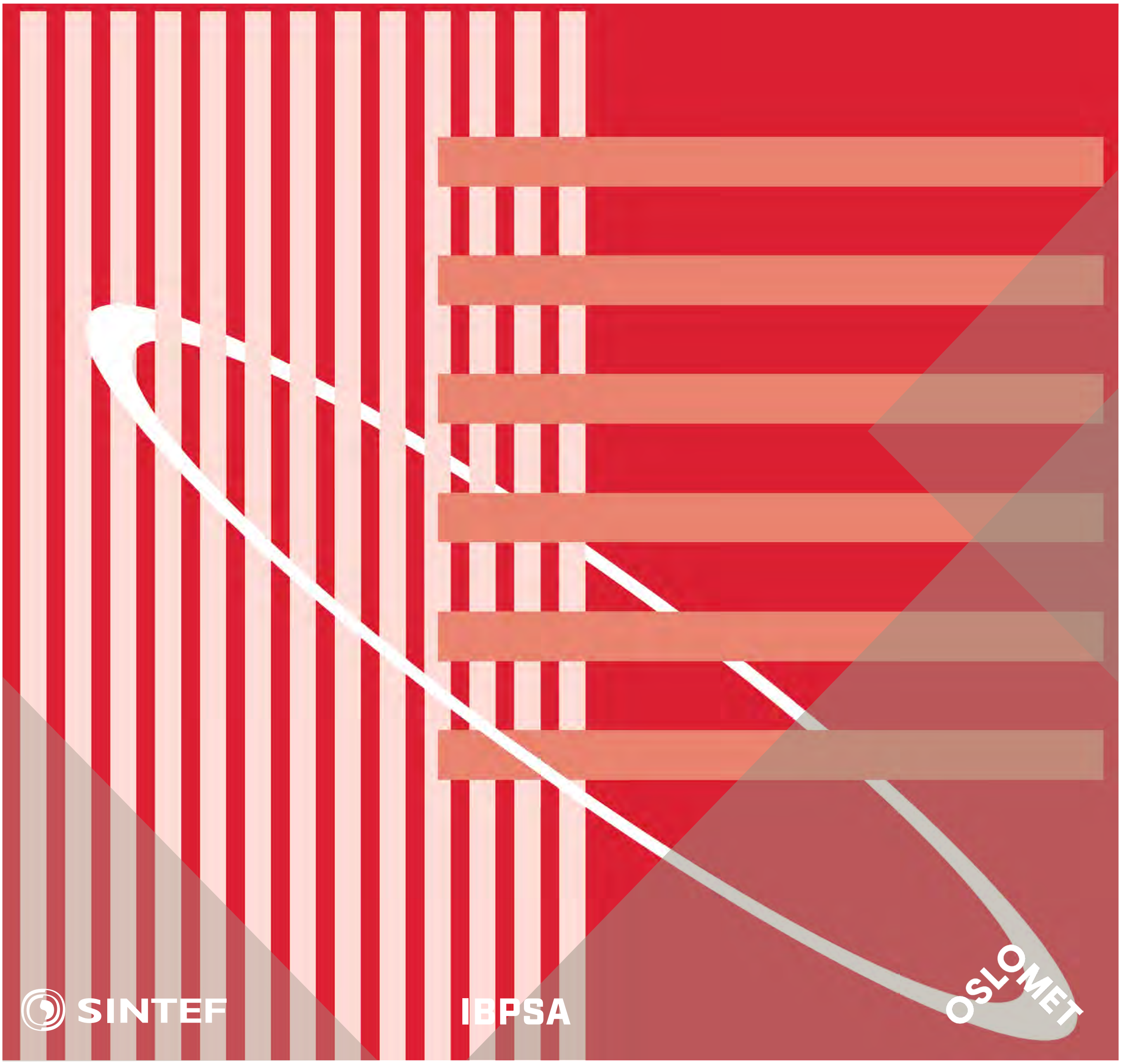

SINTEF Proceedings

Editors:
Laurent Georges, Matthias Haase, Vojislav Novakovic and Peter G. Schild

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From TEK17 to ZEB-O – A case study for a residential building in northern Norway

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Abstract

With a strong focus on reducing emissions from the building sector, it is important that new buildings can compensate for emissions caused during their operation by on-site renewable electricity generation. In academia, there is consensus on measures to achieve a so-called zero emission balance, but there are still mostly pilot projects that have a focus on emission analysis during the planning process of buildings. This work is associated to the Sjøsiden project of Gunvald Johansen Bygg AS, a local entrepreneur in the city of Bodø (Northern Norway). The main goal of this study is to assess the most suitable energy system for the Sjøsiden project in order to approach a zero emission balance, taking into consideration the local conditions in Northern Norway. Three different energy systems are analysed for this project using the dynamic building performance simulation tool IDA ICE, Version 4.8. This work confirms previous findings that a building with passive house standard equipped with a heat pump and photovoltaic panels gets closest to achieving a zero emission balance. In the end, practical implications for zero emission buildings are discussed.

Introduction

In recent years, research related to energy use in buildings has moved from single building level towards neighbourhood level, not only in Norway, but also internationally. This is evident from several international projects, such as CityXchange, Synikia, IEA EBC Annex 83 on Positive Energy Districts. In Norway, the Research on Centre on Zero Emission Neighbourhoods in Smart Cities aims to develop sustainable areas that have zero emissions related to buildings, building operation and transport.

Zero Energy Buildings

Sartori et al. (Sartori, Napolitano, & Voss, 2012) defined a framework for Net Zero Energy Buildings, also called Net ZEB. Net ZEBs are usually all-electric buildings, where *Net ZEB* refers to buildings that are connected to the electricity grid and that can do both, consume and generate electricity onsite. These buildings achieve a balance between the electricity imported from the grid and exported from the building to the grid over a certain time horizon, usually one year.

Regarding the design of a Net ZEB, starting from a reference building, the first goal is an improved energy efficiency (Figure 1). This is usually achieved by improving the energy performance of the building envelope, for example by increasing the thermal insulation and by improving the air tightness of the building envelope to decrease the building heating needs. To achieve a Net ZEB balance, local electricity generation (e.g. from photovoltaic panels) is required. This Net ZEB balance is achieved by designing an onsite photovoltaic (PV) system so that the electricity generated onsite can compensate for the energy use of the building throughout the evaluation horizon.

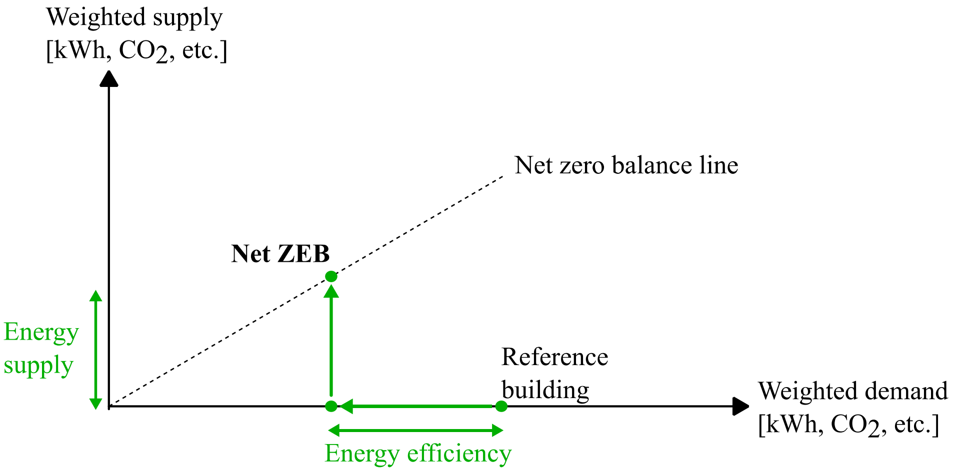

Figure 1: Concept of Net ZEB balance (adapted from *(Sartori et al., 2012)*).

Zero Emission Buildings

In an international perspective, ZEB is usually related to zero energy buildings, whereas in Norway ZEB is related to zero emission buildings.

The Norwegian Research Centre on Zero Emission Buildings (FME ZEB) decided to focus on emissions rather than energy and thus, a zero emission building is defined and evaluated based on the calculated GHG emissions during the lifetime of the building (Mamo Fufa, Dahl Schlanbusch, Sørnes, Inman, & Andresen, 2016). The GHG emissions are calculated with the help of CO_2 equivalent ($CO_{2eq.}$) conversion factors for each energy carrier ($kgCO_{2eq}/kWh$) and building material ($kgCO_{2eq}/m$, $kgCO_{2eq}/m^2$, $kgCO_{2eq}/m^3$, $kgCO_{2eq}/kg$).

As the ZEB Centre definition is ambitious, a stepwise approach with different ambition levels was developed to allow for the possibility to consider different stages of the building life-cycle for the evaluation of a zero emission balance. Figure 3 provides an overview of the different ambition levels defined by Fufa et al. (Mamo Fufa et al., 2016). These levels are briefly described in the following. Emissions are compensated for with renewable energy generation:

- ZEB-O – EQ: Emissions related to the energy use from the operational phase (O), excluding appliances and equipment (EQ)
- ZEB-O: Emissions related to all energy use during operation phase
- ZEB-OM: Emissions related to all operational phase and embodied emissions from materials (M)
- ZEB-COM: Same as ZEB-OM and additionally emissions related to the construction phase (C). The construction phase considers the transport of materials and products to the building site and the construction installation process.

When targeting a ZEB ambition level, it is of outmost importance to have an integrated design process, which *"involves establishing clear goals, employing multi-disciplinary cooperation from the early design stages, implementing a high level of energy integration and synergy of systems, and using modern performance prediction tools throughout the process to improve the environmental performance of a building"* (Andresen, Wiik, Fufa, & Gustavsen, 2019).

This approach is still rather theoretical for entrepreneurs and this project aims to bridge the industry and research sector. This work assesses three different energy systems for the Sjøsiden project in Bodø to approach a zero emission balance, taking into consideration the local climate conditions in Northern Norway. The paper also investigates measures that can be applied to satisfy a zero emission balance. The gained knowledge is of value for entrepreneurs with regards to building design.

Methods

This section introduces the building and describes the methodology of the energy system analysis.

Description of the building

The two-family house (TFH) is a three-story building and has a heated floor area of 711 m^2. A sketch of the THF is presented in Figure 2.

Figure 2. Simplified sketch of the two-family house.

Simulation setup

Different energy systems are simulated using the dynamic building simulation software tool IDA ICE Version 4.8.

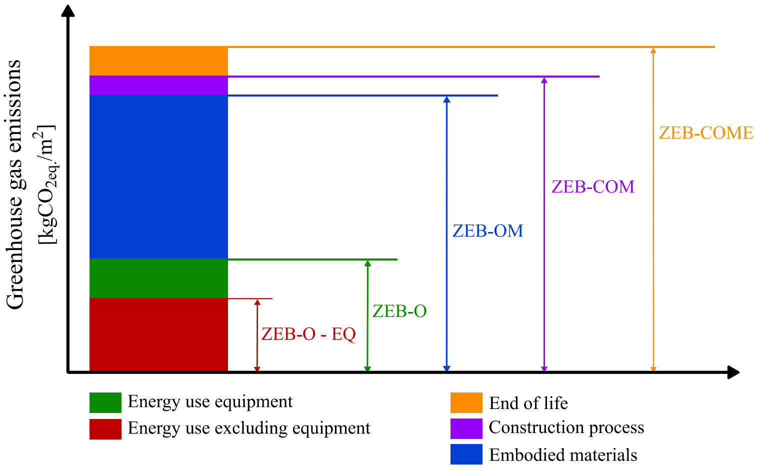

Figure 3. ZEB ambition levels (explanation in the text above; GHG emissions calculated as kg $CO_{2eq.}$ per m^2 heated floor area per year distributed over a 60-years life time).

IDA ICE applies equation-based modeling and allows to investigate building energy systems and to evaluate the energy use of buildings. IDA ICE has been validated in several studies (EQUA Simulation AB, 2010; EQUA Simulation AB & EQUA Simulation Finland Oy, 2010). The energy system analysis uses the results from the dynamic simulations in IDA ICE as input for further evaluation of the carbon footprint of the tested systems during annual operation. Regarding the simulations, the following simplifications and assumptions are taken:

- Local climate data for Bodø is taken into account. An ASHRAE IWEC2 weather file is applied. It contains hourly values for the dry-bulb temperature, relative humidity, direction and speed of the wind, and direct and diffuse solar radiation.
- Specifications according to Norwegian building regulation TEK17 are considered to achieve a required minimum energy efficiency of the buildings.
  - Requirements for minimum U-values of the building envelope and windows (Table 1).
  - Requirements for ventilation as well as internal heat gains from occupants, lighting and electrical appliances.
- Schedules for occupancy, lighting and the use of electric appliances based on SN-TS 3031:2016.
- Regarding thermal zoning in buildings, the room layout is simplified by creating one zone per floor per apartment/housing unit, since the main focus of this work is the energy system analysis and less on the detailed thermal comfort. Assuming that the heating temperature set-point is 21°C in each zone, there are only slight differences in the heating energy use compared to having one zone per room.

Table 1. Building envelope properties for the TEK17 building.

Properties	**Unit**	**TEK17**
U-value external walls	$W/(m^2*K)$	≤ 0.18
U-value roof	$W/(m^2*K)$	≤ 0.13
U-value external floor	$W/(m^2*K)$	≤ 0.10
U-value windows/doors	$W/(m^2*K)$	≤ 0.80
Thermal bridges	$W/(m^2*K)$	≤ 0.05
Air handling unit heat recovery effectiveness	%	> 80
Infiltration at 50 Pa, n_{50}	h^{-1}	≤ 0.6

Simulation procedure for the energy system analysis

The energy systems considered in the analysis are district heating (DH), combined heat-and-power (CHP) and a seawater heat pump (SWHP). The "reference" system is DH because by regulation there is an obligation to connect to DH if the infrastructure is in place. There is one annual simulation for each energy system.

Regarding the sizing of the heating system, a heating load simulation (HLS) at design outdoor temperature is performed. This approach is used to determine the thermal load (peak power) that needs to be covered by the energy system and thus the heat distribution system. This distribution system can be sized for a given design outdoor temperature (DOT), which is -15 °C for Bodø according to (Sintef Byggforsk, 2012). No internal heat gains are considered for this evaluation. The peak power presented in Table 3 shows the peak power for space heating and DHW at the time of the total maximum peak power.

Performance evaluation

The three energy systems are evaluated based on the annual energy use and annual emissions during building operation (Table 7).

The energy use considers the delivered energy for heating and the delivered electricity for lighting and electrical appliances. Lighting and appliances are included because they impact the total amount of energy to be delivered to the building and the amount of PV electricity that can be used on-site or exported to the grid.

For the sake of clarity, different operation strategies are not considered in this report, but are of course worth to be investigated in future work.

Each electricity or heat generating technology has a specific $CO_{2eq.}$ factor, which is used to determine the total annual emissions and the ZEB balance. The Norwegian Standard NS3720 recommends to calculate the emissions from electricity for two different scenarios: i) 18 $gCO_{2eq.}/kWh$, which is the current average factor for the Norwegian electricity grid and ii) 136 $gCO_{2eq.}/kWh$, which is the assumed average $CO_{2eq.}$ intensity of the European electricity grid for the period 2015 to 2075. Referring to NS3720, two scenarios are used in this report (Table 2): (1) current Norwegian $CO_{2eq.}$ factor for electricity and (2) estimated future $CO_{2eq.}$ factor for electricity. The $CO_{2eq.}$ factors for biomass are chosen based on NS3720, which proposes a bandwidth between 8.5 to 130 $gCO_{2eq.}/kWh$ as a factor.

Table 2: Emission factors for two scenarios, S1 and S2 (value according to the FME ZEB).*

Energy carrier	**$CO_{2eq.}$ factor [$gCO_{2eq.}/kWh$]**	
	S1: current $CO_{2eq.}$ factor for El.	S2: estimated future $CO_{2eq.}$ factor for El.
Solid biomass	12	50
Electricity	18	132*

Energy System Analysis

The energy system analysis is done on a higher level, meaning that the aim of the project is the evaluation of the energy systems based on the maximum power need and total annual energy demand. Different control strategies for the operation of the energy systems are not evaluated. This project focuses on energy systems installed to meet the required heating demand of the building. For all three energy systems, DH, CHP and SWHP, it is assumed that the building is directly connected to the energy system.

An HLS at the design outdoor temperature -15 °C is performed for the buildings. An overview of the resulting heating needs for SH and DHW heating is given in Table 3. The specific characteristics for each energy system are discussed in the remainder of this section. The based load system covers both SH and DHW and the electric auxiliary heater supports the base load whenever required.

Table 3: Thermal capacities resulting from the heat load simulation at DOT -15 °C for the two-family house.

Characteristics	**Peak thermal capacity**
Space heating: Peak power / thermal capacity [kW]	18
DHW: Peak power [kW]	9

All three energy systems can be combined with on-site PV panels for electricity generation, so that it is possible to evaluate whether the buildings could reach a certain ZEB ambition level. The energy systems are evaluated for each building separately.

Photovoltaic panels

PV panels for on-site electricity generation are considered in combination with the three other technologies. With regards to zero emission buildings/neighborhoods, the electricity generation from PV panels is used to compensate for emissions from the building. In this project, it is assumed that PV panels would be installed on the roofs of the three buildings leading to a total PV area of 260 m^2. The efficiency of the PV panels is set to 17 % which is a typical efficiency of PV panels available on the market. Tilt angles of the panels follow the roof tilt angle (11°). The PV panels are facing south.

The assumption that PV panels are installed on the entire roof area provides a best-case scenario. The scenario is examined to see if ZEB-O could be achieved at all. It is more realistic to have a PV area that is smaller than the roof area. With a certain tilt angle, there would be several rows of PV panels, thus causing shadowing effects. In detailed planning of the PV system, there should be an optimal solution between tilt angle, and thus distances between several rows of PV panels to avoid shadow effect, and the location of the PV system. Optimization should aim for a maximum energy generation for a given location. It is obvious that the installation of several rows will lead to a lower total area of PV panels, and thus lower annual electricity generation

District heating

District heating supplies heat for DHW heating and space heating. The required temperature for DHW is 55 °C. The energy use from DH considers the delivered energy that is needed to cover the heating demand of the building for both, SH and DHW.

Table 4: Simulation data input for the DH system.

Characteristics	**Thermal System**	
	Base heating	Peak heating
Thermal capacity	Unlimited	Not required
Thermal eff. [%]	90	-

Heat losses from the pipes of the DH system are not considered in the analysis. Input data for the simulation of the DH system are presented in Table 4. The peak power is provided by an electric auxiliary heater

Combined heat and power (CHP)

A CHP plant typically uses biofuels which can be solid biomass or biogas. Solid biomass has a rather low electric efficiency, but also a rather low $CO_{2eq.}$ factor which is advantageous with regards to achieving a ZEB balance. Compared to solid biomass, biogas has a higher electric efficiency, but also a higher $CO_{2eq.}$ factor. In this study, the heating efficiency of 69 % and the electricity production efficiency of 11 % is set in accordance with SN/TS3031:2016. The CHP plant is used to supply DHW and SH. The peak power is provided by an electric auxiliary heater.

Table 5: Characteristics of the CHP system.

Characteristics	**Thermal System**	
	Base heating	Peak heating
Thermal capacity [kW]	20	10
Thermal/el. eff. [%]	69 / 11	90

Seawater heat pump (SWHP)

A modulating SWHP is evaluated as a third alternative. This choice is based on the geographical conditions since the Sjøsiden neighborhood is located right at the shoreline. The thermal capacity of the simulated heat pump is presented in Table 6. The peak power is provided by an electric auxiliary heater.

Table 6: Characteristics of the SWHP system.

Characteristics	**Thermal System**	
	Base heating	Peak heating
Thermal capacity [kW]	20	10
Electric eff. [%]	Nominal COP 4	100

Results

The results show that the SWHP leads to a lower annual energy use for heating and to lower annual carbon emissions compared to the DH system and a CHP plant (see Table 7). The energy use for the CHP plant is higher than the energy use for the DH system because more energy must be delivered to meet the same demand due to the lower thermal efficiency of the CHP plant.

Regarding the two scenarios for carbon emissions, S1 and S2, it is shown that the total annual carbon emissions are very dependent on the choice of $CO_{2eq.}$ factor. It can be seen in Table 7 that the total emissions for the CHP plant are higher than for the DH system for scenario S1, whereas they are lower compared to the DH system for scenario S2. This difference is due to the choice of emission factors and their respective ratio (S1: 12 vs. 18 and S2: 50 vs. 132). The importance of the exported electricity generated from the CHP plant increases in scenario S2. A detailed overview of the results is presented in Table 8.

Table 7: Annual energy use and emissions for the three investigated energy systems.

Performance indicator	District heating	CHP plant	Seawater heat pump
***Two-family building** (711 m^2 heated floor area)*			
Energy [kWh/m^2/year]	65	75	17
Emissions S1 [kg$CO_{2eq.}$/year]	541	606	218
Emissions S2 [kg$CO_{2eq.}$/year]	2164	2091	1599

A cost analysis has not been performed in this study, but it can be referred to a report by Sartori et al. (Sartori, Skeie, Sørnes, & Andresen, 2018), who have performed an analysis of possible energy system at Zero Village Bergen.

Table 8: Detailed overview over annual energy balance and annual emissions.

		Energy system		
		DH	CHP	SWHP
DH	[kWh/y]	47503	0	0
CHP	[kWh/y]	0	61690	0
El_{Import}	[kWh/y]	15459	10035	27591
El_{Export}	[kWh/y]	17059	17662	15478
$El_{Balance}$	**[kWh/y]**	**-1600**	**-7627**	**12113**
$E_{Balance}$	**[kWh/y]**	**45903**	**54333**	**12113**
Em_{S1}	**[kg/y]**	**541**	**606**	**218**
Em_{S2}	**[kg/y]**	**2164**	**2091**	**1599**

They compared DH, a CHP plant and a ground-source heat pump also with regards to global costs of the energy systems and found that the ground-source heat pump leads to the lower global costs even though the investment costs were much higher compared to DH. A similar trend could be expected for the SWHP for the Sjøsiden project.

Case study

Results show that it was not possible to reach a ZEB balance with a building that meets the requirements of the building code TEK17.

A case study has been performed to investigate which measures have to be taken to upgrade a TEK17 building to a ZEB-O using the specific case of Sjøsiden. The following measures are investigated in combination with the CHP plant and the SWHP:

- Upgrade insulation level from TEK17 to Passive House (PH – NS3700),
- Increase the efficiency of the PV panels from 17 % to 22%.

The balance for the DH system lies between the SWHP and the CHP plant.

Here it is pointed out that it is important to know which ZEB ambition level one is aiming for. As a reminder, common procedure to achieve a ZEB balance focuses first on (1) reducing the energy demand of a building and then (2) designing the on-site electricity (or heat) generation based on the energy demand.

Therefore, the first measures to be taken in this case study are the upgrading of the building envelope to PH standard by increasing the insulation level, improving the U-values of windows and doors and by improving the air-tightness of the building envelope. Once the heating needs of the building are reduced, the on-site renewable energy generation technology can be dimensioned for the PH case. To reach the ZEB-O ambition level, the PV panels have to generate enough electricity to compensate for all emissions from the operational phase during the lifetime of the building. Shown graphically in Figure 4, this means that the symbol has to be above the diagonal line; the further above the line, the more emissions can be compensated for, thus being also able to reach more ambitious ZEB-levels (Figure 3). The analysis in Figure 4 applies the $CO_{2eq.}$ factors for scenario S1 (biomass: 12 g$CO_{2eq.}$/kWh; electricity: 18 g$CO_{2eq.}$/kWh).

It is shown in Figure 4, that improving the building envelope from TEK17 to PH standard "moves the building" further towards the left, as the heating needs are decreased and thus less energy has to be delivered to the building to cover those needs. For this specific case study, the insulation thickness of the external walls, the roof and the floor were increased by 12 cm, 10 cm and 4 cm respectively to reach the desired U-value.

Several conclusions can be drawn from Figure 4:

1. Comparing the three energy systems for the reference building (TEK17), the building is not able to achieve a ZEB-O level for any of the three energy systems. However, the SWHP helps to reduce the imported energy (and thus emissions) significantly compared to DH and CHP.
2. For both, the SWHP and CHP, it helps to improve the building envelope to PH standard to decrease energy imports (*CHP-PH*, *SWHP-PH*).
3. A rather simple measure is the installation of PV panels with a higher efficiency. With continuously decreasing costs and at the same time improving efficiency for PV panels, the application of PV panels with efficiencies around 20 % to 25 % becomes more cost-effective. It is shown that an efficiency improvement from 17 % to 22 % leads to more exported energy/emissions since more energy can be harvested, but not necessarily self-consumed on-site.
    a. The two-family house in combination with a SWHP almost achieves a ZEB-O level, if the building envelope would be improved to PH

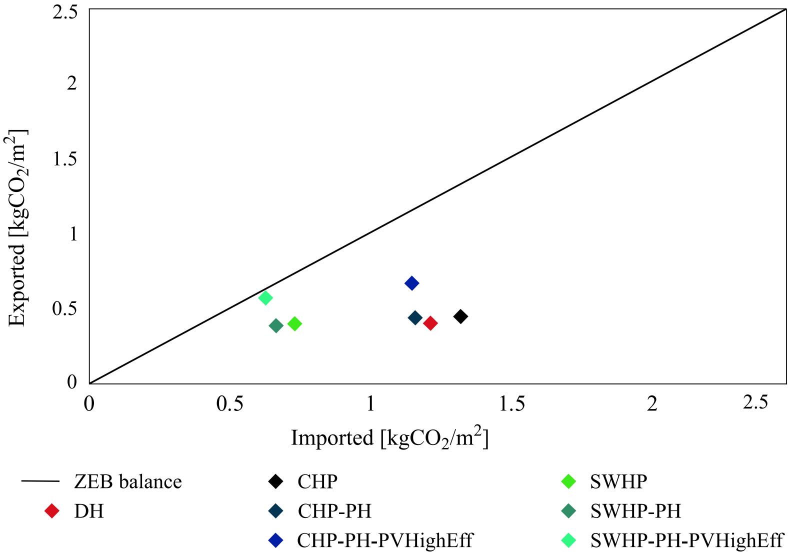

Figure 4: ZEB balance for the two-family house to reach the ZEB-O ambition level.

standard and if the PV panel efficiency is increased by 5 %. Again, this is the case, if the size of the PV area corresponds to the total roof area.

   b. This is an important finding because it shows that rather simple measures can lead to achieving a ZEB-O level (in combination with a heat pump system), especially considering further improvements in electric efficiency and thus cost-efficiency of PV panels.
   c. Regarding the TFH in combination with a CHP plant, the total PV panel area must also be increased additionally to an improved building envelope and an increased PV efficiency, to achieve a ZEB-O level. This can be challenging in a residential area where space for the placement of PV panels often is limited.
4. If the measures were taken in combination with the DH system, the effect of the measures on the ZEB balance would be rather similar to the effect in combination with the CHP plant

This case study demonstrates that it is important to think about relevant solutions for the energy system already during planning phase, if one is aiming for a zero emission building.

Discussion

The discussion focuses on, and tries to put awareness on practical issues faced by entrepreneurs during the early planning phase and construction process for zero emission buildings.

A few relevant challenges and questions are:

- *Regarding building operation:*
  - In this project, the energy systems are evaluated for one building, which is not connected to its neighboring buildings. With regards to interaction between buildings in a neighborhood, it is recommended to integrate the buildings into one energy system to evaluate the energy use of the buildings combined. This will be important when the focus is on the exchange of surplus electricity between buildings and thus feasible operation strategies.
  - Different operation strategies of the energy systems during operational phase are not considered in this project, but it is important to think about desired goals of operation strategies of the energy systems. Operation strategies also influence the choice and dimensioning of system components and relevant operation strategies are thus important to consider from the early design process on.
- *Regarding regulations, business models and costs:*
  - National or municipality regulations, project costs and business models for building and energy system operation go hand-in-hand as they often influence each other.
  - With regards to the choice of energy systems, how can entrepreneurs choose if to connect to DH or not, if the buildings to be constructed are situated in a concession area for DH? Should entrepreneurs be responsible for taking the decision, or the municipality?
  - With regards to achieving a ZEB or ZEN, how would it be possible to attribute more common space to PV panels rather than green area? If so, how would that be accepted by inhabitants?
  - How does the local zoning plan consider the businesses of entrepreneurs? For example, if ZEBs are to be built instead of TEK17 buildings, extra insulation in the walls should be installed to decrease building heating needs which leads to thicker walls. If more insulation is put on the inside, living area is decreased and thus sellable living area. This is a

drawback especially for apartment buildings, which often already have rather narrow rooms, so that it could not be functional to decrease the apartment width even more. If the insulation is to be put outside, the dimensions of the buildings increase, but the distance between the buildings still has to be kept according to the zoning plan. If many buildings are to be built, it could be necessary to adjust the zoning plan accordingly because otherwise, the increased building dimensions comes at the cost of decreased common area. This problem should ideally be considered during the planning phase already so that architects can take it into account.

- Regarding costs and business models there are uncertainties with no simple answers provided by today`s models; e.g., who is owning what of the energy system? If a local heating grid is to be built, who is responsible for operating and maintaining it? Who takes the investment costs for a new energy system? If a heat pump supplies heat to a local heating grid, who owns and operates the heat pump? Who owns on-site PV panels, what is the payback time and who gets the possible savings from sold PV electricity?
- What is the value of the energy systems from a private economic and public economic point of view? If there is an obligation to connect to district heating, is it feasible to establish a local heating grid and operate a heat pump to supply heat?
- Starting from the ZEB definition how can the ZEN definition be defined in order to make use of district heating, even if a ZEB could not? For now, the ZEB balance is purely energy-based and thus favors the technologies that use the least energy to cover the demand.

Conclusion

An energy system analysis has been performed for a two-family house at the Sjøsiden neighborhood in Bodø. The energy systems considered in the analysis are district heating (DH), combined heat and power (CHP) and a seawater heat pump (SWHP). The "reference" system is DH because by regulation there is an obligation to connect to DH if it the infrastructure is in place. The performance of the systems is evaluated based on the annual energy use and resulting annual emissions of the buildings. A case study is performed investigating different measures to "upgrade" the building from TEK17 to a ZEB-O.

It has been found that the TEK17 building does not reach a zero emission balance for any of the three energy systems. Therefore, the envelope of the building has been improved to passive house standard and the efficiency of the PV panels has been increased from 17 % to 22 %. Confirming findings from literature, it is found that the SWHP reaches the zero emission balance easier than DH or a CHP plant. If a SWHP is used, it is almost sufficient to improve the building envelope and the PV efficiency. From a practical point-of-view and based on the ongoing development of PV efficiency, cost-effective PV panels with an even higher efficiency will be available in the (near) future, so that the zero emission balance of the case study building could be achieved by installing highly-efficient PV panels. This is important for a residential area where space for PV panels is limited. For the DH system or the CHP plant, it is not sufficient to only improve the building envelope and the PV efficiency, but it would also be required to increase the total PV area to generate enough electricity to compensate for the imported electricity.

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Nomenclature

CHP	Combined heat and power
DH	District heating
E	Energy
Eff.	Efficiency
EF	Emission factor
el.	Electric
El	Electricity
Em	Emissions
EQ	Equipment
M	Materials
O	Operation
PH	Passive house
SWHP	Seawater heat pump
TEK17	Norwegian building regulation
TFH	Two-family house
ZEB	Zero energy building / Zero emission building
ZEN	Zero emission neighbourhoods

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