Kasparas Pajarskas

Achieving a nearly zero-energy building (nZEB) status for a residential house in Finland

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Achieving a nearly zero-energy building (nZEB) status for a residential house in Finland

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Abstract

The objective of this thesis is to research the feasability of nZEBs as an option for residential housing in Finland. Secondary objectives include determening the best type of heating system as well as renewable energy technologies for such a building. An additional objective is to determine whether the best appraoch for an nZEB in Finland is to prioritize energy efficiency or energy generation from renewable energy systems.The initial hypothesis is that nZEB energy consumption levels can be successfully reached in Finland only by adding a moderate amount of renewable energy generation to already existing and known to be cost – optimal Passive House or Very Low Energy House standards.

Methods of this research included finding out what technical solutions, taken both from the Passive House and Very Low Energy House standards as well as recommendations for nZEBs in cold climates should be applied when designing a nZEB in Finland. After this was done, different nZEB concepts have been created and their energy performance simulated using IDA ICE 4.7.1 software. In order to meet the objectives of the thesis, building concepts with different thermal insulation levels, heating systems and renewable energy technologies have been compared, totaling up to 18 different building concepts. Additionally, all of these building models were simulated in three different parts of Finland - Southern (Helsinki), Central (Jyvaskyla) and Northern (Sodankyla).

The results of the simulations revealed that nZEBs are indeed an optimal choice for residential housing with today's technological development. This is known as the nZEB performance levels have been reached only by adding moderate amount of renewable energy technologies to already widely used and known to be cost – optimal Passive House and Very Low Energy House standards. It was not expected, although, that all of the created building concepts, even with insulation levels representing only the minimum Finnish National Building Code requirements have reached the nZEB energy performance levels. The best heating system choices proved to be District Heating and Ground-Source Heat Pumps while the best renewable energy technologies proved to be Photovoltaic cells, Solar Thermal collectors and if counted, the same Ground Source Heat Pumps.

After attaining such results, a conclusion has been made that nZEBs are a perfectly viable option for residential housing in Finland. However, it was speculated that such good results might not have been achieved if more variables would have been analyzed in the simulation and if the requirements for nZEBs in Finland would be mores strict.

Keywords

nZEB, energy efficiency, renewable energy, building energy simulation.

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1 INTRODUCTION

While the problem of climate change gains more and more momentum worldwide Europe is one of the leading parties in supporting, developing energy efficient technologies and encouraging environmental responsibility. In 2007 leaders of the European Union (EU) have arrived to a decision to create and implement a goal package called „20/20/20“ in order to meet EU's climate and energy targets by 2020 /2/. This means that a 20% cut of greenhouse gas emissions compared to 1990, a totalconsumed energy share of 20% from renewables and a 20% improvement in energy efficiency compared to "business as usual (BAU)“ scenario would have to be achieved by the year 2020.

Buildings are responsible for 40% of total energy consumption and 36% of CO_2 emissions in the EU, therefore they play a key role in reaching EU's sustainability goals. Current building stock also offers the biggest savings potential compared to other sectors /2/. Developing and adopting energy efficient building concepts is not a new practice in the EU. But since the sustainability goals are far from being reached, the European member states are beginning to move from Low-Energy Building or Passivhaus concepts towards a nearly Zero-Energy Building (nZEB) concept. The member countries will be required for their new buildings to be built as nZEBs from 2020 December 31st and all of their new buildings owned and occupied by public authorities from 2018 December 31st.

This means that nZEBs will soon become highly demanded. Even though the technology and means to achieve cost-optimal nearly zero-energy status for buildings already exists, this transition poses its challenges and therefore must be taken seriously and prepared for in advance by all EU member countries. Preparation includes everything from adapting the building construction industry to setting and meeting the milestones in terms of definitions, calculation principles, regulations, governmental incentives and other things needed to lay a firm groundwork for a smooth transition. The European Commission urges that the national plans of the member countries for increasing the number of nZEBs should at least include:

- "A detailed application in practice of the definition of nearly zero energy buildings, reflecting their national, regional or local conditions;
- intermediate targets for improving the energy performance of new buildings for

2015;

- information on the policies and financial or other measures undertaken nearly zero energy buildings, including details of national requirements and measures concerning the use of energy from renewable sources in new buildings and existing buildings." / 13 p. 2/

The member states shall produce detailed progress reports every 3 years, based on which the European Commission will decide if the progress is fast enough and persuade the member countries to move faster if needed. B-f

nZEBs are expected to demand about two times less energy than the modern buildings built today. The advantages should also include a long life of such buildings and an indoor environment of high quality. / 2 p. v./ The main advantage of nZEBs is a significantly increased energy efficiency, therefore it is crucial to stress the importance of different technical solutions that would allow this to happen. These solutions include everything from optimal building geometry to energy efficient ventilation and heating, all of which will vary according to the buildings location. Energy efficiency, however, is not the only problem that needs to be tackled in order to meet the nZEB requirements. Renewable energy is another field of solutions that need to be utilized. Even though there is a variety of options both for on-site and nearby production, solar, geothermal and wind energy are most likely to be be applied for the majority of nZEB buildings.

Since the nZEB concept needs to be implemented in all the member countries of the EU, different climate conditions need to be taken into account. This means that stricter energy efficiency solutions need to be applied to the colder climates in order to display similar energy performance as in the warmer ones. For example, thermal insulation needs to be increased for nZEBs in Nordic countries compared to Central-European countries. Luckily, Finland is already advanced in terms of building energy efficiency as an energy performance of a building equal to or higher than a Passivehaus standard is quite common. Therefore, the improvements needed to be made on the energy efficiency side are relatively small. Similar considerations are needed regarding renewable energy generation. It is highly important to take into account the location-dependant availability of renewable energy sources and choose the best systems to utilize them in the early stages of the building design. If this is only taken into account in the construction phase, the building might become cost-inefficient due to poor positioning, orientation and choice of location.

2 AIMS AND METHODS

2.1 Aims

High energy efficiency and a significant share of renewable energy-those are the two goals that need to be achieved in order to reach a nearly zero-energy status. However, neither of them is equally available and easily achievable in different climates. Cold northern climates in particular pose a threat to highly energy efficient house concepts due to high levels of thermal losses. In terms of renewables, solar energy, currently being the most easily harvestable renewable energy form of them all, has unfortunately a much lower potential here than in Southern climates. These conditions make it more difficult to reach the nZEB performance levels while not braking the bank. Naturally there are still doubts whether it’s optimal to choose the nZEB concept when designing a new house in the cold climates today. The aim of this research is to get rid of these doubts and find out whether a nZEB can be an optimal choice for a detached residential house in Finland and what technical solutions are best fit to achieve this goal. The initial hypothesis is that nZEB energy consumption levels can be successfully reached in Finland only by adding a moderate amount of renewable energy generation to already existing and known to be cost-optimal Passive House or Very Low Energy House standards. In this particular case, ‘moderate amount’ refers to an amount of renewable energy generation installations which does not exceed the boundaries of the building (i.e. does not require to build additional plants on the ground). The general position the EU is taking when it comes to the building sector is to be moving towards higher and higher efficiency with the end goal being to reduce and eliminate the damage inflicted on the environment. Having that in mind, promoting the most effective and eco-friendly energy generation technology choices today seems logical. This is why, when it comes to the choice of nZEB heating systems, attention in this thesis is mostly given to heat pumps (HP) and district heating (DH). As far as renewable energy technologies (RET), solar wind and geothermal energy forms are underlined the most.

2.2 Methods

The first part of the thesis will be to determine the official definitions, system boundaries and other requirements that the nZEB concept is bounded by. Next step is to research the applicability of nZEBs in Finland, the country's progress in this matter and what might be the requirements for this building concept in the near future.

After that, technical solutions that are suitable and would be recommended for nZEBs in Finland are covered. Since there are no official Finnish nZEB requirements yet, a combination of recommendations from other building concepts, foreign nZEB practices and a draft version of these concepts have already been tailored for the cold climate of Northern Finland's National Building Code (NBC) will be used for reference. This where the the Passive House Standard (PHS) and a Very Low Energy House (VLEH) concept will be applied. Both of Europe. A concept that has been proven successful for more than 20 years, Passive House is an ideal basis for the Nearly Zero Energy Building. There are already numerous examples of buildings throughout Europe that, through a combination of Passive House Standard with renewable energy sources, can be regarded as Nearly Zero Energy Buildings. /12 p. 9/.

After providing the recommended technical solutions, building models with these solutions will be created and their energy performance simulated using IDA ICE 4.7.1 software. Only one building category is chosen for this work-a detached residential building. Since there are many different options regarding the choice of heating systems, renewable energy systems and level of insulation, several models will be simulated and the results compared. The different building concepts are described in chapter 5.1.8. It is important to note that all of them are simulated in three different parts of Finland-Southern (Helsinki), Central (Jyvaskyla) and Northern (Sodankyla).

Only two types of heating systems are used-DH and a GSHP. The latter is chosen because it is virtually the best choice for a heating system for an nZEB in cold climates when energy efficiency, environmental friendliness and cost effectiveness need to be combined. District Heating is chosen due to its wide availability and popularity throughout Finland, especially in the heavily populated areas. Other heating systems like pellet or oil boilers are a possible choice but are not included in the simulation because the whole reason behind the nZEB concept is to be moving towards minimizing the detrimental impacts of human activities on the environment. Therefore, designing new buildings with heating systems that use fossil fuels would contradict these efforts. Other types of HPs are also possible, but are inferior compared to GSHP in majority of the cases while in the cold Finnish climate. The reasons why they are inferior are discussed in more detail in Chapter 4.4. If we don't count the GSHP, only two types of renewable energy generation technology (REGT) are simulated-solar thermal (ST) collectors and photovoltaic (PV) cells. Reasons for this are laid out in more detail in Chapter 4.5.

As mentioned in the beginning of this chapter, variation of thermal insulation level is also possible. One could choose to heavily insulate his house and incorporate only a moderate amount of REGT or to save on the thermal insulation side while including more REGTs. That is why models with different insulation and thermal bridging levels will be created. U-values for the highly insulated building concept will be taken from a study done by the Technical Research Centre of Finland - VTT about an already existing nZEB in Helsinki /5 Annex B1/. While the U-values of the concept with light insulation will be taken from the new Finnish Building Regulations draft (Table 4). Thermal bridges will be selected as 'good' and as 'typical' respectively from the IDA ICE thermal bridge menu. The end difference between the two choices would me mainly economical. This thesis unfortunately does not cover the economics of nZEBs. Regardless, both of these cases will be simulated and compared. The first concept will be insulated according to the recommendations from PHS and the VLEH building concept. The second case will represent a house insulated according to the minimal requirements taken from the draft version of the new Finnish NBC. In the end all building concepts from Table 1 are compared and conclusions drawn. After which it will be evident whether the initial hypothesis was correct.

3 BACKGROUND

3.1 Defining the nZEB

The Energy Performance of Buildings Directive (EPBD) provides a general definition for a nZEB-"nearly zero-energy building means a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from

renewable sources produced on-site or nearby.” / 3 p. 18. / European Commission (EC) does not provide the exact requirements and definitions of what a „very high energy performance“ and „to a very significant extent“ means, therefore, this is left for the member countries to decide on that by themselves and apply these requirements to their NBCs /8 p. 8/. This is needed to adapt the nZEB concept to their local climate conditions while taking into account the availability of renewable energy sources. Another definition of a nZEB provided in the EPBD recast for its uniform implementation in the member countries states that a nZEB should display „technically and reasonably achievable national energy use of > 0 kWh/(m^2,a) but no more than a national limit value of non-renewable primary energy is achieved with a combination of best practice energy efficiency measures and renewable energy technologies which may or may not be cost optimal“ /8 p. 14/. Additional notes added to this definition:
Note 1-„reasonably achievable “means by comparing with national energy use benchmarks appropriate to the activities served by the building or any other metric that is deemed appropriate by each EU Member State. Note 2-renewable energy technologies needed in nZEBs may or may not be cost-effective, depending on available national financial incentives.

Currently, a nZEB is not required to be cost-optimal. /8 p. 8/. Therefore, a wider spectrum of technical solutions for reaching a nearly zero-energy status can be chosen. As a result, if renewable energy sources are highly available, one would be able to reduce investments on the energy efficiency side.

Since the the concept needs to be adapted to the local climate conditions, the member countries are required to specify a numerical indicator of total primary energy use expressed in kWh/m^2 per year. /8 p. 7/. Primary energy indicator (E), calculated according to equation 1, sums up all delivered and exported energy (electricity, district heat/cooling, fuels) into a single indicator with national primary energy factors. Which can then be used to define the energy performance of a building /8 p. 7/.

$$E = \frac{f_{DH} \cdot Q_{DH} + f_{DC} \cdot Q_{DC} + \sum_i f_{fuel} \cdot Q_{fuel} + f_{el} \cdot W_{el}}{A_{net}} \tag{1}$$

where:

E	the total energy use of the building weighted by coefficients calculated for purchased energy in buildings of its net heated area per year, [(kWh/(m^{2}a));
Q_{DH}	the total annually consumed district heating energy, (kWh/a);
Q_{DC}	the total annually consumed district cooling, (kWh/a);
Q_{fuel}	the total annually consumed energy in the form of fuels, (kWh/a);
W_{el}	the annual electricity consumption, which takes into account the reduced consumption due to ’free energy’ from on-site renewables as long as it is used for standardized electricity use within the building. (kWh/a);
f_{DH}	the primary energy form factor for district heating;
f_{DC}	the primary energy form factor for district cooling;
f_{fuel}	the primary energy form factor of a given fuel type;
f_{el}	the primary energy form factor for electricity;
A_{net}	the net heated area of the building, (m^2). /10 p. 4./

In order for this indicator to be accurate and its calculation easily understandable, system boundaries with energy flows need to be specified. This, however, can be done by on-site, nearby or distant assessment. A simplified model in Figure 1 illustrates on-site assessment.

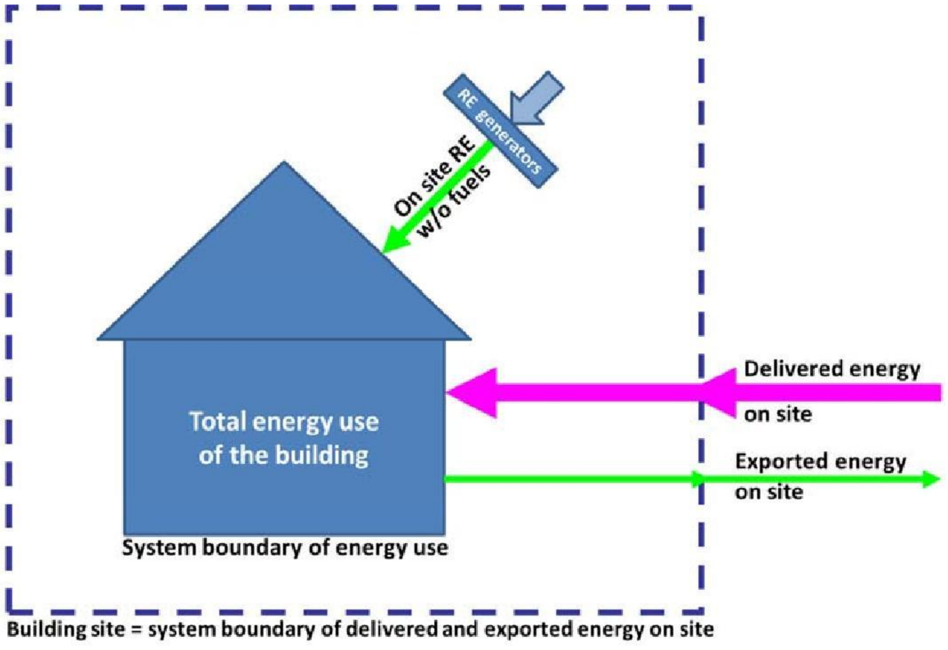


FIGURE 1. System boundaries for on-site assessment for a nearly zero energy building definition. / 8 p. 9./

The energy use boundaries in this figure are represented by the physical boundaries of the building as only the energy use of the building’s technical systems is accounted for. The dashed line showing the building site represents the boundary for exported and delivered energy on-site. In the case when nearby production is not linked to the building only on-site renewable energy generation is taken into account in this type of assessment. The EC offered equations (Equation 2 and 3) for E-value calculation for on-site assessment, requires to sum the total used electricity and total used thermal energy.

$$E_{use,el} = \left(E_{del,el} - E_{exp,el}\right) + E_{ren,el} \tag{2}$$

and

$$E_{use,T} = \left(E_{del,T} - E_{exp,T}\right) + E_{ren,T} \tag{3}$$

where:

E_{use}	total energy use kWh/(a);
E_{del}	delivered energy on site (kWh/a);
E_{exp}	exported energy on site (kWh/a);
E_{ren}	on-site renewable energy without fuels (kWh/a);
T	thermal energy;
el	the electricity. /8 p. 10/.

According to EPBD recast, all energy flows are mandatory to be included except electrical energy use of occupant appliances and transport (elevators, escalators). Therefore, it is upon a national decision to account for electricity for households and electrical outlets or not. „Delivered and exported energy have to be calculated separately for each energy carrier, i.e. for electricity, thermal heating energy (fuel energy, district heating) and thermal cooling energy (district cooling)" /8 p. 10/. All these flows are illustrated in Figure 2, which shows a more detailed model representing on-site assessment.

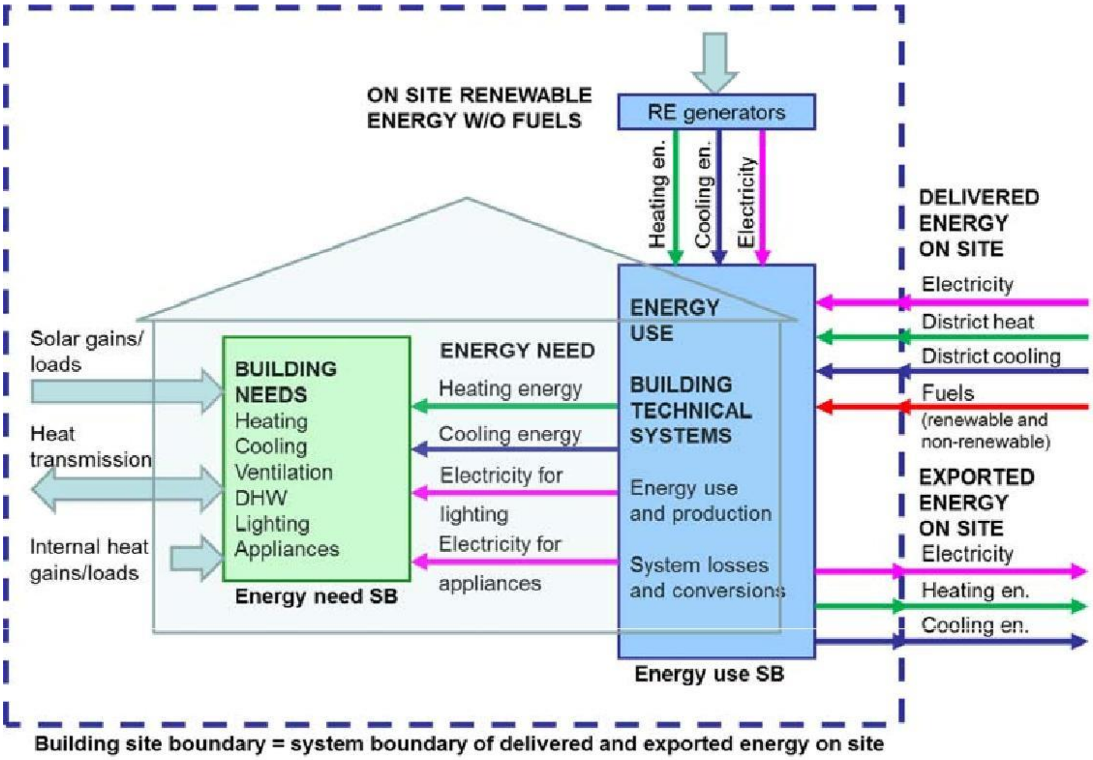


FIGURE 2. Three detailed system boundaries for on-site assessment. / 8 p. 17./

Figure 2 shows all of the energy flows that need to be included for a complete on-site assessment. Similar but more detailed SBs for energy use and delivered and exported energy calculation are shown. A boundary for building needs is additionally included. The latter includes needs for heating, cooling, ventilation, domestic hot water (DHW), lighting and appliances. These needs require different types of energy, all of which are either delivered or produced on-site. They are listed in Figure 2 next to “energy need”. This model also shows the three different types of renewable energy that can be accounted for on-site. These include heating energy, cooling energy and electricity. External and internal heat gains as well as heat transmission losses effect the final energy need and therefore need to be assessed. All of the possible heat losses are not shown in this model due to simplification. Both delivered and exported energy calculations include heating, cooling and electric energy while also including renewable and non-renewable fuels as a form of delivered energy.

The generation of renewable energy as stated in the EPBD recast: „ is taken into account so that it reduces the amount of delivered energy needed and may be exported if cannot be used in the building“ /8 p. 9/. As stated in the EPBD recast, renewable energy can only be subtracted from the total consumed energy amount if it is generated on-site or nearby. „On-site renewable energy without fuels means the electric and thermal energy produced by solar collectors, PV, wind turbine or hydro turbine. The thermal energy extracted from ambient heat sources by heat pumps is also on-site renewable energy and the ambient heat exchangers may be treated as renewable energy generators in the renewable energy calculation." / 8 p. 10./ Nearby RE production can be treated similarly as on-site RE production, only a nearby assessment has to be done. In such case, as shown in Figure 3, delivered and exported energy on-site is treated as delivered and exported energy nearby. Nearby plants can be taken into account as follows:

- With a different primary energy factor than that of he grid or the network mix if nearby production is linked to the building;
- With the primary energy of the network mix (for common clients of district heating or cooling);
- With the system boundary extension for a site with multiple buildings and site energy centre. / 8 p. 19./

Renewable energy produced nearby can only be used to reduce the energy demand if connected directly to the building.

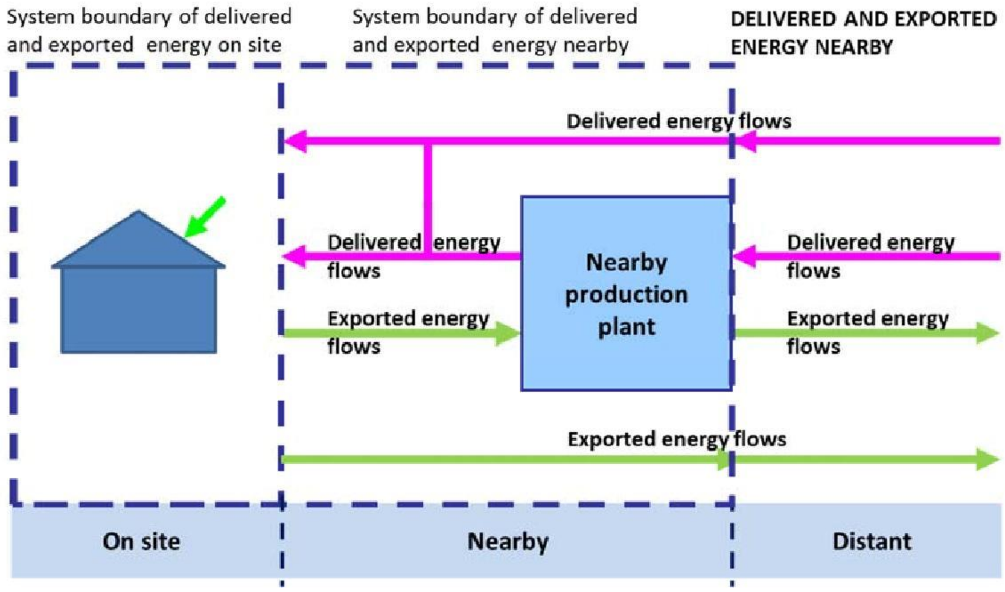


FIGURE 3. On-site, nearby and distant assessment system boundaries for a nZEB. / 8 p. 12./

As seen in Figure 3 delivered and exported energy flows on-site are replaced by delivered and exported energy flows in a nearby assessment. Since a nearby production plant would inevitably have production, conversion and transportation losses all of those which are inside the SB must be accounted for. Losses that are outside the SB are represented in the primary energy factor. As the nearly zero-energy concept suggests, the energy needs are usually not completely covered by renewables. As seen in Figure 3 even if there's a renewable energy production plant nearby, it's delivered energy flows are usually coupled with delivered energy flows from distant production which are not necessarily produced from renewables. The same principle is applied for exported energy flows. Unused energy from renewables can be exported either directly from on-site production or from a nearby production plant or even both.

3.2 nZEB in Finland

The currently existing buildings in Finland are responsible for 40 % of total energy consumption in Finland, therefore nZEBs have a substantial energy saving and environmental conservation potential for Finland's future building market. One of the major milestone for Finland to reach is to update the NBC, which will come in act from 2018. In order to perfect these requirements before their release, further cooperation with companies and research institutes is needed. For a building in Finland to reach a nearly zero energy status, it has to meet all of the requirements regardless of the tougher climate conditions. The requirements can be simplified and put in the following categories:

1) Extremely high energy efficiency;
2) Majority of energy demand covered with renewable energy.

In terms of energy efficiency Finland is already advanced since all new buildings have been required to be built as passive houses since 2015. Therefore, the demanded increase in energy efficiency is not that large in the context of all member countries. Because of this reason Passivehaus and Low-Energy Building concepts will be used for reference in this work as these standards are perfectly suitable for nZEB energy efficiency foundation and only renewable energy generation needs to be added to achieve a nZEB standard. It is important to mention, however, that reaching high levels of building energy efficiency in a colder climate is not as easy as in a moderate one. This does not mean that it is impossible or not cost-effective, but greater improvements in the building's energy efficiency need to be made. An example can be taken from Passivhaus standard implementation in Finland. Thermal transmittance coefficient (U-value) for walls must be improved from <0.15 W/(m^2K) to 0,07-0,1 W/(m^2K). These and many other technical solutions are crucial to ensure a low primary energy demand for a building concept like a nZEB.

From 2018 January 1st new Finnish regulations of the energy performance of new buildings will come into act. These requirements will define the allowable limits for newly built nZEBs. New E-value requirements calculated in accordance with the intended use of the building class for small residential buildings are presented in Table 1. Note: this is only the draft version of the regulations so it possible that these values might slightly change.

TABLE 1. Primary energy demand requirements for a new Category 1 residential buildings (2017.02.16 draft). / 10 p. 3./

Category 1) Small residential buildings:	(E), kWh / (m^2 a)
a) A separate small house or a part of the chain of house building, which net heated area (A_{net}) is not more than 150 m^2.	200-0.6 A_{net}
b) A separate small house or a part of the chain of house building, which net heated area (A_{net}) is more than 150 m^2 but not more than 600 m^2.	116-0.04 A_{net}
c) A separate small house or a part of the chain of house building, which net heated area (A_{net}) is more than 600 m^2.	92
d) Terraced and a maximum of a two-storey block of flats	105

The new numerical values of energy form coefficients used in the building are also included in the draft version of the new regulations (Table 2):

TABLE 2. Primary energy factors from the Finnish NBC draft version. /19 p. 1/.

Electric	1.2
District Heating	0.5
District Cooling	0.28
Fossil fuels	1.0
Renewable fuels for use in building	0.5

Renewable energy production for a nZEB is another problem that Finland has to tackle. Geothermal energy and solar are the most promising renewable energy forms for on-site production due the Finnish climate conditions. Small-scale windmills for on-site production are also a possible choice, although in most cases they can offer only a small fraction of electricity demand coverage while posing additional construction challenges. Nearby and off-site production make it possible to effectively utilize renewable energy forms like wind and hydro as well as renewable fuels, although, all of them would be assessed as purchased energy and would not directly reduce the energy demand of the house.

It is important to stress, however, that for Finland's climate, energy efficiency is key. Therefore, it is not recommended to be too conservative on the building energy efficiency side and expect to cover the energy demand by installing more RET as the building wouldn't be cost effective.

nZEBs targets-energy saving, energy efficiency and renewable energy usage can already be reached in Finland with combination of current technologies. However, further developments in technology energy efficiency still need to be made in order to make the nZEB concept more cost-effective. This is especially true for renewable energy technologies as they are still expensive and of relatively low efficiency.

3.3 Energy consumption of a building

In order to to be able to calculate the E-value of a building (equation 1), the total amount of purchased energy needs to be calculated first. According to the NBC of Finland, Part D5, it can be done by using equation 4.

$$E_{purchased} = Q_{heating} + W_{heating} + W_{ventilation} + Q_{cooling} + W_{cooling} + W_{appliances} + W_{lighting} \tag{4}$$

where:

$E_{purchased}$	the building's consumption of purchased energy, kWh/(m^{2}a);
$Q_{heating}$	the heat energy consumption of the heating system, kWh/(m^{2}a);
$W_{heating}$	the electric energy consumption of the heating system, kWh/(m^{2}a);
$W_{ventilation}$	the electric energy consumption of the ventilation system, kWh/(m^{2}a);
$Q_{cooling}$	the heat energy consumption of the cooling system (district cooling), kWh/(m^{2}a);
$W_{cooling}$	the electric energy consumption of the cooling system, kWh/(m^{2}a);
$W_{appliances}$	the electric energy consumption of household or consumer appliances, kWh/(m^{2}a);
$W_{lighting}$	the electric energy consumption of the lighting system, kWh/(m^{2}a). / 17 p. 13./

Renewable energy generated on-site is subtracted from the energy balance. This goes for heat (e.g. GSHP, Solar thermal, etc.), cooling (e.g. free cooling) and exported electricity (PV, wind, etc.). Heat and cooling energy forms simply reduce the corresponding energy type demand, while exported electricity is simply subtracted. Equation 4 also accounts for energy delivered elsewhere from the house.

The biggest energy needs usually belong to building heating needs. They include space, domestic hot water and ventilation heating. Out of those three, space heating calculated according to equation 5 is usually responsible for the largest share of heating energy demand.

$$Q_{heating,spaces,net} = Q_{\ spaces} - Q_{int.heat} \tag{5}$$

where:

$Q_{heating,spaces,net}$	the net heating energy need for heating spaces in a building, kWh;
$Q_{\ spaces}$	the heating energy need for heating spaces in buildings, kWh;
$Q_{int.heat}$	the utilized thermal gains for space heating, kWh. / 17 p. 15./

The second largest contributor to net heating energy demand is the energy demand for DHW. However, as buildings get more and more efficient due to insulation and airtight envelopes, the share of energy demand for DHW is increasing as the demand for space heating decreases. Energy demand for DHW heating can be calculated according to equation 6.

$$Q_{dhw,net} = \rho_v c_{pv} V_{dhw}(T_{dhw} - T_{cw})/3600 \tag{6}$$

where:

$Q_{dhw,net}$	the net energy need for domestic hot water, kWh;
ρ_v	the water density, 1 000 kg/m^3;
c_{pv}	the specific heat capacity of water, 4.2 kJ/kgK;
V_{dhw}	the domestic hot water consumption, m^3;
T_{dhw}	the domestic hot water temperature, °C;
T_{cw}	the domestic cold water temperature, °C;
3600	the factor for converting the denomination to kilowatt hours, s/h. / 17 p. 21./

The final share of the total heating needs belongs to ventilation heating. The need for supply air heating is calculated according to equation 7.

$$Q_{iv} = \rho_i\, c_{pi}\, t_d\, t_v\, q_{v,supply}\left(T_{sp} - T_{recov}\right)\Delta t/1000 \tag{7}$$

where:

Q_{iv}	the net heating energy need for ventilation, kWh;
ρ_i	the air density, 1.2 kg/m^3;
c_{pi}	the specific heat capacity of air, 1000 Ws/(kgK);
t_d	the ventilation system's mean daily running time ratio, h/24h;
t_v	the ventilation system's weekly running time ratio, days/7 days (day=24 h);
$q_{v,\ supply}$	the supply air flow, m^3/s;
T_{ib}	the in blown air temperature, °C;
T_{recov}	the temperature after heat recovery device, °C;
Δt	the time period length, h;
1000	the factor for converting the denomination to kilowatt hours. / 17 p. 19./

Electricity consumption for that same ventilation system also need be evaluated. This is done according to equation 8.

$$W_{ventilation} = \sum P_{es}\, q_v\, \Delta t \tag{8}$$

where:

$W_{ventilation}$	the electric energy consumption of the ventilation machine or blower, kWh;
P_{es}	the specific electric power of a ventilation machine or blower, kW/(m^3/s);
q_v	the air flow of a ventilation machine or blower, m^3/s;
Δt	the running time of a ventilation machine or blower during a counting cycle, h. / 17 p. 50. /

Energy needs for lighting can be calculates according to equation 9.

$$W_{lighting} = \sum P_{lighting} A_{room} \Delta t\, f/1000 \tag{9}$$

where:

$W_{lighting}$	the electric energy consumption of lighting, kWh;
$P_{lighting}$	the total electrical power of the lighting in the space to be illuminated per room surface area/room-m^2;
A_{room}	the surface area of room to be illuminated, room-m^2;
Δt	the lighting running time. / 17 p. 24. /

The total cooling energy demand can be calculated according to equation 10.

$$Q_{ct} = (1 + \beta_{sca})Q_{ca} + (1 + \beta_{scw})\, Q_{cw} \tag{10}$$

where:

Q_{ca}	the annual cooling energy used by the ventilation machine’s cooler batterry, kWh/a;
Q_{cw}	the annual cooling energy used by room units, kWh/a;
B_{sca}	the factor taking into account the air-side losses (thermal, condensation) of a system;
β_{scw}	the factor taking into account the water-side losses (thermal) of a system. / 17 p. 52. /

The annual electric energy need of a system that uses electric energy to produce cooling energy (not including the electric energy for auxiliary devices) is calculated using equation 11.

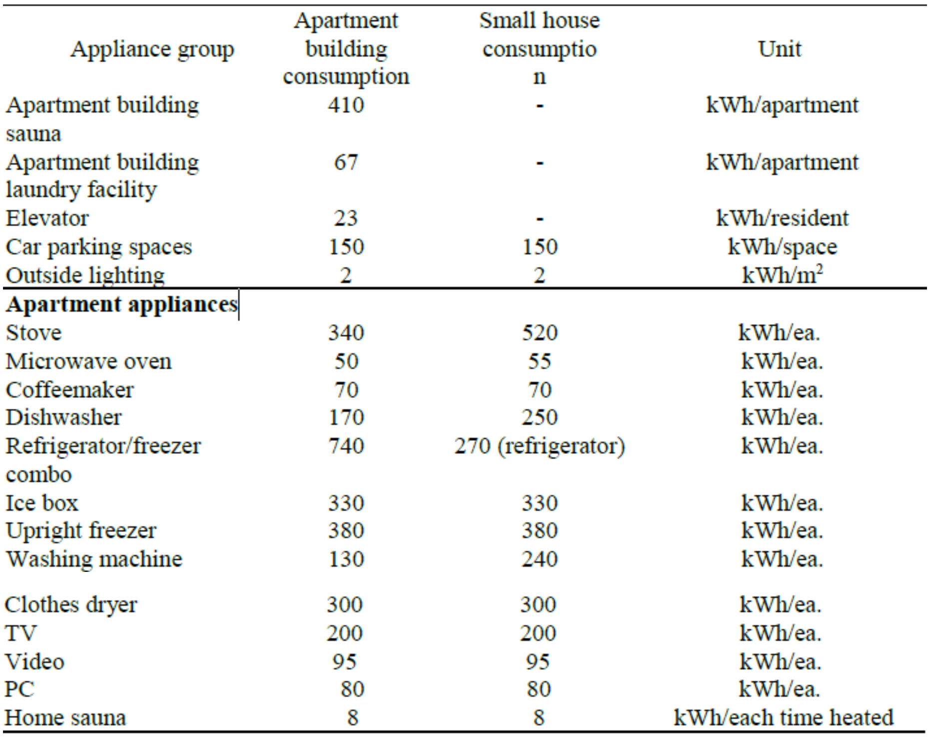
$$W_{cooling} = \frac{Q_{ct}}{\varepsilon_Q} \qquad (11)$$

where:

ε_Q	the annual energy efficiency ratio of the cooling energy production process. / 17 p. 53. /

As far as energy need for appliances, there are several methods to evaluate this need. If the house is already in use, the energy demand for appliances can be determined by subtracting the electricity needs for ventilation, heating, lighting and others from the total electricity demand. If the building is only in the design or construction phase, approximate consumption can be established by using specific consumption values that are provided in National Building Code of Finland, Part D5. These values are listed in Table 3.

TABLE 3. Specific electricity consumption values for equipment in residential buildings /7 p. 104/.



Appliance group	Apartment building consumption	Small house consumption	Unit
Apartment building sauna	410	-	kWh/apartment
Apartment building laundry facility	67	-	kWh/apartment
Elevator	23	-	kWh/resident
Car parking spaces	150	150	kWh/space
Outside lighting	2	2	kWh/m^2
Apartment appliances			
Stove	340	520	kWh/ea.
Microwave oven	50	55	kWh/ea.
Coffeemaker	70	70	kWh/ea.
Dishwasher	170	250	kWh/ea.
Refrigerator/freezer combo	740	270 (refrigerator)	kWh/ea.
Ice box	330	330	kWh/ea.
Upright freezer	380	380	kWh/ea.
Washing machine	130	240	kWh/ea.
Clothes dryer	300	300	kWh/ea.
TV	200	200	kWh/ea.
Video	95	95	kWh/ea.
PC	80	80	kWh/ea.
Home sauna	8	8	kWh/each time heated

4 ENERGY EFFICIENCY SOLUTIONS

When designing a nearly zero-energy building it is crucial to understand that energy efficiency must be the primary goal of the building if looking for the best energy performance and cost ratio. The task of someone building a nZEB in northern Europe is simple: „One has to try to reduce the heat losses and to cover as much as possible of the remaining losses by heat gains. All this is realized by optimising the building site, building layout, building envelope and the building services." / 14 p. 15/

The general path to take on the road to reduce the energy demand of new buildings has been known for a long time and has been applied to other building concepts as well. A five step strategy for low energy design (Figure 4) is recommended, which was developed within the project 'Cost effective low energy buildings':

1. Reducing heat losses (and need for cooling);
2. Reducing electricity consumption;
3. Utilising passive solar energy including daylight;
4. Controlling and displaying energy use;

5. Supplying the rest of the energy demand with renewable energy sources. / 14 p. 15/

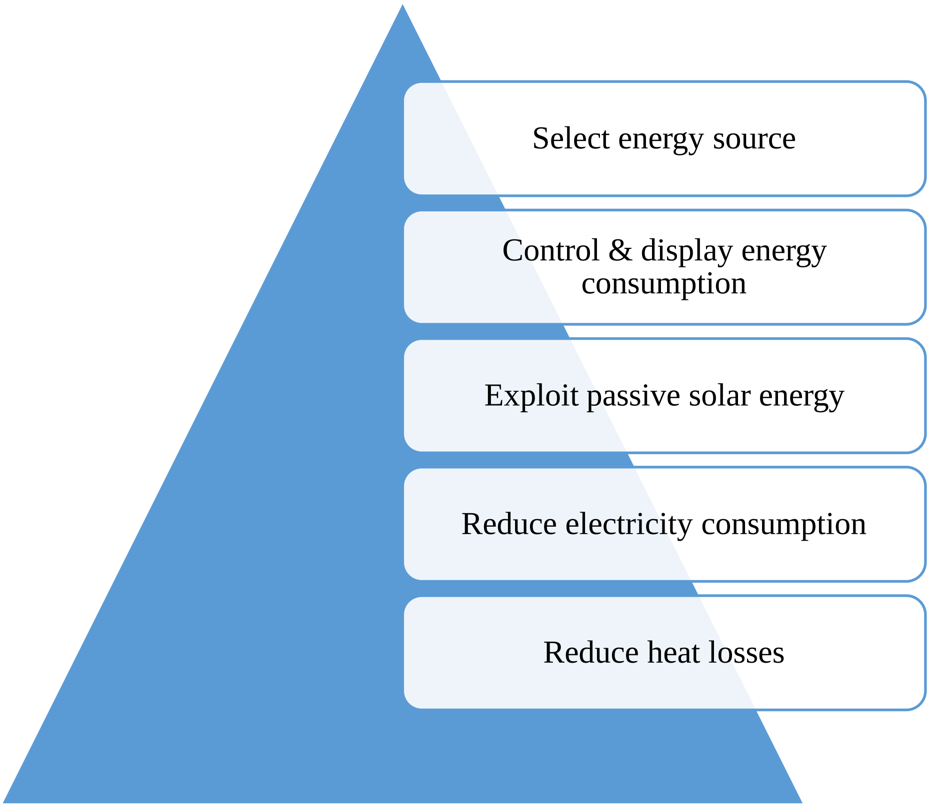


FIGURE 4. The 5-step design principle for new low-energy buildings /14 p. 15/.

In the case of nZEBs, step 5 will also include selecting the best on-site or nearby renewable energy sources and RET to utilize them.

Energy efficiency should be underlined from the very first phase of the building design. This means that energy efficiency has to be taken into account even in the architectural design phase, otherwise early decisions can later result in expensive or impossible to solve problems in terms of energy use. “Massing not supporting energy-efficient design or lack of space for technical systems is a typical example of potential drawbacks” /8. p. 103/.” Another important factor to keep in mind is that very often room layouts change in the construction phase due to requests of the client, therefore the technical systems (primarily HVAC systems) must be designed in such a way that they would be able to stay flexible but still be able to reach the required performance levels. Other important design aspects like shadings, daylight and fenestration need to be taken into account in an early stage. The pyramid in Figure 5 shows the correct order of choices in the design process and the impact of those on energy performance and cost.” / 8 p. 104./

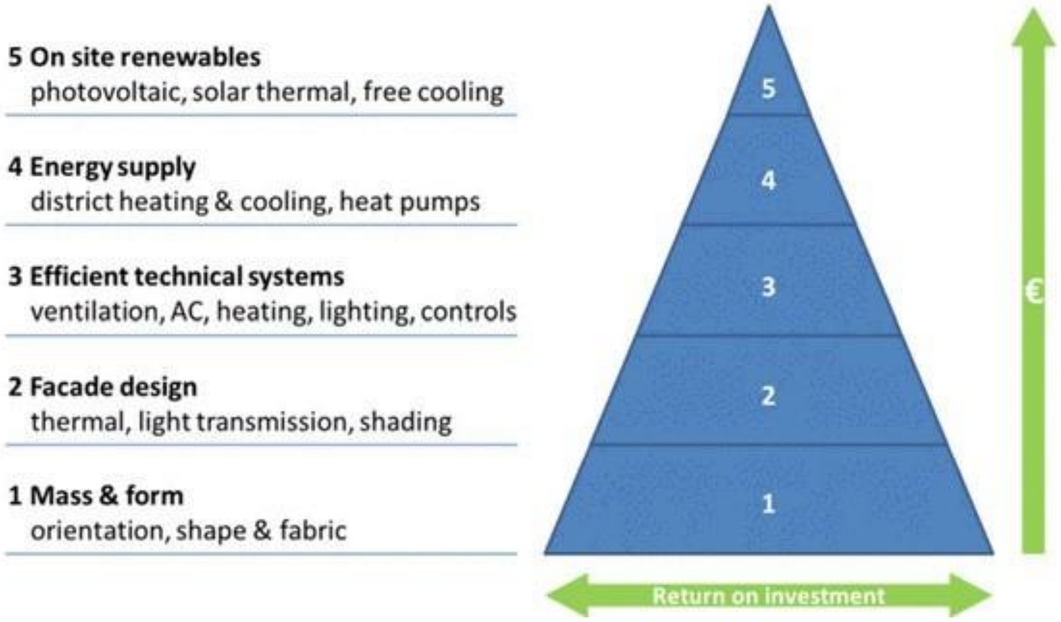


FIGURE 5. Energy performance weighted choices for a nZEB building design. /7 p. 104/.

Areas presented in the bottom part of the pyramid - building massing as well as it’s orientation have a crucial effect on the final energy demand while requiring little investment. The thermal resistivity of the envelope elements as well as the amount of transparent elements and their properties are also highly significant and if done incorrectly can result in large energy losses. The arrows representing the cost and return of investment (Figure 5) illustrate the importance of making the right choices for the categories on the bottom of the pyramid as they present the highest energy saving potential and demonstrate high return of investment. “For example, mistakes in massing cannot be compensated with on-site renewable energy. / 8 p. 105/.” The upper parts of the pyramid represent choices that are more expensive and of low return of investment (ROI) potential. Nevertheless, for a nearly zero-energy house, all of these steps need to be addressed with care.

4.1 Building envelope

4.1.1 Building form

While designing a nearly zero-energy building it is important to take into account the geometry of the house. Designers should be aware of the fact that any irregular shapes in the house design could result in unwanted increases of energy demand. “Dormers, roof windows, bay windows, long narrow extensions to the main body, split levels, are all examples of features that cost energy in practice" /1 p. 14/. The shape and size of a building can all have a significant impact on its useful energy requirements. „The more compact the building is, the less is the area of thermal envelope that causes transmission heat losses. In addition, a compact building usually also means less square meters of expensive thermal envelope to be invested in and maintained in the future." / 14 p. 16. / The compactness ratio has a pronounced influence on the heating and cooling demand, independently of the thermal transmittance value (U-value) of the building fabric /6 p. 51/. This can be demonstrated mathematically by considering the surface area to volume ratio for a cube, the illustration of which is demonstrated in [figure 6 and calculation formula in equation 12.

$$SA/V_{cube} = \frac{nx^2}{x^3} \tag{12}$$

where:

SA/V_{cube} the surface area to volume ratio of a perfect cube (regular hexahedron);
x the length of one side of the cube (m);
n the number of wall of the cube.

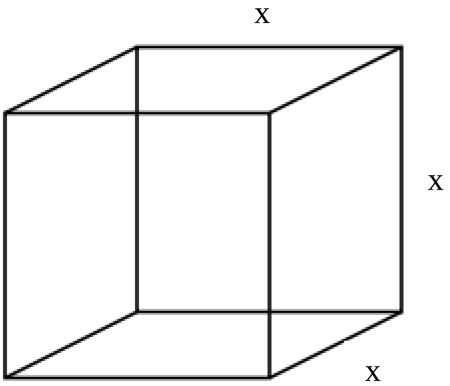


FIGURE 6. Surface area to volume ratio of a compact cube. /6 p. 52/.

A similar indicator of compactness is the 'form factor', which describes the surface area to treated floor area (SA/TFA) ratio. An SA/V ratio of 0.7 m^{-1} or a SA/TFA ratio of 3 is considered to be the upper limit beyond which small domestic dwelings in Central Europe may become uneconomical /6 p. 52/. This means that in a Finland's cold climate it is highly recommended that these ratios would not exceed the above mentioned values. As a general rule, energy demand per unit of area (kWh/m^2) decreases as building volume rises relative to its surface area. This means that increasing the building size alone without minding the building form can be detrimental. This relation is illustrated in Figure 7.

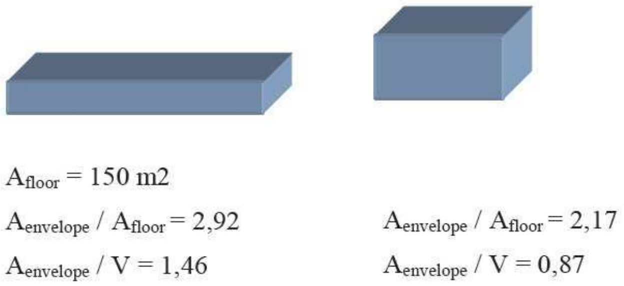


FIGURE 7. A_{env} / V (or SA/V) ratio dependency on building form. /9 p. 7/.

4.1.2 Building site and orientation

The final energy consumption of a building is also heavily influenced by its orientation "When possible, a residential building should be located on a sunny southern slope to enable the integration of passive solar gains and solar energy systems /14 p. 16/." Care should also be taken in planning the distances between other buildings so that they would not shade each other. The same goes for terrain, trees and other objects (Figure 8).

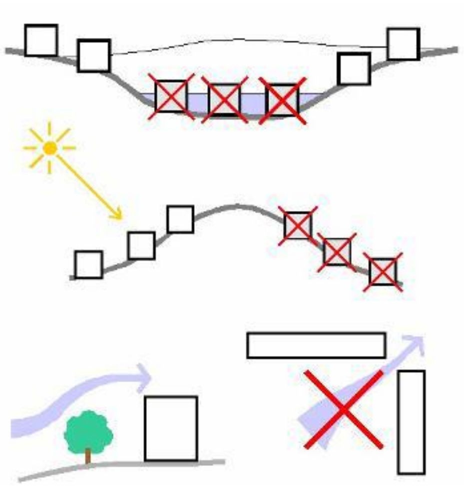


FIGURE 8. Building location and orientation in regards to shadows /14 p. 16/.

„A main window orientation from South-East to South-West enables effective winter time solar utilization /14 p. 16/." It is recommended that "the area of South oriented glazing should be 5-12 % of total floor area of the building /1 p. 14/." It is important to mention, however, that too much glazing in the South oriented facade can result in overheating during the warm summer months. Therefore, shading solutions should be applied, these include measures like: „balconies, optimized overhangs of
roof structures and external solar shading /14 p. 16/."

4.1.3 Air tightness

For a building to be of very high energy efficiency its envelope must be airtight. Poor airtightness results in air leakages which in turn result in increased heating and cooling demands, draught, moisture convection and other unwanted effects. Air leakages happen due to cracks in in the building fabric, poorly sealed windows and doors. Just as for other categories of energy efficient buildings, the nZEB category needs to have a minimal value for airtightness. It is expressed as n_x, the number of air changes in the building per hour at a certain pressure difference between outdoors and indoors and is calculated according to equation 13.

$$n_{50} = \frac{v_{50}}{V} \tag{13}$$

where:

n_{50} the number of air changes per hour at a pressure differential of 50 Pa (h^{-1});
v_{50} the mean volumetric air flow rate at a pressure differential of 50 Pa (m^3/h);
V the net air volume within the building (m^3). /6 p. 52./

Since it is up to the member countries to set the requirements of air tightness, the new NBC will have to include limit values. Since there are no such values provided yet, a reference airtightness value that of a Passivehaus standard or of a Very-Low Energy concept can be taken since they are both highly efficient building categories. According to both, the final air pressure test carried out at the completion of the building must demonstrate $\mathrm{n}_{50} \leq 0.6\ \mathrm{h}^{-1}$ at 50 kPa /12 p. 2/.

To determine the actual air leakage q_{50}, the before mentioned air leakage coefficient is used in equation 14.

$$q_{50} = \frac{n_{50}}{A} V \tag{14}$$

where:

n_{50}	the air leakage number of a building with a 50 Pa pressure difference, 1/h;
V	the air volume of a building, m^3;
A	the floor area of the building. / 17 p. 18./

From equation 15 it is seen that these leakages result in an increased energy need for heating of the building.

$$Q_{air\ leakage} = \rho_i\ c_{pi}\ q_{v,air\ leakage}(T_{ind} - T_{outd})\Delta t/1000 \tag{15}$$

where:

$Q_{air\ leakage}$	the energy required to heat air leakage, kWh;
ρ_i	the air density, 1.2 kg/m^3;
c_{pi}	the specific heat capacity of air, 1 000 J/(kgK);
$q_{v,\ air\ leakage}$	the air leakage flow, m^3/s;
T_{ind}	the indoor air temperature, °C;
T_{outd}	the outdoor air temperature, °C;
Δt	the time period length, h;
1000	the factor for converting the denomination to kilowatt hours. / 17 p. 17./

In order to achieve airtightness of $n_{50} \leq 0.6\ h^{-1}$, it is essential to specify a single continuous airtight barrier using appropriate materials. When referring to this barrier it is usually meant that a vapour control layer (VCL) is applied on the inside (the warmer side of the wall) in order to prevent the moisture and warm air from entering the insulation and structural layers. To improve the airtightness and prevent cold external air from entering the construction due to winds, a wind barrier layer (WBL) is often used on the outside. An airtight barrier must be impermeable or virtually impermeable (i.e. not allow air to pass through at 50 Pascals). Typical air barrier materials include:

- vapour control layer (VCL) membranes (used in timber-frame construction);
- cast concrete (but not unpurged concrete blocks);
- oriented strand board (used for closed panel systems and in timber-frame);
- plaster or purging coat (applied directly to a masonry substrate, but not plasterboard). /6 p. 53/

Regardless of what technique or materials are used it is essential that the airtight barrier would meet the requirements and would keep its properties during and after the construction. This is why it is important not only for the designers to design the barrier correctly and select the appropriate materials, but also for the construction workers to carry out the installation flawlessly. Special care needs to be taken to ensure that there is no leakage trough plumbing or wiring penetrations, joints and places where windows and doors meet the wall. Figure 9 illustrates some of these cases. For this purpose, special seals and airtight tapes are used. After installing this barrier tests may be run to check if the job was done properly. The most widely used test for this purpose in the so called “blower door test” which checks the air change rate at an overpressure and under pressure of 50 Pascals.

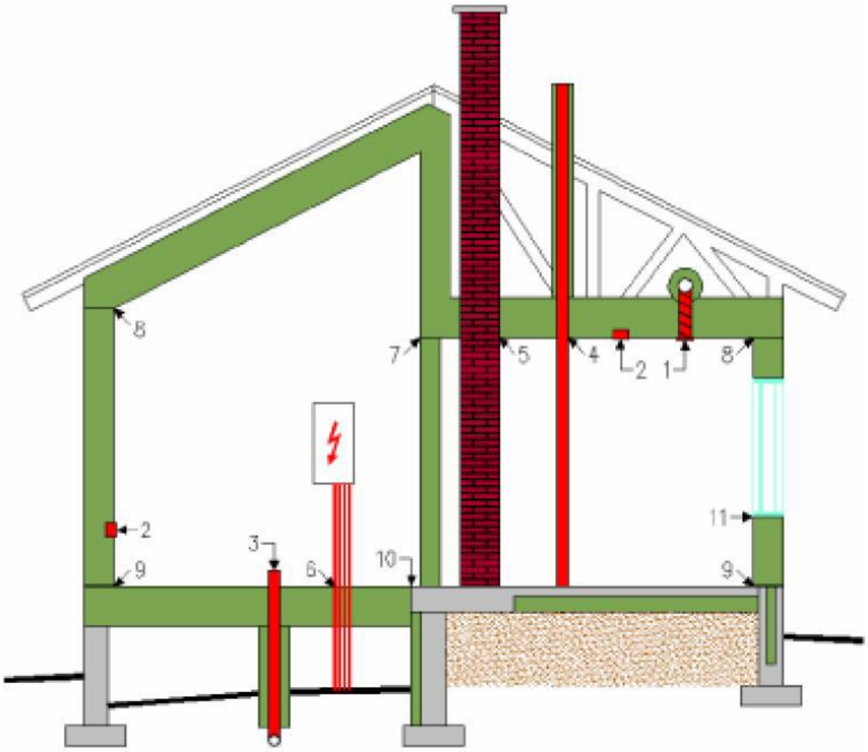


FIGURE 9. Typical places, where problems with airtightness within a thermal envelope exist (marked by numbers) /14 p. 21/.

4.1.4 Thermal insulation

Insulation in a nearly zero-energy building is of crucial importance due to its key role in the buildings thermal losses. The total specific thermal loss of the building components can be calculated according to equation 16.

$$\sum H_{der} = \sum(U_{external\ wall} \cdot A_{external\ wall}) + \sum(U_{upper\ floor} \cdot A_{upper\ floor}) + \sum(U_{base\ floor} \cdot A_{base\ floor}) + \sum(U_{window} \cdot A_{window}) + \sum(U_{door} \cdot A_{door}) \quad (16)$$

where:

$\sum H_{der}$	the total sum of the specific thermal loss of the building components, (W/K);
U	the thermal transmittance coefficient of the building component, (W/m^{2}K);
A	the area of the building component, (m^2).

As it is seen from the equation, the thermal transmittance coefficient is the factor responsible for the the thermal loss trough building components. For this reason, thermal transmittance coefficients have to meet the requirements of current building regulations. In the case of nZEBs in Finland, the new regulations coming in act from 2018 give the following maximum U-values (Table 4). Thermal transmittance coefficient (U) describes the rate of transfer of heat through one square meter of structure for every one degree of temperature difference across the structure (W/m^{2}K) /6 p. 53/.

TABLE 4. Thermal transmittance maximum values (U), Finnish NBC (2017.02.16 draft).

Building envelope element	**U-value, W/m^{2}K**
Outside wall	0.17
Log wall (the minimum thickness of the log structure 180 mm)	0.40
Upper floor and base floor bordering on outside air	0.09
Base floor bordering on crawl space (total area of ventilation openings not exceeding 8 thousandths of the base floor area)	0.17
Building component against the ground	0.16
Window, roof window, door	1.0

However, these values are the maximum ones. As it was mentioned in the beginning of the thesis, the building owner has a right to choose whether to invest more in the building insulation or to pay the price for having to install additional expensive RET to cut the energy demand to the allowed limit. For this reason, the new NBC also provides guidelines for a more efficient building concept (Table 5).

TABLE 5. Recommended thermal transmittance values (U) for an energy-efficient residential building, Finnish building regulations (2017.02.16 draft).

Building envelope element	U-value, W/m^{2}K
Outside wall for Category 1 residential building	0.12
Outside wall for Category 2 residential building	0.14
Roof and base floor bordering on outside air	0.09
Base floor bordering on crawl space or building block in contact with the ground	0.07
Building component against the ground	0.1
Window, roof window, door	0.7

For a broader understanding of the U-value range for highly energy efficient building concepts, values for the Finnish Passive House are presented in Table 6.

TABLE 6. Thermal transmittance values for a Finnish Passive House /1 p. 14/.

Building envelope element	U-value, W/m^{2}K
Outside wall	0,07 - 0,1
Base floor	0,08 - 0,1
Roof	0,06 - 0,09
Windows	0,7 - 0,9
Fixed windows	0,6 - 0,8
Door	0,4 - 0,7

For their Very Low energy House concept, North Pass suggests thermal transmittance values that are less strict, they are presented in Table 7. Although, it is evident that the importance of windows with low thermal transmittance properties is still underlined.

TABLE 7. Thermal transmittance values for a VLEH suggested by North Pass /14 p. 17/.

Building envelope element	U-value, W/m^{2}K
Outside wall	≤ 0,12
Base floor	≤ 0,12
Roof	≤ 0,12
Windows	≤ 0,8
Door	≤ 1.0

Despite the differences between suggested U-values, it is perfectly clear that an airtight envelope with thick construction and multi-layer high quality insulation is key for reducing the thermal losses. Example of such construction is presented in Figure 10.

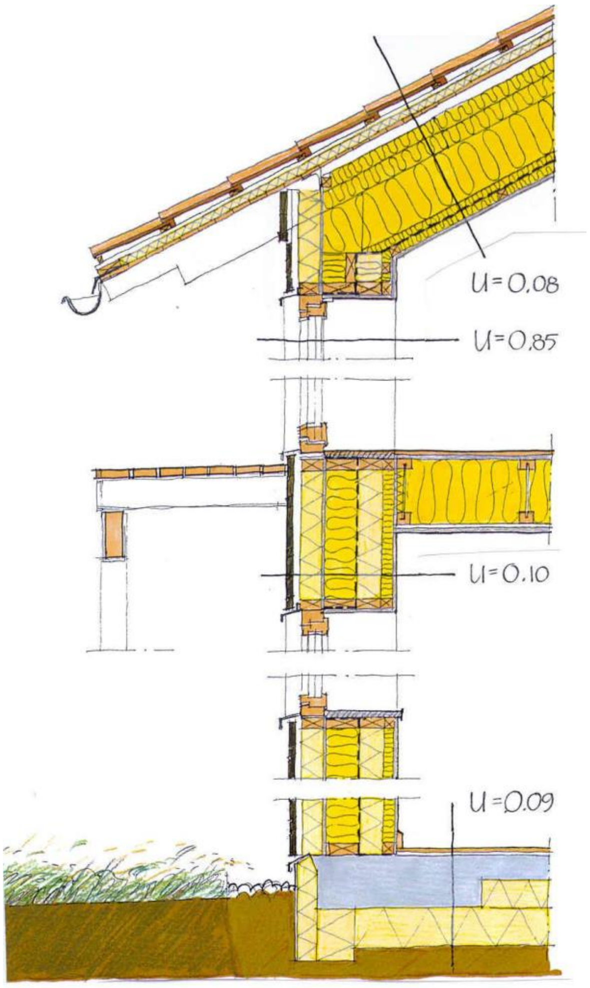


FIGURE 10. Thick multi-layered building structure /14 p. 21/.

In terms of insulation materials, the most common ones include mineral wool, fibreglass and cellulose. The guideline thermal conductivity (ʎ) value for high efficiency building insulation materials is 0.05 (W/m K). „Polystyrene and polyurethane are used quite frequently in low energy residential buildings, but mostly only as ground insulation and occasionally as roof insulation /14 p. 20." Vacuum insulation is also a possible solution. These panels have a very low U-value, therefore allowing to design thinner walls. Unfortunately, they are rather expensive due to their recent introduction to the market. „A vacuum insulation panel 2-3 cm thick is equivalent to 10-15 cm of mineral wool. Another insulation material with low thermal conductivity and higher cost is PIR (polyisocyanurate) insulation." /14 p. 21./

For a house to reach a nZEB status in the cold Finnish climate, accurate knowledge over the properties of building components is essential. This is needed to evaluate factors like thermal bridging and include them into the thermal transmittance values of the building envelope. Thick insulation layers necessitate special attention to be paid to the performance of the structures. Frost protection of foundations, drying capacity of insulated structures, avoidance of thermal bridge effects, and long term performance of the airtight layers need to be considered. /9 p.5/ Heat losses to the ground if taken into account and addressed correctly can be reduced. Ground conditions vary in different parts of Finland. During a cold winter the ground may freeze down to 1.5 meters in Southern Finland, and even down to 2.5 meters in Lapland. These conditions require special attention to foundation system design. Basically, depth of the foundation bed in the ground, heavy foundation insulation, or change of ground mass to non-frosting soil removes the risk. /9 p.5/ In a typical building the floor heat loss is used for reducing the frost risk. As the thermal transmittance of the floor becomes very low, the heat loss is not applicable any more. Therefore, the risk needs to be analysed carefully, as the as the guidelines for foundation design do not cover floor structures with U-values below 0.15 W/m^{2}K. /9 p.5/

4.1.5 Thermal bridges

A thermal bridge is a part of the building envelope where the heat flow, normally perpendicular to the surface, is clearly changed as a result of increased or decreased heat flow density. Thermal bridges can be classified into two categories-linear and point thermal bridges. Standard thermal bridge locations are presented in Figure 11.

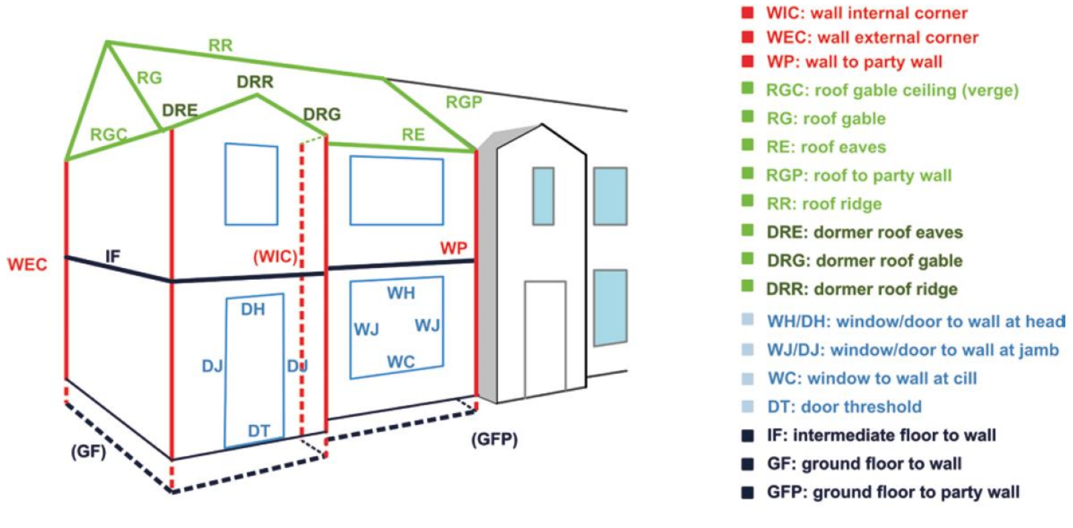


FIGURE 11. Standard thermal bridge locations. /6 p. 61/.

Thermal bridges play a crucial role in terms of the buildings energy efficiency. In the cold Finnish climate, the detrimental effects of thermal bridging are even greater. „Unaddressed they can contribute to as much as 50 percent of the total transmission heat exchange in a Passivhaus construction (Schnieders, 2009) /6 p. 58.” As stated in the Finnish NCB, heat losses through thermal bridges can be calculated using equation 17.

$$Q_{thermal\ bridges} = \left(\sum l_k \Psi_k + \sum_j X_j\right)(T_{ind} - T_{outd})\Delta t/1000 \qquad (17)$$

where:

l_k	the length of a linear thermal bridge caused by the joints in building com opponents, (m);
Ψ_k	the additional linear thermal bridge conductance caused by joints between building components, (W/mK);
X_j	the additional conductance caused by joints between building components, (W/K).

Since thermal bridges have a significant effect on the total thermal losses of the building envelope, means to minimize thermal bridging are used in energy efficient housing. The solutions for battling thermal bridging are chosen primarily according to the type of the thermal bridge, materials from which the elements are made and physical as well as economical limitations. Examples of typical thermal bridging elimination techniques are illustrated in Figure 12.

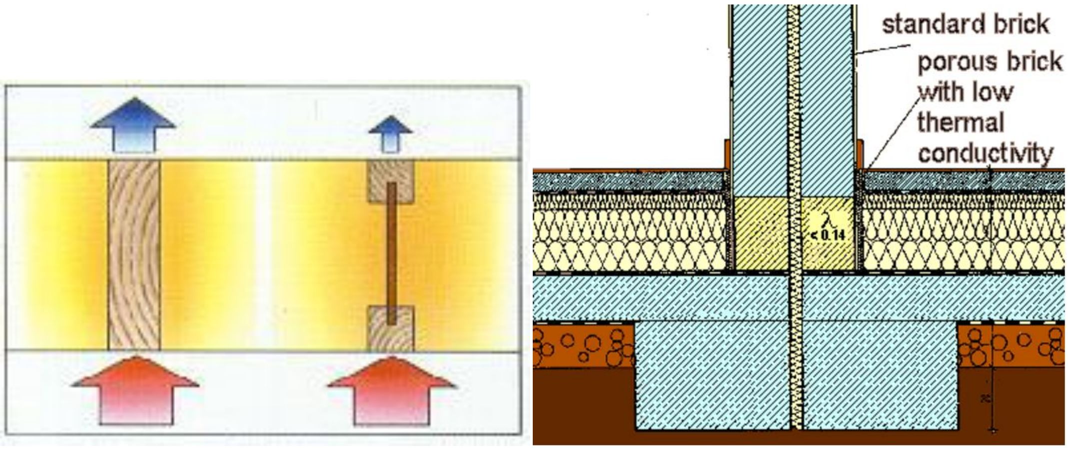


FIGURE 12. Examples of thermal bridge elimination by extrusion (1st picture) and and application of low thermal conductivity materials (2nd picture). /14 p. 19/.

As seen from the 2nd picture, thermal bridging can be eliminated by insulating the sensitive junctions with materials of low thermal conductivity. Extrusion of a construction element at the location where heat is most likely to 'escape' due to conduction is another frequently applied solution in highly insulated buildings. As mentioned earlier in this chapter, many other solutions like vapour barriers or elimination of insulation piercing can and should be applied for the best results.

4.1.6 Thermal mass

The materials with high thermal mass should be used for the construction of an nZEB building, such as brick, stone ceramic tile, and concrete./1 p.3/ These materials are chosen because of their thermal diffusivity properties. Thermal diffusivity, as such, describes the ability of a material to conduct thermal energy relative to its ability to store relative energy. Thus materials with high thermal storage capacity and low conductivity will have low rates of thermal diffusion /6 p. 66/. However, it is important to to have in mind that thermal mass is particularly important for warmer and temperate climates where there is a large amplitude of daily temperatures. In cold continental climates, during the heating season, energy efficient building concepts like Passivehaus already make very high utilisation of solar and internal gains and therefore further improvement via thermal mass will be marginal. In situations where solar access is poor and intermittent heating regimes are used, thermal mass could even increase winter heating requirements due to the release of absorbed moisture /6 p. 67/. In addition, there's not a lot of sunshine during the winter when the head demand is the highest. Nevertheless, a nearly zero-energy building should utilize solar gains as much as it is optimal.

4.1.7 Windows

Windows is another area that has been receiving lots of attention with the development of energy efficient buildings. There are numerous parameters and different choice criteria for windows like U-value, g-value, τ-value for visible light and many others, all of which will be discussed in detail in this chapter. While being a weak spot in terms of heat losses, windows have started to be perceived as "radiators" in the past decade due to the development of glazing technologies and multiple layer windows. The three modes of heat transfer (conduction, convection, and radiation) play a significant role in the performance of a window and their interaction is shown schematically in Figure 13.

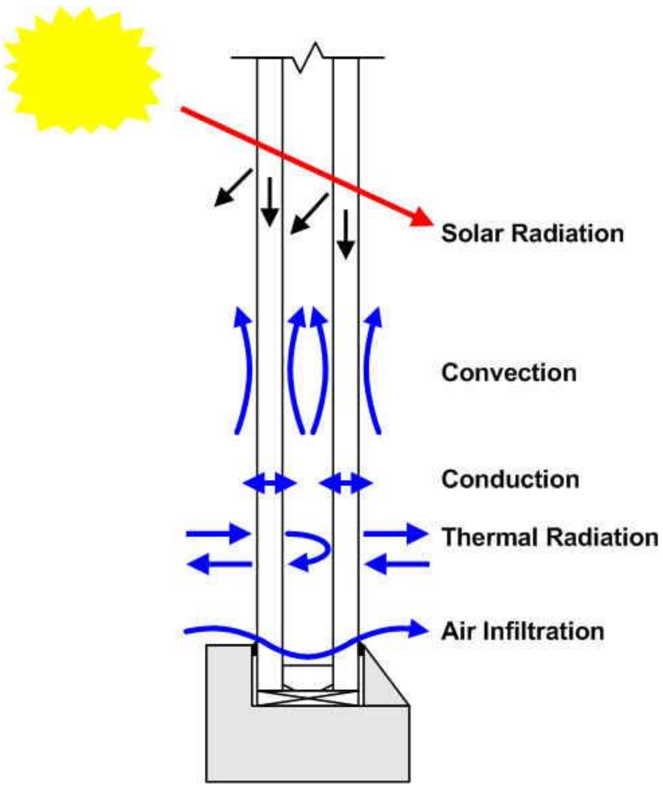


FIGURE 13. Conduction, convection and radiation heat transfer trough a double-glazed low emissivity coated window. /6 p. 72/.

Due to the cold Finnish climate convection and conduction flows are almost always directed from outside towards the interior of the building. These components of energy transfer are accounted for in the thermal transmittance value (U-value) of the windows. For a nZEB in the Finnish climate, highly efficient windows, that of a Passivehaus standard $U_{\text{window (installed)}}$-value ≤ 0.8 W/m^{2}K should be used in order to minimize the heat losses. Equation 18 shows how to calculate this value.

$$U_{w(inst)} = \frac{A_g \cdot U_g + A_f \cdot U_f + I_g \cdot \Psi_g + (I_{inst} \cdot \Psi_{inst})}{A_g + A_f} \tag{18}$$

where:

U_w	the whole window U-value, (W/m^{2}K);
U_g	the U-value of the glazing, (W/m^{2}K);
U_f	the U-value of the frame, (W/m^{2}K);
A_g	the area of the glazing, (m^2);
A_f	the area of the frame, (m^2);
l_g	the length of the glazing perimeter, (m);
l_{inst}	the length of the installed frame perimeter, (m);
$U_{w(inst)}$	is the installed window U-value when the additional term (I_{inst} ·

Ψ_{inst}) is included, (W/m^{2}K);

Ψ_g the additional two-dimensional heat flow or linear thermal bridge occurring between the glazing edge and the frame, (W/(m K);

Ψ_{inst} not a material-specific parameter but depends on the way the window is installed at the junction with the wall. Since the head, cell and jam psi-values can all be different (depending on the specific window installation and profile), Ψ_{inst} is taken to be the average value./ 6 p. 72/.

The thermal transmittance value not only represents heat losses through the glass itself but also the frame, therefore all elements of the window have to be of high quality. However, it is important to mention that even the most efficient windows (U_w = 0.6 W/m^{2}K) have much less thermal resistance compared with the nZEB walls, therefore windows must be used wisely, especially in a cold climate like in Finland.

Window glazing has three focal features, one of which is the before mentioned thermal transmittance (U-value), the other two are solar transmittance (g-value) and visible light (τ_{vis}) which also play an important role in window performance. The solar factor (g-value, also called total solar energy transmittance or solar heat gain coefficient) shows how much of the solar radiation falling on the window glazing enters the room, both directly through the glazing and trough absorption into the panes. For better energy efficiency windows with as high visible light transmittance (τ_{vis}) and with as low solar transmittance (g-value) as possible should be used. This dependency for triple-pane glazing units is presented in Figure 14 Performance of such units in cold climate is marked in the graph by larger square figures.

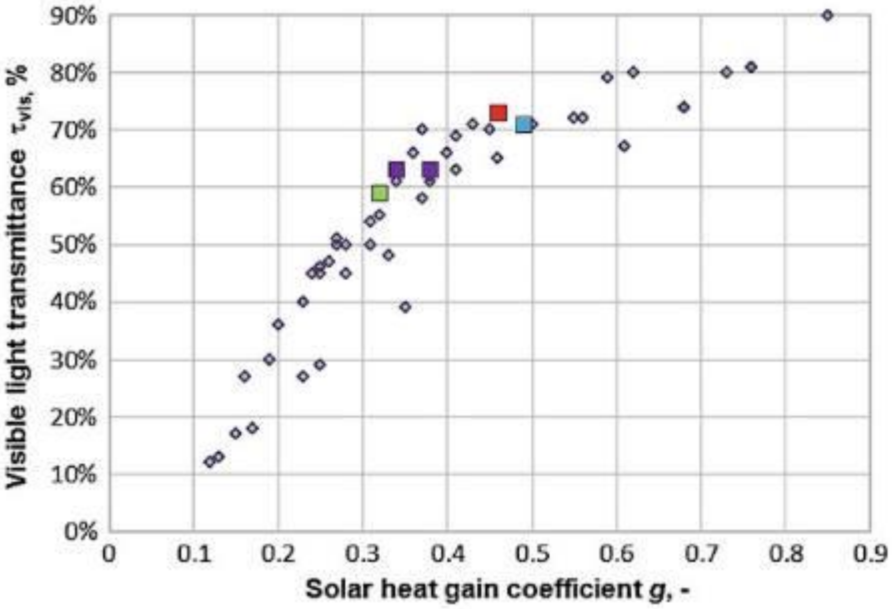


FIGURE 14. Dependence of visible light transmittance on the g-value in triple-pane glazing units. /8 p. 114/.

In terms of shading, external shading should be used when its needed because if lower g-value units are used (g < 0.4) visible light also decreases. While external blinds can block 90% of solar radiation (g=0.1). North Pass VLEH concept suggests that the g-value should be higher than 0.4 (40%) while the visible light transmittance higher than 0.5 (50%).

For northern climates it is recommended to use triple-glazed inert gas filled windows, which by comparison to double glazed windows save more than 50 per cent of heat losses trough windows. Quadruple-glazed windows with U-values of 0.6 W/m^{2}K are a possible, but rarely used option in residential buildings. The following aspects are important in order to achieve this level of thermal performance:

- at least triple glazing using inert gas fill and optimal glass cavity width;
- thermally broken frame (thermally insulated frame);
- warm edge spacer;
- low emissivity gas coatings;
- multiple airtight seals;
- effective gearing system (airtight seals);
- optimised installation of the glazed unit into the building envelope.

It is also crucial that the windows would be installed correctly otherwise the whole point of installing expensive and highly efficient windows is lost. „The importance of good window installation cannot be overstated, with careful attention to detail, it is possible to almost completely eliminate the thermal bridge caused by the installation /6 p. 77.“ A failure to do so, could result in significant heat losses as the total perimeter around all of the windows is typically very long.

With the development of glazing technology and reducing their heat losses windows have come closer to having a positive energy balance even in the Finnish climate. Additional conditions for this to be possible is a suitable orientation of windows and no over-shading. Since the g-value indicates the percentage of the incident solar energy that will travel through the glazing and into the building, and the U_g-value indicates the rate at which heat will be lost, a rule-of-thumb equation (Equation 19) can be used to determine whether the glazing properties of the window are sufficient to achieve a positive energy balance. By using an annual solar transmission coefficient (S) which is derived for each climatic location, the appropriate U_g -value and g-value required to achieve a positive energy balance in winter can be estimated. / 6 p. 78. /

$$U_g - S \cdot g < 0 \tag{19}$$

where:

S the annual solar transmission coefficient;
U_g the thermal transmittance of the glass, (W/m^{2}K);
g the solar heat gain coefficient.

The annual solar transmission coefficient from equation 19 can be calculated according to equation 20. / 6 p. 78. /

$$S = (c \cdot l)/(Gt \cdot 24\ h/d) \tag{20}$$

where:

c the correction factor (for frame percentage, dirt, orientation);
l the mean incident radiation (location specific);
G_t the heating degree days (kKd).

If this is fulfilled, the windows can reach a positive energy balance. While in the cold Finnish climate, this effect can only be reached if the windows are in the direction from southeast to southwest. Additional condition is that these windows wouldn’t be shaded too much - would be exposed to direct solar gains between 10 am and 2 pm during the winter solstice.

In order to determine which windows are suitable for a nZEB performance in Finnish climate, it is necessary to assess heat transfer coefficients $U_{w,\ installed}$, U_w and U_g while also determining minimum internal surface temperature (T_{si}) and surface temperature factor (f_{Rsi}) at the glass edge / 6 p. 79./ The results are presented in Appendix 1.

After installation, airtightness of windows and doors needs to be tested and verified if they indeed meet the requirements. However, the performance of windows at the installation phase is one thing. With time materials deteriorate, therefore high quality windows as well as high quality of installation is a must for a nZEB.

4.1.8 Solar shading

In order to prevent glare, overheating or overcooling in the summer time, shading should be applied. External, internal and between the panes shading options can be applied, with the first one being the most efficient. Sometimes, overhangs (Figure 15) or glazing control is used in highly efficient buildings. In practice this means that the best shading systems permit a variable shading that responds to current climatic conditions (e.g. solar altitude), and are adjustable to weather and personal choices /6 p. 93/.

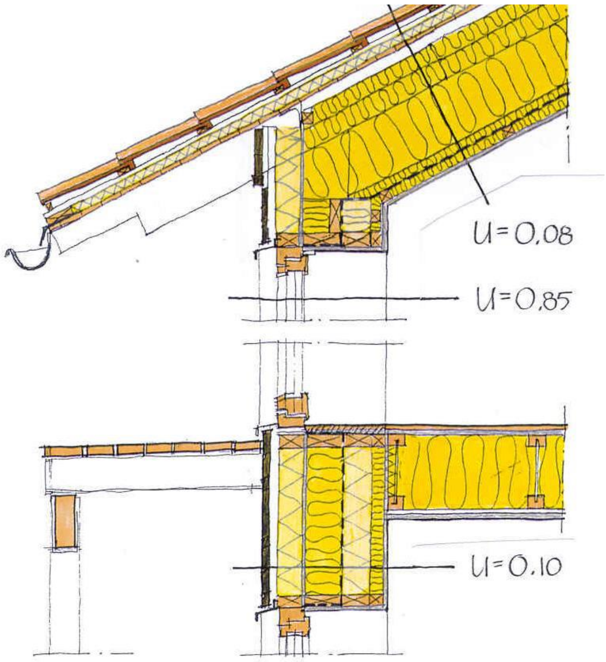


FIGURE 15. Solar shading provided by overhangs. /14 p. 21/.

With this kind of shading system overheating can be prevented in the summer time while allowing for the maximum amount of sunshine to enter during the winter.

4.2 Lighting

Lighting is an essential function that any house must have. Good daylight in not only provides light for our comfort but also can save energy for heating, cooling and electric lighting. Even though daylight should not be abused in the building design due to the higher thermal transmittance of the windows, enough of them should be installed in the building for the lighting to be sufficient in the day time, thus avoiding electric lighting during the day. This means positioning the windows cleverly maximizing the lighting in areas where it is needed while reducing the heat losses as much as it's rational. This also means that in respect to building orientation rooms need to be designed in a certain order. Since the northern facade receives the least sunlight, rooms in this orientation should be used as 'short-stay' rooms (i.e. utility rooms, storage, entry and etc.). Rooms in east orientation should be used in the first part of the day (kitchen, bedrooms) because the sun shines from the east in the morning, thus offering heating potential. The south orientation receives the most sunlight and therefore rooms in this orientation should be the 'long-stay' rooms (living room, work room and). West orientation provides lighting in the evening therefore places for dinning should be placed in this part of the building (dining room). / 6p. 94/. Cleverly designed openings in the house interior would allow for the daylight to travel further towards the middle of the house thus illuminating dark corners and reducing the need to turn on electric lighting.

In terms of electric lighting type Compact Fluorescent Lamps (CFLs) as well as Light Emitting Diodes (LEDs) display the highest efficiency and should be used in order to reduce electricity demand. „Most LEDs have currently still problems to produce the light colour that is good/normal for reading. However, the industry developments are improving, and in the near future this problem is expected to be solved /6 p. 14." Energy-saving controls should be integrated for the highest savings. Most common of these include motion/absence detectors to only turn on the light when it is needed and wireless dimmers/ switches/ controls to control the lighting, thus eliminating the need for physical switches the wires of which can reduce the performance of the insulation due to penetration. „Dimming optimizes the daylight use and reduces the electricity consumption /6 p. 14." The most primitive, although, effective solution is to use white or light paint for interior walls in order to reduce demand for lighting.

4.3 Ventilation

For a nZEB ventilation is another area of crucial significance. Since the building envelope is very airtight, and the airflow in the house is controlled by the mechanical ventilation system (MV), a cross ventilation needs to be created. This means that the air has to move from one side of the building to the other. For this reason, the location of the supply and extract points of the ventilation air and the air flow path through the building are a critical part of the design. /6p. 163/. The supply air terminals should be placed in living rooms (bedroom, living room, etc.) from where air would flow to wet rooms (kitchens, bathrooms, etc.) where outdoors and excess humidity often form. Trough the extract air terminals in these rooms the air should then be extracted (Figure 16).

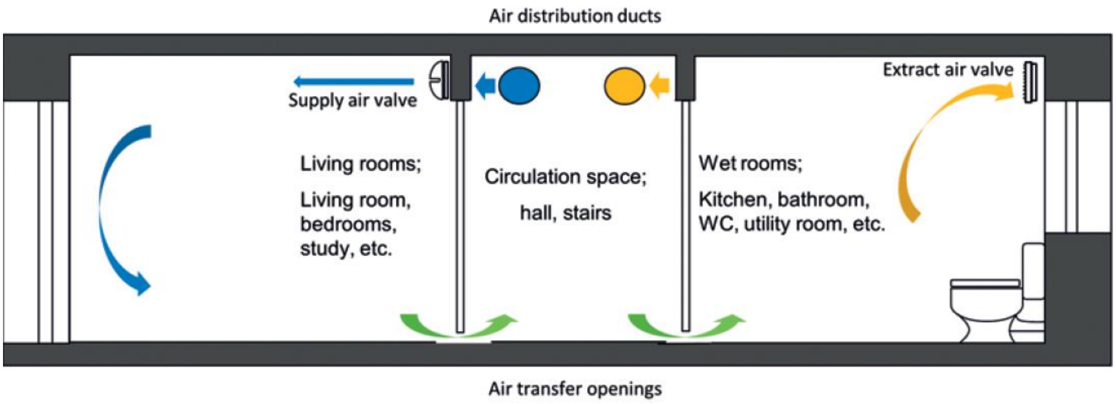


FIGURE 16. Air movement between spaces within a house, from ‘living’ to ‘wet’ rooms. /6 p. 164/.

Following the recommendations for the Passive House standard and VLEH guidelines for northern climates, the building has to be equipped with mechanical exhaust-supply ventilation with heat recovery (HR). Two types of heat exchanger currently used for residential buildings are - plate heat exchangers, rotating heat exchangers. A plate heat exchanger is the most common and should be used for this purpose due to it being passive. It can reach efficiencies up to 85~94 %. A common air-to-air heat exchanger in energy efficient buildings is the counter flow plate heat exchanger (Figure 17a). Rotating heat exchangers (Figure 17b) can be used in apartment buildings, although they are less efficient and reach only up to 75~85%. The energy efficiency of the air-to-air heat recovery ($\eta_{HR,eff}$), calculated according to equation 21, should be higher than 80 % in order to reduce heat losses of a nZEB ventilation significantly /17 p. 23/.

$$\eta_{HR,eff} = \frac{(\theta_{Extract} - \theta_{Exhaust}) + \frac{P_{el}}{v.C_p\,\rho}}{\theta_{Extract} - \theta_{Intake}} \qquad (21)$$

where:

$\eta_{HR,eff}$	the ventilation heat exchanger thermal efficiency;
$\theta_{extract}$	the temperature of air extracted from wet rooms, (°C);
$\theta_{exhaust}$	the temperature of air exhausted from the heat recovery (HR) unit, (°C);
θ_{intake}	the temperature of fresh air entering the HR unit from outside, (°C);
P_{el}	the total electrical power of the HR unit-including controls and sensors, (W);
v	the average volumetric flow rate of air through the MVHR unit, (m^3/h);
C_P	the volumetric specific heat capacity of air, (kJ/(kg K)). /6 p. 172/.

FIGURE 17. A counter-flow plate heat exchanger (a). A rotating heat exchanger (b).

It is important to note that thermal efficiency is the highest with low airflow rates and decreases as the airflows increase (Figure 18). The rate of reduction in efficiency is a function of the size of the heat exchanger /6 p. 174/. Which means that larger heat exchangers of a given design will have a smaller reduction in efficiency with the rise of airflow rates, thus stressing the importance of choosing the right heat exchanger for the design airflow rate values. It is therefore vital that actual performance at a given operating condition is used, rather than an optimum efficiency figure /6 p. 174/.

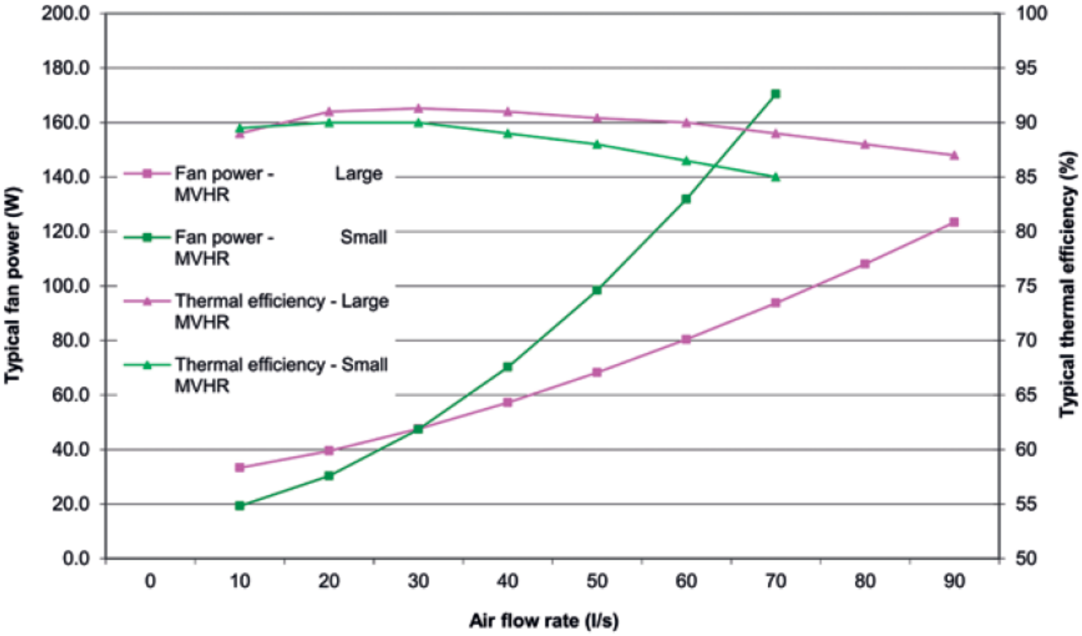


FIGURE 18. Typical variations of thermal performance and fan power (W) in relation to air flow rate /6 p. 173/.

Due to low temperatures in Finland, there is a high risk of heat recovery system freezing on the exhaust side. So defrosting or a limitation of the exhaust air temperature is needed to prohibit a temperature lower than 0 °C. A typical solution is to preheat the outdoor air before the heat exchanger. „This requires active or passive heating of cold outside air up to a temperature of approximately –3°C to ensure that the condensate in the exhaust air remains above freezing /6 p. 169.” Active measures mean directly heating the air with a heating coil, thus resulting in additional energy demand. A passive solution would be to heat the air with a so called ground heat exchanger as a ground loop system. Of course this use of geothermal energy could also be just a part of a bigger system that is used to cover the whole building’s heating demand.

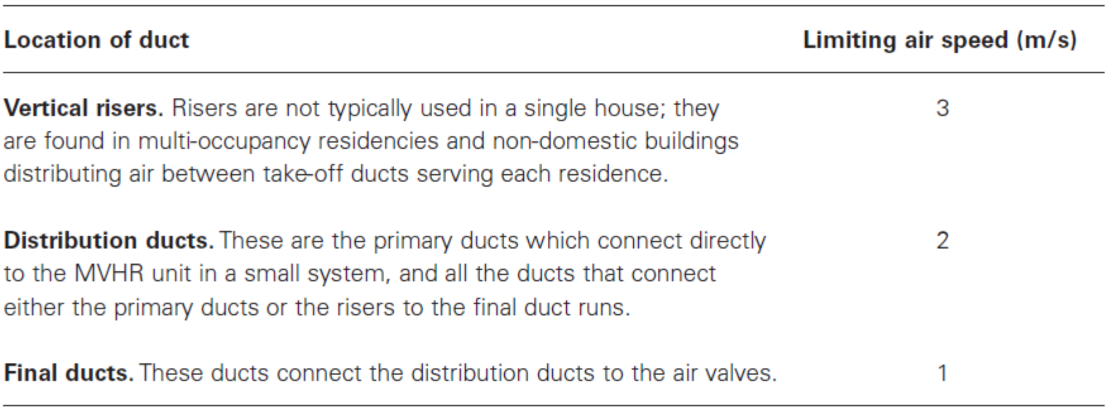
Attention also needs to be given to using energy efficient fans. Fans both in exhaust and supply system should not exceed the specific fan power (SFP) value of 1.0 kW/(m^3/s). Preferably an DC EC (Electronically Commutated) fan motor should be used due to its ability to combine AC and DC voltages, bringing the best of both technologies. / 14 p. 23./ EC motors offer significant advantages for fans used in heat recovery systems, including:

- high efficiency is maintained at reduced speed settings;
- cooler motor temperatures compared to AC motors;
- simple speed control interface and fan fault monitoring;
- low noise levels;
- reliability, as the electronics are protected inside the motor. / 6 p. 168./

Another important part of the ventilation that affects its efficiency is the ductwork. If designed correctly, the ductwork should be integrated into the building, insulated well, be well accessible for maintenance. This means the full energy-saving potential of the MHVR system itself can be realised, and a quiet and effective ventilation system achieved /6 p. 174/. Bends, valves, filters, silencers and the duct itself create pressure losses which in turn require additional fan power to deliver the needed airflows. The principle of an energy efficient ductwork is to design in in such a way that it would deliver its targets with as little pressure loss as possible. In order for this to happen, ducts should be kept as short as it is optimal and the number of bends should be minimized. Bends in duct should be kept swept when it is possible. As a rule of thumb, the inner radius of a bend should be at least the same as the diameter of the duct / 6 p. 180/.

The ducts should also be designed in such diameters minimize sound due to high velocities. Velocity limits are presented in Table 8. Another major issue is to successfully integrate the duct design into the building structure design at an early stage. This way re-work can be avoided that would normally decrease the efficiency of the system as well as increase in its costs. The ducts need to pass through voids and access rooms with the minimum number of changes in direction /6 p. 174/.

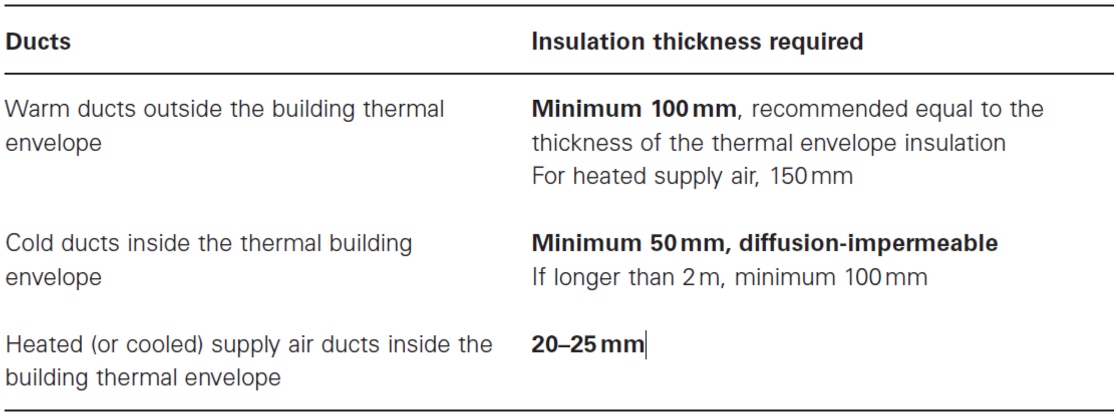
TABLE 8. Limitations of the fan speed for an energy efficient ventilation system /6 p. 182/.



Location of duct	Limiting air speed (m/s)
Vertical risers. Risers are not typically used in a single house; they are found in multi-occupancy residencies and non-domestic buildings distributing air between take-off ducts serving each residence.	3
Distribution ducts. These are the primary ducts which connect directly to the MVHR unit in a small system, and all the ducts that connect either the primary ducts or the risers to the final duct runs.	2
Final ducts. These ducts connect the distribution ducts to the air valves.	1

In order to increase the efficiency of the ventilation system, exhaust and the outdoor air intake ducts must be well insulated and a very effective vapour barrier must be applied. Taken from the Passive House standard (Table 9), for ducts shorter than 2.0 m, a minimum of 50mm insulations is required, while for longer ducts the insulation thickness increases up to 100mm. Due to the dramatically loss of thermal resistance properties, the risk condensation in the duct insulation should be taken very seriously. To minimise the potential for condensation becoming a problem, it is recommended that the ducts are insulated with closed cell foam insulation and very effectively sealed to the warmer components at each end. / 6 p. 179./ If additional insulation is needed, less expensive insulation options can be applied on top.

TABLE 9. Ventilation duct insulation requirements taken from Passive House standard. /6 p. 179/.



Ducts	**Insulation thickness required**
Warm ducts outside the building thermal envelope	**Minimum 100 mm**, recommended equal to the thickness of the thermal envelope insulation For heated supply air, 150 mm
Cold ducts inside the thermal building envelope	**Minimum 50 mm, diffusion-impermeable** If longer than 2 m, minimum 100 mm
Heated (or cooled) supply air ducts inside the building thermal envelope	**20–25 mm**

After installation, it is recommended that the ductwork would be tested by a pressure test. Significant leakages result in losses, which in turn lower the overall efficiency of the system. If serious leaks are found during the commissioning they can be fixed before covering the ductwork, after which any repair work would be more costly and difficult.

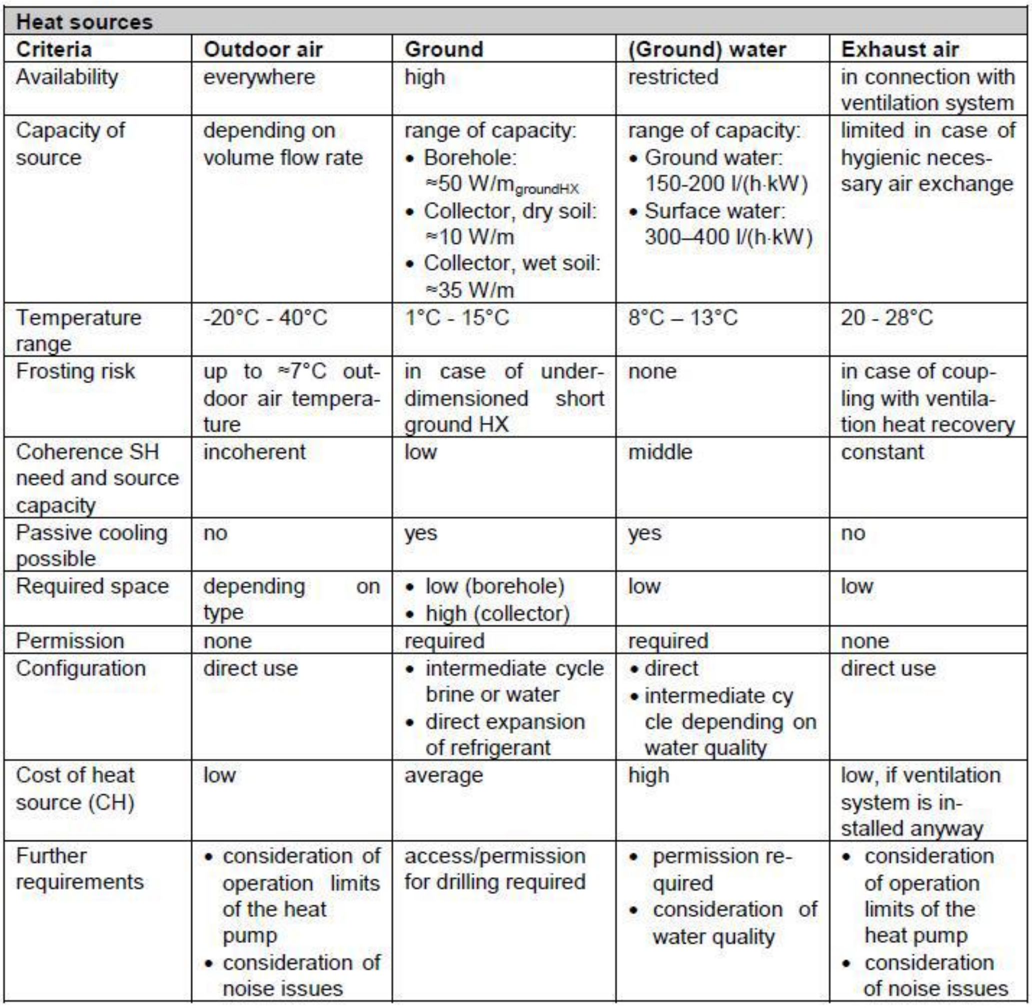
4.4 Heating systems

As stated in the beginning of this thesis, due to the reason behind a global movement towards eliminating human footprint on the environment, only DH and GSHP systems are researched. The first one due to the high efficiencies that Finland has been able to achieve both in district heating and district cooling. Additionally, having such a vast DH network it only makes sense to utilize if it’s efficiency. The amount of labour and costs to replace this network with even more efficient heating systems would be unreasonable. Furthermore, having a central heating plant, utilizing eco-friendlier biomass and waste as fuel becomes an efficient way to provide energy. Cogeneration heat plants (CHP) is another way that district heating increases the overall energy efficiency in Finland. One of the strategies to make DH even more eco-friendly is to include more and more biomass into the fuel mix, so that the primary energy factor of DH would drop even lower.

Due to the above mentioned reasons, DH system will be simulated as well. The goal of this is to find out how big of a difference does it make when compared to GSHP. If the gap is very large, it would mean that a significant amount of RE installations will be required to meet nZEB goals. If the performance of these systems are somewhat close, then DH can be proposed as a good option for heating system of nZEBs.

Another good choice for a heating system is heat pumps. Heat sources of all types of heat pumps are compared in Table 10. Seeing the advantages and disadvantages of each heat pump heat source we can compare them and choose the best one.

Table 10. Characteristics of most common heat sources of heat pumps (Wemhoener, 2011d). / 5 p. 10./



Heat sources				
Criteria	**Outdoor air**	**Ground**	**(Ground) water**	**Exhaust air**
Availability	everywhere	high	restricted	in connection with ventilation system
Capacity of source	depending on volume flow rate	range of capacity: • Borehole: ≈50 W/$m_{groundHX}$ • Collector, dry soil: ≈10 W/m • Collector, wet soil: ≈35 W/m	range of capacity: • Ground water: 150-200 l/(h·kW) • Surface water: 300–400 l/(h·kW)	limited in case of hygienic necessary air exchange
Temperature range	-20°C - 40°C	1°C - 15°C	8°C – 13°C	20 - 28°C
Frosting risk	up to ≈7°C outdoor air temperature	in case of under-dimensioned short ground HX	none	in case of coupling with ventilation heat recovery
Coherence SH need and source capacity	incoherent	low	middle	constant
Passive cooling possible	no	yes	yes	no
Required space	depending on type	• low (borehole) • high (collector)	low	low
Permission	none	required	required	none
Configuration	direct use	• intermediate cycle brine or water • direct expansion of refrigerant	• direct • intermediate cycle depending on water quality	direct use
Cost of heat source (CH)	low	average	high	low, if ventilation system is installed anyway
Further requirements	• consideration of operation limits of the heat pump • consideration of noise issues	access/permission for drilling required	• permission required • consideration of water quality	• consideration of operation limits of the heat pump • consideration of noise issues

Air to air heat pump might not the best choice for a nZEB due to the fact that there's not much heat to take from outside air that is already cold. Nevertheless, if it's combined with a heat pump of another type or other renewable energy generation source it can still be used. In an energy efficient building, for instance a nZEB, the difference in energy savings between the ground source heat pump and the air source heat pump (air to water) becomes smaller. According to Saari et al. (2010) the higher investment costs of the ground source heat pump may not be justified anymore and the actual life cycle costs of the ground source heat. /5/. Water heat pump is a rare choice due to the restricted availability of heat source and has the largest investment costs which could result in the nZEB not being cost-optimal although it is still possible choice if combined with other heat generation sources.

Exhaust air heat pump is a possible choice as it would take the heat from exhaust air and use it to post heat the air exiting from the heat exchanger. Although, such system may not be able to cover the heat demand of a nZEB in the Finnish climate. A ground source heat pump would be a better option due to higher efficiency and its applicability to both space heating and domestic water heating. GSHP use either horizontal or vertical collectors (boreholes) to extract the heat from the ground by circulating cold water through the buried pipes (Figure 17). It goes along very well with underfloor water-based heating systems and low temperature radiators as it uses low temperatures, typically of 30/35-40 °C. In well insulated houses and with a high density of pipes in the floor the temperature can also be lower. Another advantage is that in the summer a borehole can serve as a means for free cooling. COP (coefficient of performance) of such heat pump should be higher than 3.0. By combining such system with solar (thermal) collectors even greater capacities are achieved while increasing the ecological factor of the system. There are without a doubt numerous other possibilities for space heating of a nZEB, but due to their higher popularity and good performance only the before mentioned heat pump types are considered in this work.

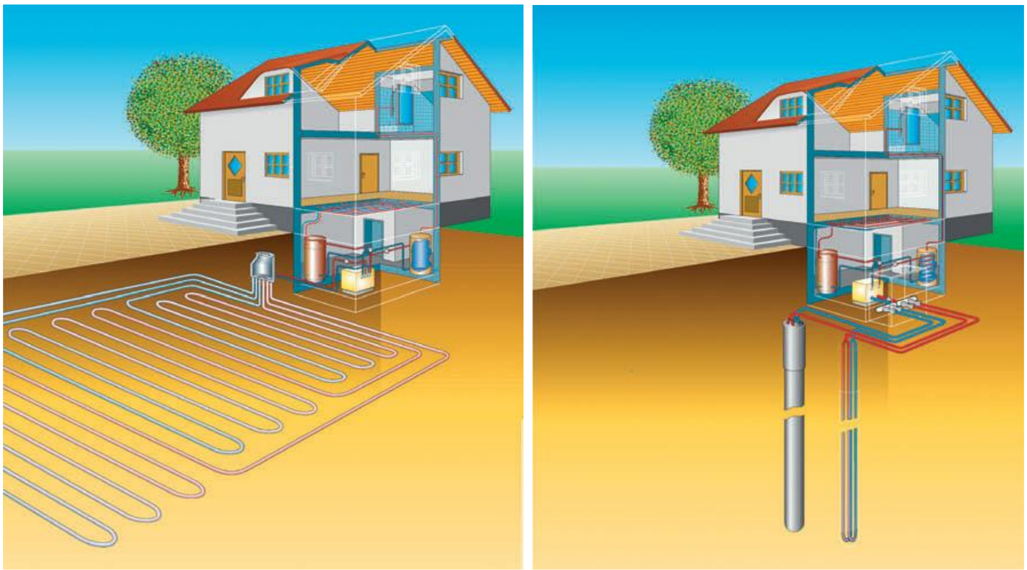
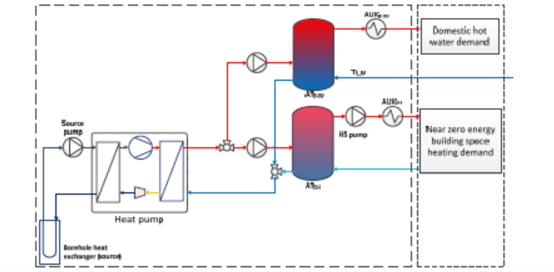
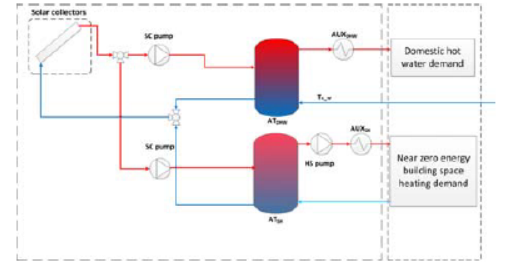
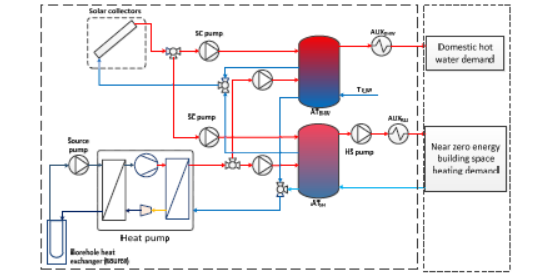


FIGURE 17. Vertical and horizontal collectors for a GSHP /6 p. 130/.

Figure 18 illustrates and describes several possible configurations of a GSHP. Combination between solar collectors, free cooling, parallel and series system connection and other aspects allow to reach the best performance in each individual case.

	STAND-ALONE GROUND SOURCE HEAT PUMP SYSTEM • Typical heat pump system with separated accumulation tanks for space heating system and DHW preparation • Back up heaters provide additional heat if set point value is not meet for DHW and SH flows • Space cooling demand is not covered by this system
	SOLAR COMBI SYSTEM WITH ELECTRICAL BACK UP • Main heat supply system is solar collectors • Solar system is controlled by temperature difference between solar collector outlet and accumulation tank top section temperatures • Additional electrical heaters support and add heat if set point temperature is not reached for DHW and SH flows • Space cooling demand is not covered by this system
	PARALLEL SOLAR ASSISTED GROUND SOURCE HEAT PUMP SYSTEM • Main heat source is heat pump which provides heat supply for space heating and domestic hot water preparation • The purpose of a solar collector is to reduce heat pump running time for DHW preparation in summer • Space cooling demand is not covered by this system

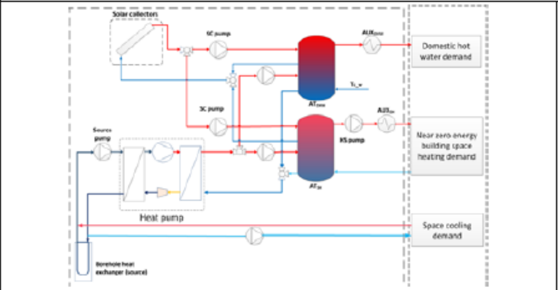
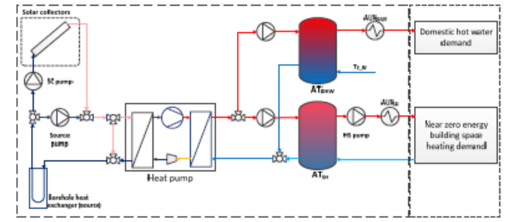
	PARALLEL SOLAR ASSISTED GROUND SOURCE HEAT PUMP SYSTEM WITH PASSIVE COOLING OPTION • Main heat source is heat pump • Solar collectors connected in hot side of heat pump reduce running time of heat pump • In passive cooling mode borehole heat exchanger works as heat sink for removed heat • The assumption is used that low temperature surface heating system works as high temperature cooling system
	SERIAL SOLAR ASSISTED GROUND SOURCE HEAT PUMP SYSTEM • Main heat source is heat pump • Solar collectors connected in cold side of heat pump provide additional heat to condenser and regenerate ground when heat pump is not operating. • Cooling demand is not covered

FIGURE 18. Different GSHP configurations /5 p. 117/.

4.5 Renewable energy technologies

All the available RE forms-solar, hydro, geothermal, wind, and heat can be utilized within Finland for supplying buildings with energy. Renewable fuels like biomass cannot be treated as RE according to the nZEB definition. There is still some debate whether RE produced off-site will be allowed to be used to reduce the buildings net energy demand, but for now only on-site and nearby production can be treated this way.

Having that in mind, it must be recognized that not all energy forms are equally suitable to be utilized on-site effectively, at least in the majority of cases. This is especially valid for hydro energy due to the reality that hydro plants are usually very large and provide much more energy than just for a group of houses or a district. That is why in most cases regarding coverage of nZEB energy demand, hydro will be treated as off-site RE.

“Hydro energy is power derived from the energy of running or falling water on an energy conversion equipment (turbine or wheel). These energy conversion equipment converts the kinetic energy into mechanical energy, which is further converted to electrical energy by means of a generator.” / 20./ Three main categories of hydro energy plants are:

1. Impoundment-large hydro plants that require a damn to keep the water in a reservoir. The water is allowed to flow through a turbine, thus spinning it and generating electricity.
2. Diversion-river hydro plants. Part of the river is diverted into the plant, where the water then spins the turbine and generates electricity.
3. Pumped storage-this type of a plant is more similar to energy storage. When the electricity demand is low, water is pumped into higher reservoir from where the water flows to a lower reservoir when needed. Again, the working principle of electricity generation is the same-converting kinetic energy to electric with the help of a turbine.

Even though hydro is one of the cleanest and most economical sources of RE, its applications for nZEBs to this day is mostly as off-site RE. This means that it would be treated the same as just buying normal electricity from the grid, except that the primary energy factor would be different.

Next on the list of potential RE for nZEBs in Finland is wind energy. „Wind power is generated by using wind turbines to harness the kinetic energy of wind. Wind blowing across the rotors of a wind turbine causes them to spin. The spinning of rotors converts a portion of the kinetic energy of the wind into mechanical energy. A generator further converts this mechanical energy into electricity." / 20./ A typical wind energy system is presented in Figure 19.

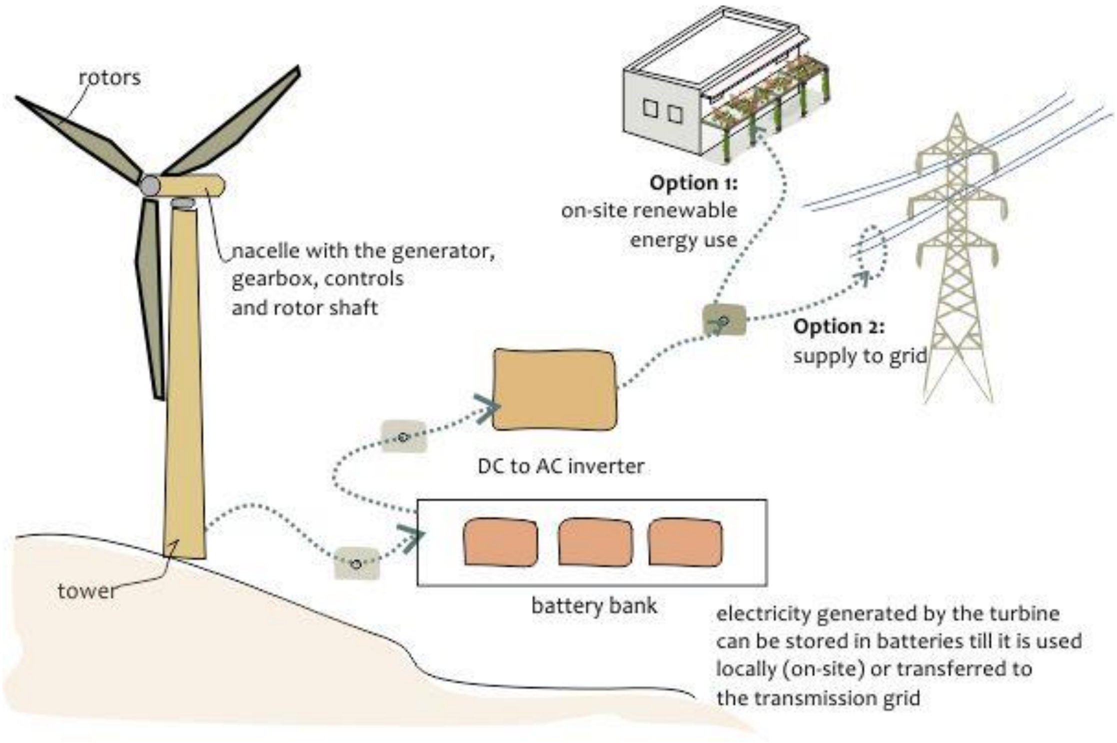


FIGURE 19. Typical wind energy system /21/.

In the case of a large windmill or even several windmills, their supplied RE can be regarded both as on-site and nearby, depending on their distance and connection to the building. If the turbine is quite near and is directly connected to the building it can be regarded as on-site RE energy. The same goes for storing the generated energy into batteries and using them later. Another option is to just simply supply the energy to the grid thus subtracting that amount of energy from your purchased electricity amount. According to the size and location, wind power can be classified into three main groups:

1. Utility scale wind power-usually larger than 100 kW, these systems deliver electricity directly to the grid.

2. Offshore wind power-as the name suggests, this type of wind power is located offshore. These types of plants usually include more than several windmills which are usually of very high capacity, some of the biggest reaching 8 MW per windmill.
3. Distributed wind power-usually of smaller capacity than 100 kW, these windmills supply energy directly to the house or special machinery.

„Turbines extract energy from wind based of either of the two aerodynamic forces: drag and lift. Machines working on the principle of lift are inherently more efficient as the forces are applied in the direction of wind flow while in drag driven machines, forces are applied in the reverse direction." / 20./ According to the axis of windmill blade rotation, windmills fall into two main categories (Figure 20):

1. Horizontal axis wind turbines (HAWT)-utilize wind lift effect and are dependent on the wind direction. Having in-built sensors of wind direction and speed, these windmills change their direction every time the wind shifts. The most efficient blade configuration includes 2-3 blades.
2. Vertical axis wind turbines (VAWT)-independent of the wind direction but are less efficient. Depending on their design they can be both lift and drag driven. Generally, it's a better choice for a windmill installed on a building due to its low noise levels, easy maintenance and adaptability to dynamic wind conditions.

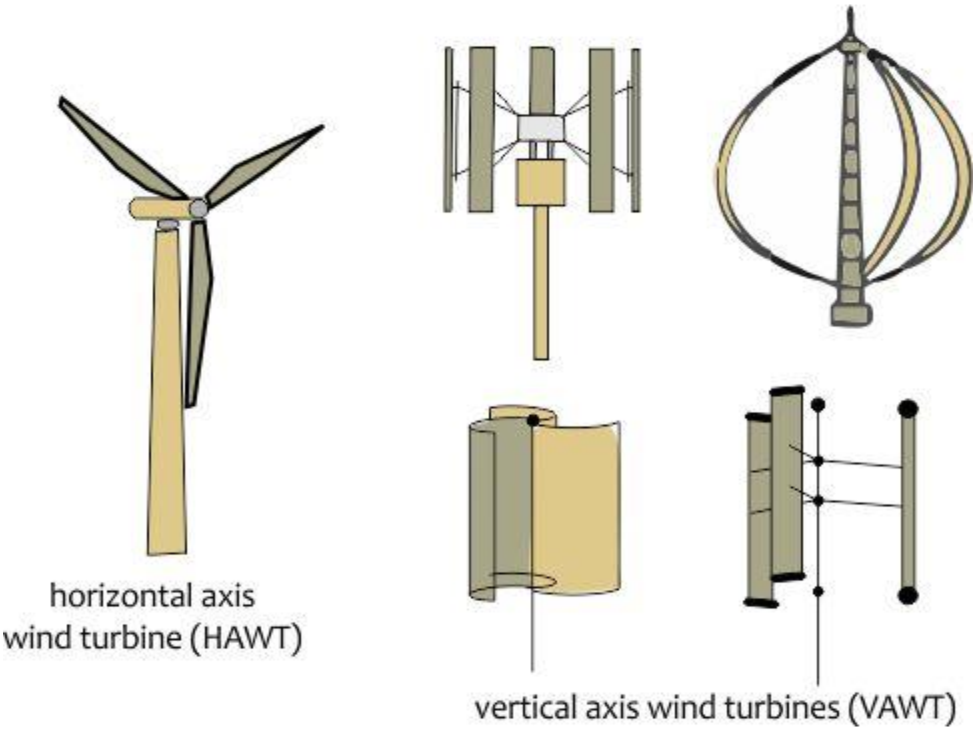


FIGURE 20. Horizontal and vertical windmill types / 21/.

Solar energy can be regarded as the most suitable RE source for nZEBs at the current technological development of RETs. Regarding this application, solar can be tapped in three ways-solar thermal collectors and PV modules. Even though solar energy has a lower potential in the northern hemisphere, it can still be used. Since in highly efficient building concepts the importance of DHW increases due to reduced space heating needs, solar thermal can be applied to cover at least 50% of this demand. Although it is important to mention that in the cold Finnish climate, PV modules have a higher energy generation potential than ST collectors. „Solar photovoltaics are a combination of panels containing a number of solar cells which convert the incident solar energy into usable electricity. These panels can be placed at any place which receives abundant amount of sunlight." / 20./

Even though solar is perfectly suitable for on-site RE generation, it can be used more broadly. According to availability of space, capital and energy need, PV solar plant deployment can be classified into these groups:

1. Utility driven solar project development-Large scale, big output solar plants which deliver energy straight into the grid. These kind of plants require large areas of land and are rather rare in the cold climates.

2. Customer driven solar project development-Small scale, small to moderate output plants. Traditional example-PV panels on the roof of a building. Based on the energy utilization, this group can be divided into two more groups:
   a) Grid Connected Systems-these kind of systems are most popular among small scale ones due to possibility to deliver the energy straight into the grids when it is not needed. Thus not wasting energy. Some systems are designed so that they could only supply energy to the grid, not covering the needs of the house.
   b) Stand-alone systems-this kind of system is fitted for direct energy use in the building. However, when the excess is not needed it can be stored in batteries which, unfortunately, is less efficient.

In cold climates ST collectors are inferior to PV modules. In Northern Finland this source cannot be used at all since the sun there is not shining for some days during the winter /1 p. 15/. Figure 21 illustrates why this is the case. However, ST can still be used for DHW in warmer seasons as well as in combination with a GSHP, as mentioned in the previous chapter.

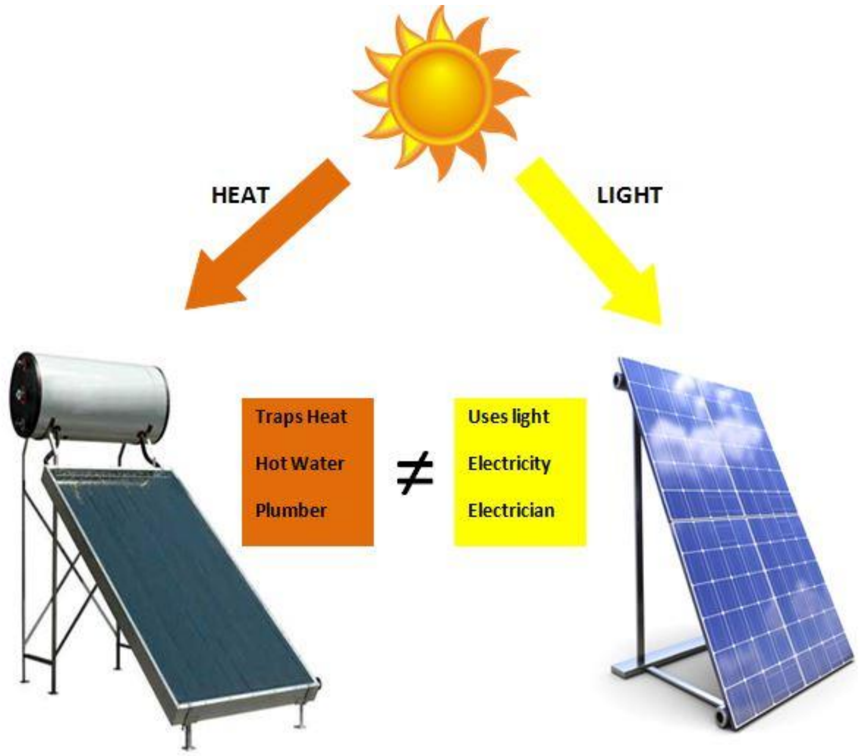


FIGURE 21. Difference between ST collectors and PV modules / 20/.

As seen from the illustration, PV modules utilize light rather than heat. This means that they don’t need direct sunlight to generate electricity therefore can generate more energy. In addition, it is even considered that it is ‘healthier’ for the PV modules to operate in a cooler climate due to the fact that when the temperature of the PV panels increase, their efficiency and output decrease.

A geothermal energy utilizing GSHP is another perfect solution of RE energy source for Finnish nZEBs, although it has already been covered in the previous chapter under Heating Systems. Other solutions of geothermal energy utilization are considered nearby or off-site only RE. This is due to the same reason as large hydro plants, discussed in the beginning of this chapter.

5 SIMULATION

This chapter is dedicated for testing the initial hypothesis raised in chapter 2.1. Different detached residential building concepts have been created and their energy performance simulated using IDA ICE 4.7.1 software. All of these concepts apply a variety of energy efficiency and RE approaches. The goal is to simulate which combination of technical solutions allow for the building to reach an energy performance of a nZEB and which do not. Each of the concepts is simulated in three different parts of Finland-Southern, Central and Northern. Naturally, these zones exhibit different outdoor temperatures, therefore the suitability of these building concepts for the different parts of Finland will also be tested.

5.1 Initial data for the simulation

5.1.1 Building architecture

The architecture of the simulated 2-storey residential building is presented in Figure 22. Floor plans of the building are presented in Appendix 2. The nZEB model was created on top of an IDA ICE „residential house“ template.

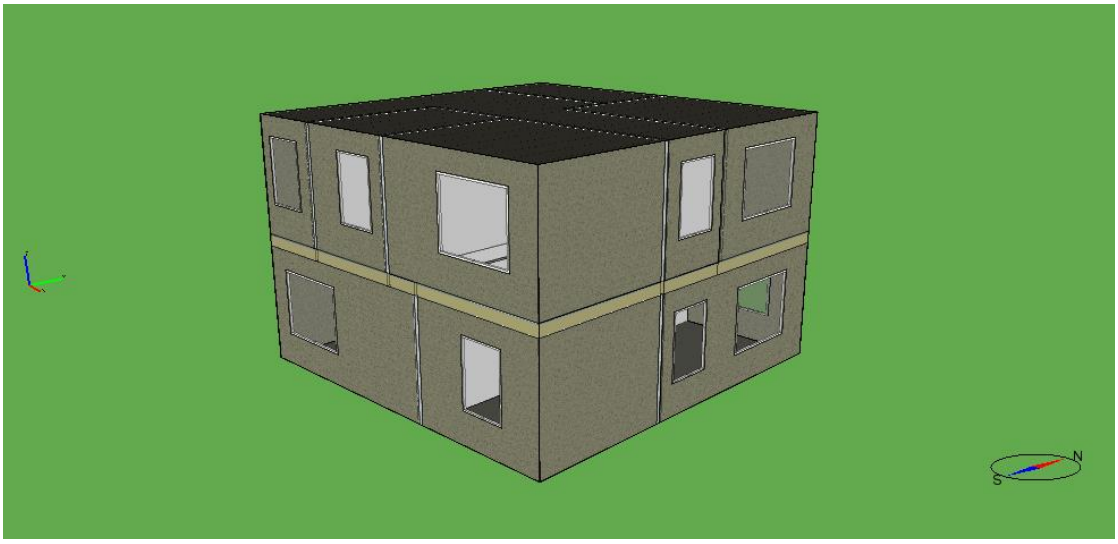


FIGURE 22. Architectural model of the simulated building.

As seen from the picture, the building has a simple, compact form with a flat roof. The simplicity of the model is partly due to simplification of the simulation and partly due to energy efficiency. As mentioned in chapter 4.1.1. compactness of the building has a significant effect on its energy performance. This is why a compact cube-like shape of the building has been chosen. The SA/V ratio of the building is 0.7595 m^2/m^3. Ideally, a ratio of ≤ 0.7 m^2/m^3 would be the best option in terms of energy efficiency. However, for several reasons this is not the case in this work. First reason is that even energy efficiency is crucial, people often want at least some room left for aesthetics. This means that an ideal cube-shaped building forms will rarely be the preferred choice. Consequently, an ideal shape of the building in terms of energy efficiency was not chosen in order to exhibit more realistic results. This can be improved by adding round shapes, to the building design, for example round corners. However, this couldn’t be done as the software has limited capabilities in terms of building shape. Additionally, experimenting with combinations of round and square shapes would require its own separate research and this is not the focus of this research. One more aspect to note is that the smaller the buildings get, the harder it is to reach the desired SA/V ratio. Building geometry data is listed in Table 11.

TABLE 11. Building geometry data.

Model volume	530.1 m^3
Model floor area	185.5 m^2
Model envelope area	402.7 m^2
Window/ Envelope area	8.1 %
Window/ Floor area	17.6 %
Windows North	4.08 m^2
Windows East	11.22 m^2
Windows South	13.26 m^2
Windows West	4.08 m^2
Window South/ Floor area	7.15 %
Average U-value	0.252 W/(m^2 K)
Envelope area per volume (SA/V)	0.7597 m^2/m^3

As it is seen from the table, the total window area to building floor area does not exceed the general recommended limit of 25%. South oriented glazing to floor area ratio equals to 7.15% which also falls into the recommended brackets of 5-12% as mentioned in chapter 4.1.2.

5.1.2 Location and climate

As mentioned before, the building concepts are to be simulated in three different parts of Finland. The location and weather data of these parts is presented in Table 12. Beside the impact of weather differences, renewable energy availability is another major factor in a nZEBs final energy demand. But since the exact locations of the buildings are not specified, this component becomes much more easy to evaluate.

TABLE 12. Location and weather data of the simulated building.

Zone	**Location**	**Weather data**	**Wind profile**
Southern Finland	Helsinki (Ref 2012)	Helsinki-Vantaa (Ref 2012)	Default Urban
Central Finland	Jyväskylä (Ref 2012)	Jyvaskyla (Ref 2012)	Default Urban
Northern Finland	Sodankylä (Ref 2012)	Sodankyla (Ref 2012)	Default Urban

As seen from Table 12, default urban wind profiles are chosen for all of the cases. In reality, wind profiles would differ due to the landscape and local objects that blocking the wind, for example forests and tall buildings. Therefore, debates whether such a house would rather be located in a suburban area than an urban one or that the wind speed would be impacted more by buildings in Helsinki than for example in Sodankyla are possible. Nevertheless, due to simplicity it was chosen to stick to an urban wind profile.

Availability of other included RE forms - solar and ground heat were less customizable. Solar irradiation levels are included in the weather data. Unfortunately, shading by surrounding objects cannot be evaluated. Regardless, the recommended approach covered in chapter 4.1.2 states that shading should be reduced as much as possible, therefore it is assumed that there is none. Ground thermal properties are automatically calculated according to the selected climate file. Computations are made using the ISO-13370 standard.

5.1.3 Thermal Insulation

Even though insulation solutions to significantly reduce a buildings’ energy demand are widely available and not very complicated, they are often expensive. The reason behind creating nZEB models with different insulation levels is to illustrate the possibility of reaching nZEB energy performance levels with different approaches. In this particular case, this means that one is free to choose whether to insulate the building heavily or relatively lightly and attempt to compensate for that in other areas. The U-values for building envelope components of these different approaches are compared in Table 13. Heavy insulation level in this work is chosen according to the Finnish PH guidelines, North Pass VLEH guidelines and a study done by VTT of an existing nZEB in Helsinki. Light insulation level is equated to the minimum insulation requirements presented in the draft version of the upcoming NBC of Finland.

TABLE 13. U-values for the building envelope elements of the different building models.

Envelope element	U-value, W/(m^{2}K)	
	Heavy insulation	**Light insulation**
External wall	0.08	0.17
Internal wall	0.40	0.4
Internal floor	0.16	0.3
Roof	0.05	0.09
External floor	0.080	0.16
Windows	0.70	1.00
Doors	0.80	1.00

While the amount of heat transfer trough building components varies so does the role of thermal bridges in the energy performance of the building. Linear additional thermal transmittance (ψ) values assigned for the heavily and lightly insulated building models are presented in Table 14.

TABLE 14. Thermal bridge values of the structure joints for the different building models.

Envelope element	Linear additional thermal transmittance (ψ), W/(mK)	
	Heavy insulation	**Light insulation**
External wall-Internal slab	0.01	0.05
External wall-Internal wall	0.00	0.01
External wall-External wall	0.01	0.08
External windows perimeter	0.01	0.05
External door perimeter	0.01	0.05
Roof-External walls	0.01	0.09
External slab-External wall	0.01	0.14
Balcony floor-External wall	0.01	0.0
External slab-Internal walls	0.00	0.01
Roof-Internal walls	0.00	0.0
External walls-Inner corner	-0.04	-0.04

As seen from the table, thermal bridging values for the heavily insulated model are almost negligible. This is because the „thermal bridge-free "construction principle from the PH standard is applied. „For the Passivhaus Standard, thermal bridge free construction is where calculating the heat loss from all the thermal bridges doesn't increase the overall building heat loss calculation /6 p. 105." In such a case, thermal conductance values equal to or less than 0.01 W/mK can be withdrawn from calculations, as the heat loss that they cause is negligible. This is done by ensuring a continuous building envelope and application of techniques described in more detail in chapter 4.1.5. Thermal bridges which are known to be relatively easy to eliminate completely are set to be 0 in the heavily insulated model.

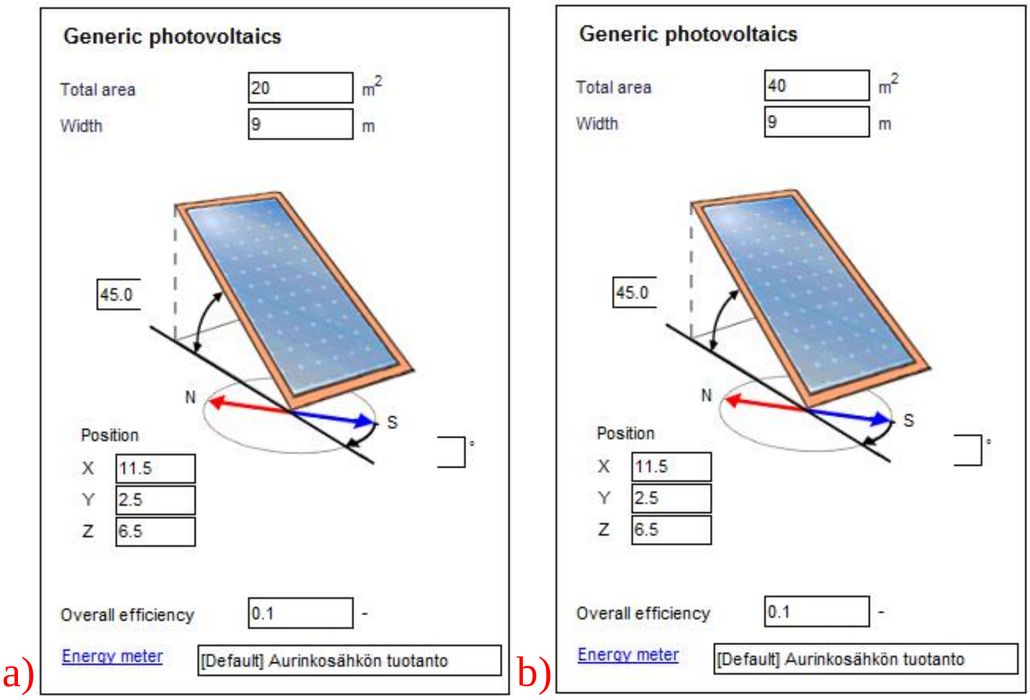
Building model with light insulation is equipped with thermal bridging values that are typical in today's residential building market. The same joints which were regarded as having a thermal transmittance value of 0 W/mK in the heavily insulated model are reduced to a value of 0.01 W/mK in this model. For difficult areas like window and door perimeters these values are increased to 0.05 W/mK as such cases are very common. For both models, joints that do not apply to this building are ignored, for example the Balcony Floor-External wall joint.

5.1.4 On-site renewables

As the results of this study will show, some form of renewable energy is without a doubt a vital part of nZEBs in the Finnish climate. Four types of RET were chosen to be tested in this work:

1) Photovoltaic cell panels;
2) Solar thermal collectors;
3) Wind turbine;
4) Ground source heat pump.

As it was mentioned before, solar energy is generally considered to be the most easily harvestable RE form. Even here in Finland it has enough potential to be considered as a viable and affordable energy source. Although it is important to note that PV systems are much more suitable for this climate as they do not require direct sunlight and can generate electricity even in cloudy conditions. Because of this, two options of PV systems were included in the simulation, both of them are illustrated in Figure 23. Although, a GSHP is usually not considered as RE, it does utilize ground heat which is essentially renewable.


a)

Generic photovoltaics

Total area 20 m^2
Width 9 m
45.0
Position
X 11.5
Y 2.5
Z 6.5
Overall efficiency 0.1 -
Energy meter [Default] Aurinkosähkön tuotanto

b)

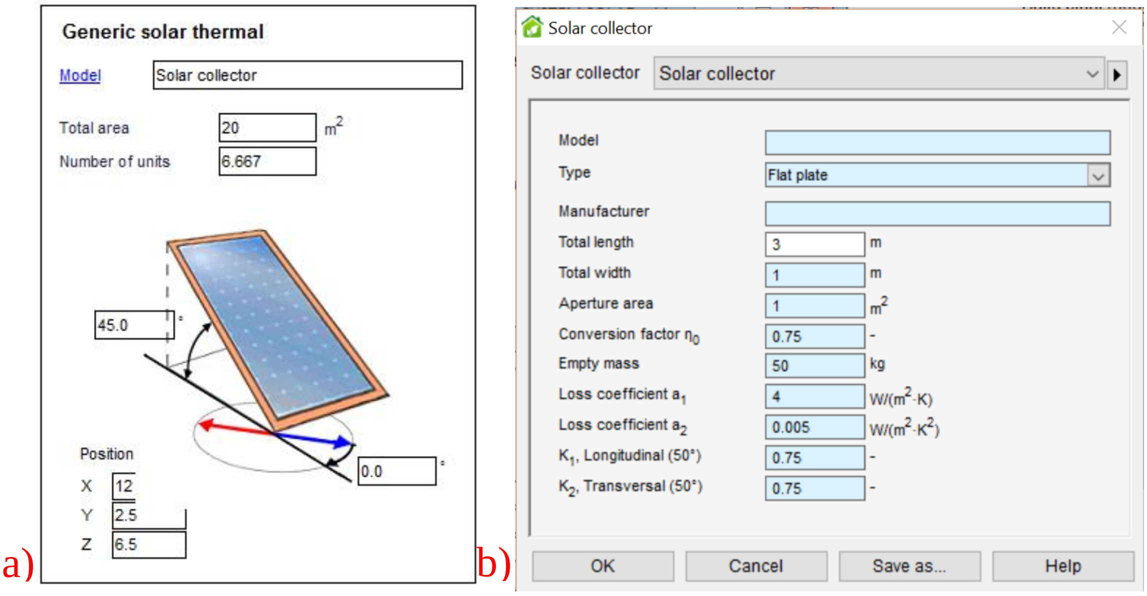
Generic photovoltaics

Total area 40 m^2
Width 9 m
45.0
Position
X 11.5
Y 2.5
Z 6.5
Overall efficiency 0.1 -
Energy meter [Default] Aurinkosähkön tuotanto

FIGURE 23. PV systems used in nZEB simulation, (a) 20m^2 (b) 40m^2.

Figure 23 illustrates the characteristics of PV systems used in the energy simulation. The only difference between them is the total area, (a) being 20 m^2 and (b) being 40 m^2. The panels are facing directly to the South with an 45^o inclination. The inclination was chosen after simulating angles from 5^o to 60^o every 5^o while the South orientation was already known to be the best. The reason why 40 m^2 is the maximum amount of panels is that it is not recommended to cover more than 50% of the roof area due to the possibility of them shading one another. This condition, however, is only valid for cases when the panels are on a flat roof and with a significant angle of at least 30^2. If the panels are being installed on the southern side of a gable roof, the natural inclination of the roof would allow them to lie flat on their backs and allow to avoid gaps between the panels which would otherwise result in loss of useful area. The 20 m^2 PV system was chosen to test how a system of half the size would compare to a bigger one while trying to reach a nZEB energy status for the building. As seen from the picture, the overall efficiency of the system is 10 %. More efficient PV systems exist, though are significantly more expensive. This level of efficiency is kept to avoid simulating with RE systems that are not cost-effective.

Solar thermal systems even though known to have less potential were also included in the simulations. The ST system and its configuration is shown in Figure 24.



Generic solar thermal

Model: Solar collector
Total area: 20 m^2
Number of units: 6.667
45.0 °
0.0 °
Position
X: 12
Y: 2.5
Z: 6.5

Solar collector

Solar collector: Solar collector

Model		
Type	Flat plate	
Manufacturer		
Total length	3	m
Total width	1	m
Aperture area	1	m^2
Conversion factor η_0	0.75	-
Empty mass	50	kg
Loss coefficient a_1	4	$W/(m^2 \cdot K)$
Loss coefficient a_2	0.005	$W/(m^2 \cdot K^2)$
K_1, Longitudinal (50°)	0.75	-
K_2, Transversal (50°)	0.75	-

FIGURE 24. ST system used in the simulation (a) and its configuration (b).

Although, only 20 m^2 of flat plate solar collectors were chosen to simulate. This was done to compare how such a system would do against a PV system of the same size. As seen from the picture, the same inclination of 45° and a southern orientation is chosen for the best performance. Just as with PV panels, a generic ST system was chosen and default values were left unchanged. This is because a comparison of such detail is sufficient to prove the superiority of a PV system in the cold Finnish climate for domestic use. It is important to mention however, that a SGSHP system which combines ST energy and a GSHP does better than the two of those separately. Such a system, however, was not simulated due to lack of knowledge of how to set it up in IDA ICE software. Regardless, it would have only improved the performance of the GSHP and would still not surpass the performance of PV systems.

5.1.5 Heating and Cooling

Due to reasons covered in chapter 4.4, only DH and GSHP heating systems were chosen to simulate. As for cooling, generic ideal chillers were put in rooms in which maximum temperatures would otherwise exceed 27.5°C during the warm months. Technical characteristics of these systems are presented in Table 15.

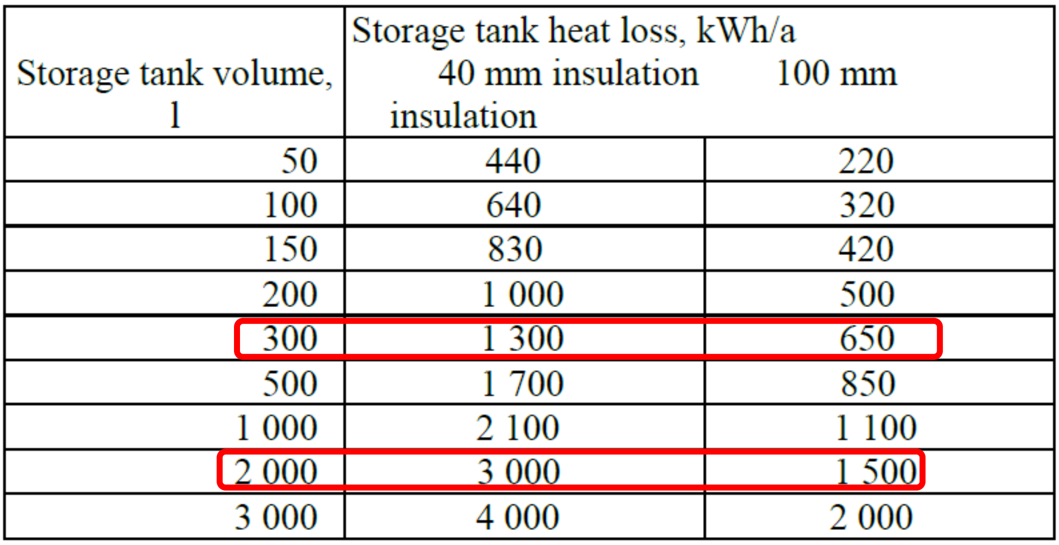
TABLE 15. Technical characteristics of DH, GSHP and Electric Cooling systems used in the building.

Parameter	**DH**	**GSHP**	**Electric Cooling**
$COP_{heating}$	0.97	4.85	-
COP_{DHW}	0.97	2.3	-
$COP_{cooling}$	-	-	3.0
T_{supply}	70° C	40° C	14° C
T_{return}	45° C	30° C	-
$T_{AHU\ supply}$	50° C	50° C	5° C
$T_{heating\ setpoint}$	21°C	21°C	-
$T_{cooling\ setpoint}$	-	-	27°C
Pum efficiency (η_p)	0.5	0.5	0.5
Nightime setback	No	No	No

COP values of DH and Electric Cooling systems we’re chosen as they are common values in Finland. Such high efficiency of DH is worth underlining as it is due to a well maintained DH infrastructure of Finland. COP value of GHSP was taken as reference from an already existing nZEB in Helsinki. Supply and return temperatures and set points are set according to NBC of Finland or common practices (e.g. GSHP underfloor heat distribution temperatures). District cooling, even though a good option was not chosen to simulate due to the fact that it is mainly available only in 1 out of 3 simulated locations-Helsinki.

DHW usage in the building is set to be 500 l/m^2_{floor} per year or 0.003 l/s. DHW heating schedule is set to “Always on” just like space heating and ventilation. Heat losses from the DHW storage tank are determined according to Table 16, from the D5 NBC of Finland.

TABLE 16. DHW storage tank losses. /17 p. 39/.



Storage tank volume, l	Storage tank heat loss, kWh/a	
	40 mm insulation	100 mm insulation
50	440	220
100	640	320
150	830	420
200	1 000	500
300	1 300	650
500	1 700	850
1 000	2 100	1 100
2 000	3 000	1 500
3 000	4 000	2 000

Normally, the size for the hot water tank is 0.3 m^3, but when a flat plate solar collector of 20 m^2 is included, a tank of 1m^3 is needed. Assuming that the hot storage tank has 100 mm of standard insulation the heat losses are 650 kWh/a and 1500 kWh/a accordingly. DHW circulation losses, as well space heating distribution losses are computed automatically in IDA ICE and are not required to be set manually.

5.1.6 Ventilation

An efficient mechanical ventilation system is another component that was needed to be included in the simulation. Without it, heat from the indoor wouldn't be recovered and sufficient ventilation while maintaining airtightness wouldn't be possible.

A Controlled Air Volume (CAV) mechanical ventilation was chosen for the building. Technical characteristics of the ventilation system are listed in Table 22.

TABLE 17. Technical parameters of the AHU used in the building.

Parameter	Value
$\eta_{\text{heat exchanger}}$	0.8
$q_{\text{v, sup. air}}$	0.4 l/(s. m^2)
$q_{\text{v, ret. air}}$	0.4 l/(s. m^2)
$T_{\text{air supply, const.}}$	17.5$^{\text{o}}$ C
$T_{\text{air temp. rise in fan}}$	0.5$^{\text{o}}$ C
SFP_{exhaust}	0.7 kW/(m^3/s)
SFP_{supply}	1.0 kW/(m^3/s)
$\eta_{\text{fan, electric to air}}$	0.5
HE operation	Always on
Fan operation	Always on

Efficiency of the heat exchanger ($\eta_{\text{heat exchanger}}$) was chosen to be 0.8 because that is the recommended limit for PH and VLEH in the Finnish climate. More efficient heat exchangers exist, but were avoided intentionally to showcase that the best available technologies are not mandatory to reach nZEB energy performance levels. The exact same principle was applied for Fan SFP values. As for the air supply temperature ($T_{\text{air supply}}$) a constant value of 17.5$^{\text{o}}$ C was chosen because this temperature would wary between 17$^{\text{o}}$ C and 18$^{\text{o}}$ C during the year. Volumetric flows both for supply and return air are set according to the NBC of Finland. As seen from Table 16 and Table 17, systems schedules both for ventilation and heating do not include breaks and work continuously throughout the year. This means that if holiday schedule and/or nigh time operation setbacks would be included the energy consumption of these systems would decrease even more. However, these factors are to vary greatly from case to case, therefore speculation was avoided.

5.1.7 Lighting and Equipment

As stated in the EPBD definition of a nZEB, it is up to the member states to decide if energy consumption of electrical devices is to be included in the energy balance calculations. The decision has not yet been announced by the Finnish authorities. Nevertheless, energy from electrical equipment is included in our work because this way the building will be more energy efficient. Occupant, lighting and equipment schedules are set according to the requirements for a detached house NBC of Finland, Part D3.

5.1.8 Simulated building models

As it was mentioned in chapter 2.1, energy performance of different nZEB concepts will be simulated and then compared. The building concepts differ in three areas-level of insulation, applied RET and location. The characteristics of these concepts are listed in a brief manner in Table 18.

TABLE 18. Characteristics of the simulated building concepts

Building concept	Insulation level	Heating system	RETs	Southern Finland	Central Finland	Northern Finland
DHH 1.0	Heavy	DH	ST (20m^2)	+	+	+
DHH 2.0	Heavy	DH	PV (20 m^2)	+	+	+
DHH 3.0	Heavy	DH	PV (40m^2)	+	+	+
DHH 4.0	Heavy	DH	PV (40m^2) + WM	+	+	+
DHL 1.0	Light	DH	ST (20m^2)	+	+	+
DHL 2.0	Light	DH	PV (20 m^2)	+	+	+
DHL 3.0	Light	DH	PV (40m^2)	+	+	+
DHL 4.0	Light	DH	PV (40m^2) + WM	+	+	+
GSHPH 1.0	Heavy	GSHP	-	+	+	+
GSHPH 2.0	Heavy	GSHP	ST (20m^2)	+	+	+
GSHPH 3.0	Heavy	GSHP	PV (20 m^2)	+	+	+
GSHPH 4.0	Heavy	GSHP	PV (40m^2)	+	+	+
GSHPH 5.0	Heavy	GSHP	PV (40m^2) + WM	+	+	+
GSHPL 1.0	Light	GSHP	-	+	+	+
GSHPL 2.0	Light	GSHP	ST (20m^2)	+	+	+
GSHPL 3.0	Light	GSHP	PV (20 m^2)	+	+	+
GSHPL 4.0	Light	GSHP	PV (40m^2)	+	+	+
GSHPL 5.0	Light	GSHP	PV (40m^2) + WM	+	+	+

Abbreviations: ST-Solar Thermal, PV-Photovoltaic, WM-Windmill. For light and heavy insulation levels see chapter 5.1.3.

As it is seen from the table, more attention is given to testing the energy performance of building concepts with PV systems. Several orientation simulations have already been completed beforehand to determine focus areas of this work. During these simulations it has been determined that the performance of ST collectors is significantly worse than PV panels and that variation in their size will have little effect on the conclusions of this work. As it will be seen from the results of the simulation, WM system also makes little difference in the primary energy consumption but just as with a ST system one concept with it will be tested to determine its feasibility. There is one building concept with a GSHP for each of the two insulation categories that doesn‘t includes any additional RETs. A GSHP itself utilizes a renewable energy form therefore building concepts containing only a GSHP will also be tested to see if they can reach nZEB performance levels.

Due to climate differences between these locations, it is clear that not all building concepts that will be able to reach nZEB performance levels in Helsinki will be able to do so in Sodankylä or maybe even Jyväskylä. Simulation results will show which building concepts will reach the nZEB performance levels and which won’t, thus indicating applicability of such concepts in Finland.

5.2 Simulation results

In this chapter, nZEB performance results are presented and analysed. The focus areas of the result analysis are the following:

- Determine which building concepts reach nZEB energy performance levels;
- Evaluate the performance of these concepts in 3 different parts of Finland;
- Evaluate how insulation level affects final primary energy consumption;
- Evaluate and compare the suitability of the simulated RETs for the Finnish climate.

The limit value of final primary energy consumption is taken from the draft version of Finnish Environment Ministry's regulation for the energy performance of new nZEBs. The target value to reach a nZEB status is (equation 22):

$$E_{primary} = 116-0.04\ A_{net} = 116-(0.04*185.8) = 108.6\ (kWh/m^2,a) \tag{22}$$

where:

$E_{primary}$ the total primary energy demand, (kWh/m^2,a);
A_{net} the total floor area of the building, (m^2).

5.2.1 Building performance in Helsinki

The first and the most promising energy efficiency-wise part of the country is Southern Finland. In this case buildings were situated in Helsinki. Performance of the different simulated building concepts in Helsinki are presented in Table 19.

TABLE 19. Energy performance of the simulated building concepts.

	Used energy		Purchased energy		Primary energy	
	kWh	kWh/m^2	kWh	kWh/m^2	kWh	kWh/m^2
DHL 1.0	17761	95.6	17761	95.6	13202	71.1
DHL 2.0	18923	101.9	18922	101.9	11759	63.3
DHL 3.0	16716	90	16716	90	9110	49
DHL 4.0	16552	89.1	16553	89.1	8914	48
DHH1.0	13081	70.5	13081	70.5	10878	58.6
DHH2.0	14212	76.6	14213	76.6	9408	50.7
DHH3.0	12005	64.7	12006	64.7	6759	36.4
DHH4.0	11842	63.8	11843	63.9	6563	35.4
GSHPL 1.0	9213	49.7	9213	49.7	11056	59.7
GSHPL 2.0	8940	48.3	8940	48.3	10729	57.9
GSHPL 3.0	5962	32	5961	32	7155	38.5
GSHPL 4.0	4810	26	4810	26	5773	31.2
GSHPL 5.0	4646	25.1	4648	25.1	5577	30.1
GSHPH 1.0	8167	43.9	8167	43.9	9801	52.7
GSHPH 2.0	7859	42.2	7859	42.2	9430	50.7
GSHPH 3.0	5962	32	5961	32	7155	38.5
GSHPH 4.0	3757	20.2	3757	20.2	4509	24.2
GSHPH 5.0	3594	19.3	3594	19.3	4313	23.2

As it is seen from the table, every singly simulated building concept has reached nZEB energy performance levels in Helsinki. Even with the lightly insulated DH and GSHP building concepts it’s possible to reach these performance levels. As it was mentioned in chapter 5.1.8, only building concepts with GSHP heating systems are tested without any kind of additional RETs. If this was also done for DH concepts, they probably wouldn’t reach the required primary energy limit and could not be acknowledged as nZEBs. Another reason for such great results is the updated primary energy factors. In this case, primary energy factors for electricity and DH were most beneficial as they were used as the main energy sources in the designed buildings. Although, not presented in this table, the same building concepts have been simulated using the current primary energy factors from NBC part D3 (2012), and not all building concepts have passed.

Even though such results were expected it is important to mention that GSHP equipped building concepts did significantly better than the DH ones. In the case of Helsinki, lightly insulated buildings with a GSHP did 19% to 39% better, depending on the RET used, than the buildings with a DH system. Heavily insulated GSHP equipped buildings did 13% to 34% better accordingly.

As far as RETs, simulation results were unexpected. Before carrying out the simulations it was thought that ST systems have a significantly lower energy potential than PV systems due to low temperatures and relatively low levels of direct sunlight in Finland. Performance of 4 different RET set ups in a heavily insulated GSHP building is presented in Figure 25.

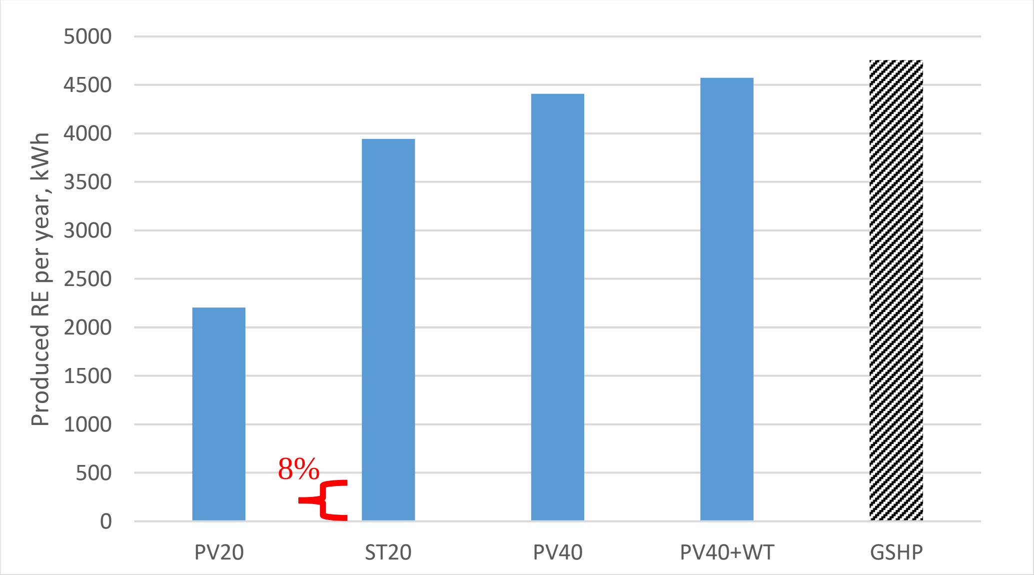


Figure 25. Produced RE energy by different RET set-ups.

It is important to note that with this graph it is not attempted straight-forwardly compare all of these set-ups with each other, as it would be inaccurate due to different sizes of the systems. Attention is rather given to conclusions which can be drawn from this graph. First of all, the amount of energy produced by a ST system is unexpectedly much larger than by a PV system of the same size. However, the abundant free energy from

ST system is poorly utilized and is wasted. Only 8 % of all the received ‘free eenergy’ are used with the ST setup used in this simulation.This results in PV system still being the superior one in this particular case. This is clearly evident from Table 25, as the final primary energy consumption is always lower with a PV system than with ST system of the same size. Energy from the ST system is wasted when the temperature of the heated medium is lower than the DHW temperature and therefore cannot be used. This problem is present in this case because a simple DHW heating system has been used. If a system with a pre-heater or pre-storage is used, much of the lost energy could be utilized effectively. Other options include using the low temperature medium to preheat air heat pumps or be used in a SAGSHP system. These setups, however, were not tested in this work. Another solution could be to use vacuum-tube ST collectors instead of plate ST collectors, the latter of which is actually known to be less efficient in cold climates.

If “PV40” and “PV40 +WT“ systems are compared it is clear that the wind turbine generates very little energy compared to the other RETs used in the simulation. The potential of wind energy could be utilized much better if the house was in an open area, therefore the wind would change to a better profile which in turn would generate more electricity. As mentioned in chapter 4.5, large-scale wind turbines would also be a better solution for nearby, off-site or on-site production due to larger production capacities and efficiencies of larger wind turbines. That is why a larger wind turbine WT* with a wind profile setting of an open country was simulated as well. The performance of this wind turbine is illustrated in Figure 26 with a column „WT*“.

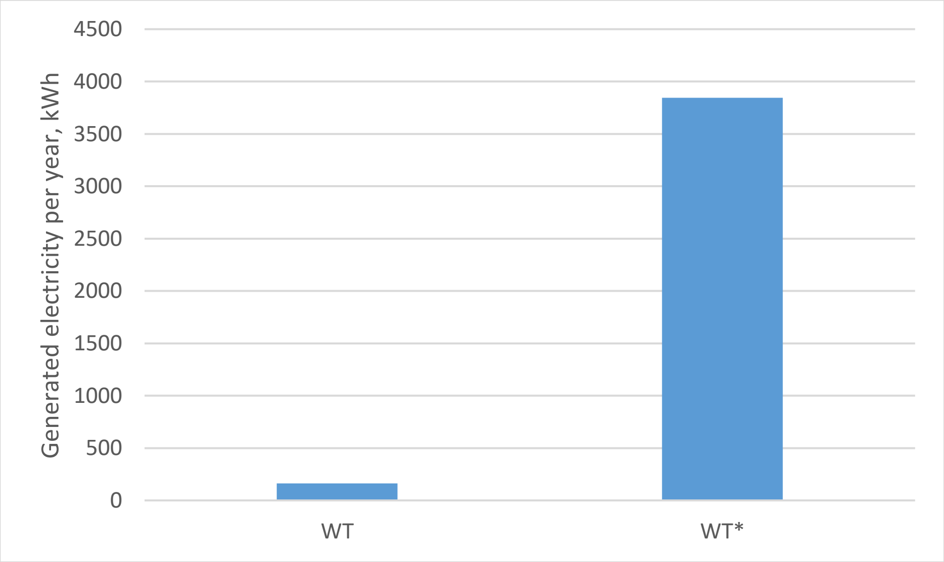


Figure 26. Energy production from wind turbines of different sizes and wind profiles.

The original WT is of 15 m height and has the capacity of 5.3 kW, while the WT* is of 20 m height and has the capacity of 10 kW. The wind profile, as mentioned, was also changed from Default Urban to Open Country. The resulting amount of generated electricity showcases the viable potential of larger wind turbines as RETs for nZEBs.

Utilized ground heat by a GSHP is isolated in red colour due to the fact that it ‘s not entirely a RET. Regardless, the amount of utilized free RE energy in the form of ground heat surpasses every other simulated RET. However, this does not mean that 100% of this energy was used as some may have been wasted. Free cooling energy utilized in the summer with the same ground heat exchanger only adds up to the total amount of utilized free energy of the GSHP system. In order to make an accurate comparison between a GSHP and other RETs in terms of free energy utilization some kind of standardization would have to be made. However, this is not the goal of this work and both GSHP and RETs are encouraged to be used in a building simultaneously.

Different levels of insulation mean different levels of heat losses through building envelope components. Figure 27 illustrates how these heat flows compare between lightly and a heavily insulated GSHP building concepts.

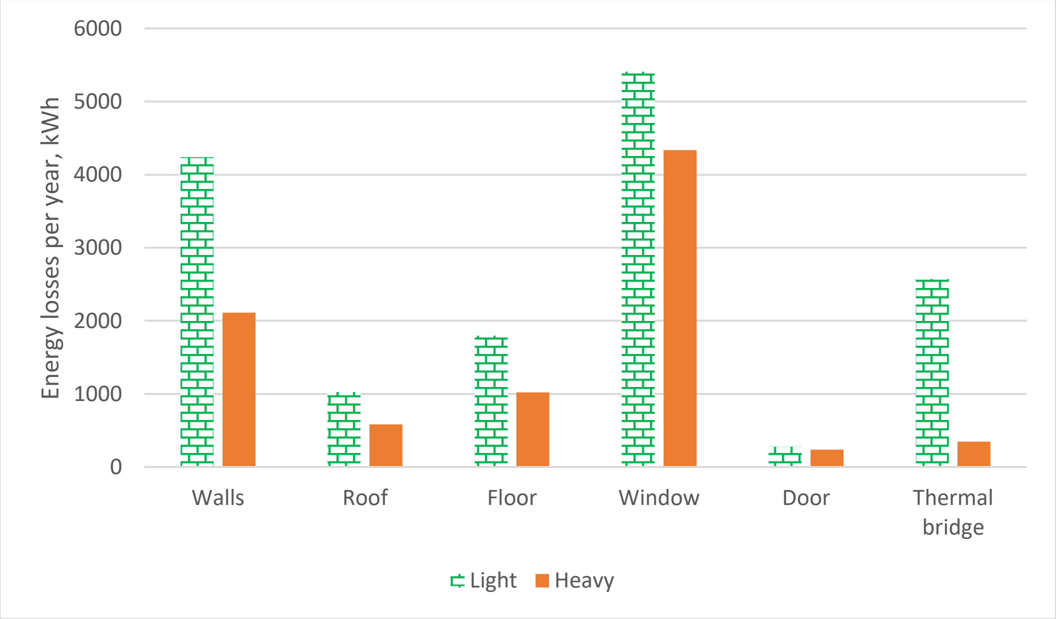


Figure 27. Energy losses in heavily and lightly insulated GSHP building concepts.

As it is seen from the graph, the biggest difference is for heat losses through thermal bridges. By improving thermal bridges from „typical “values to a thermal bridge-free envelope as stated in the PHS, heat losses through thermal bridges were reduced by 76% in this case. Second most impactful building envelope element improvement is the outside walls. By improving the U-value from 0.17 W/(m^{2}K) to 0.08 W/(m^{2}K), the heat loss through walls was reduced by 50%. Roof and floor also demonstrated significant improvements. Although, their share in the total heat loss balance was marginal so these improvements did not have a large effect on the final primary energy consumption. Windows on the other hand, having a key role in the building envelope heat losses did not improve a lot. Having in mind that highly efficient windows are rather expensive, an improvement of only 20% is less satisfactionary.

5.2.2 Building performance throughout the whole Finland.

All of the simulated building concepts have reached the nZEB energy performance level when situated in Helsinki. Now, all of these buildings will be simulated in Central and Northern Finland as well. The results are presented in Figure 28. The full simulation data is listed in Appendix 3.

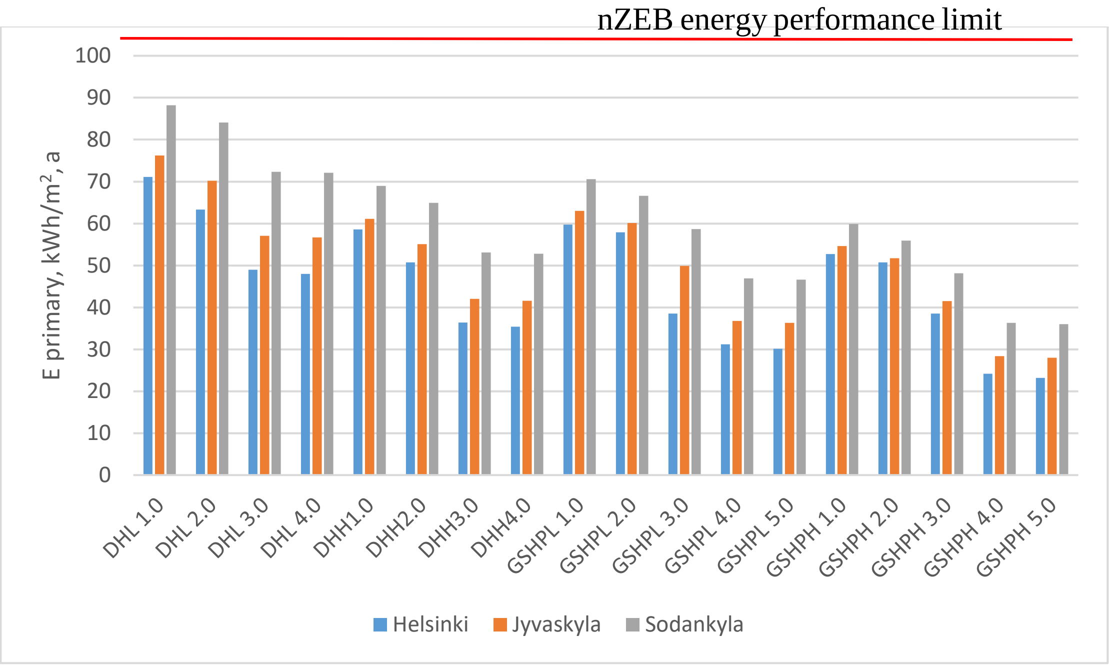


Figure 28. Energy losses in heavily and lightly insulated GSHP building concept.

As seen in the graph, energy consumption of all of the buildings is increasing as they move towards Northern of Finland. Another thing that is clearly visible from the graph is that lightly insulated building concepts demonstrate bigger amplitude energy consumption amplitude between different parts of Finland. This means that thermal losses due to building insulation become more and more significant as the weather gets colder. Heavily insulated buildings are evidently more resistant to these changes.

Unexpectedly, every single building concept has met the Finnish nZEB energy requirements as the primary energy consumption of the simulated nZEB haven' t surpassed the maximum allowed value according to the upcoming Finish NBC.

As the importance of building energy efficiency solutions rises when moving in the direction of colder climate, the potential of RETs decreases. This is illustrated in Figure 29.

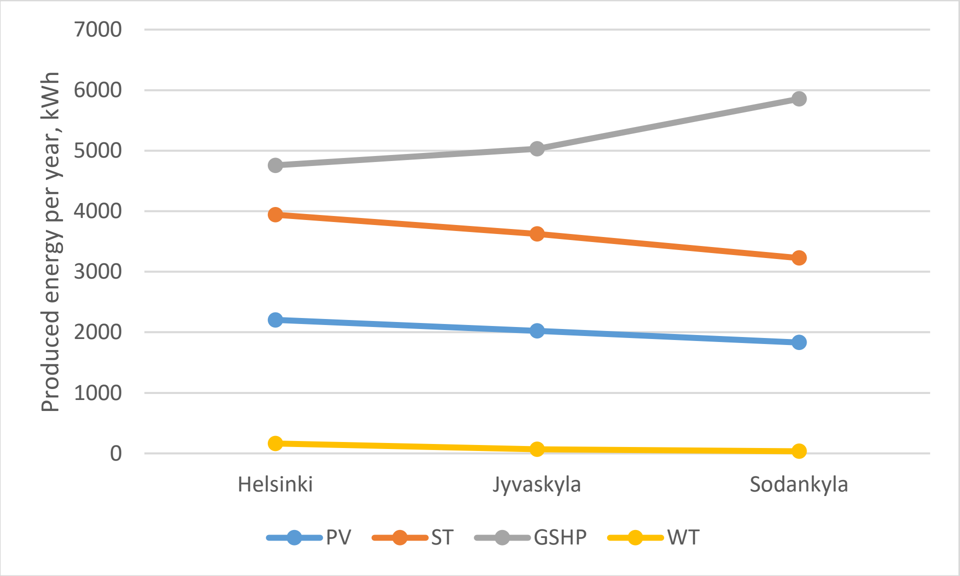


Figure 29. Change of RE potential throughout Finland.

As seen from the graph, energy potential of all RE forms except geothermal decreases when moving towards the North of Finland. ST and PV system potential decrease due to lowers temperatures and lower amounts of sunlight. Wind energy potential decreases due to weakening winds. Though this difference can easily be offset if a nZEB in Sodankyla in an open field. As for the GSHP, it's energy yield increases due to a larger difference between the ground temperature and room temperature. However, when ground temperatures are getting lower, risks of permafrost and/or GSHP working outside its limit values and thus reducing the COP arse. All of these effects urge to increase the energy efficiency side of the building as much as reasonable and plan RET yield carefully.

6 DISCUSSION

The goal of this work was to prove the hypothesis that nZEBs are relatively easily achievable in Finland while staying in the rational cost limits. The secondary task was to find out whether nZEBs are feasible in colder areas of Finland-Central and Southern. And the last one, evaluate the possible renewable energy solutions for nZEBs in Finland. In order to answer these questions, theoretical research as well as dynamic simulations using IDA ICE 4.7.1. software was done. This study revealed the following points:

- nZEBs can successfully apply Finnish PH or VLEH standards to ensure energy efficiency. These standards aren't new and are being used in Finland today. Consequently, ensuring “extremely high energy efficiency” as stated in the official nZEB definition looks relatively easy and is without a doubt a rational choice.
- Various RETs have enough potential to be used in Finland to reduce the primary energy consumption to the required limit. ST, PV, GSHPs, WTs, large scale Geothermal and Hydro plants are all viable solutions to reach nZEB levels. For on-site RE generation, GSHPs, ST, PV systems seem to be the best choices in the majority of cases. Some of them, solar thermal for example require special space heating and/or DHW system configurations for it to work efficiently.
- Most recommended heating systems for an nZEB in Finland-GSHP or DH systems, possibly with a combination of ST system. This is due to their high efficiencies and environmental friendliness. Simulated building models with GSHP systems performed 26% better than the ones with DH systems on average.
- nZEB energy performance can be achieved both with high and low levels of insulation. High being PH insulation level and low equating to the minimum level of insulation requirements from the draft version of the 2018 NBC of Finland.
- In this study, all of the lightly insulated buildings have been able to reach nZEB performance levels throughout the whole Finland because only insulation levels were reduced. If one would think for example to skip on an efficient AHU ($\eta_{AHU} \leq 0.8$) or an efficient heating system, nZEB performance levels would probably

not be reached in Central and/or Northern Finland due to low outdoor temperatures.
- Prioritizing energy efficiency and only then adding RE to the building concepts has proved to be the best approach in terms of cost optimality and ROI potential. This is especially true for Central and Northern Finland as thermal losses increase and RE generation potential decreases.
- Results of dynamic energy simulations of the 18 different residential building concepts have confirmed the hypothesis that nZEB energy performance levels are relatively easily achievable in the Finnish climate with today’s technologies while only requiring moderate amounts of RETs.

7 CONCLUSIONS

After conducting this research, it has become clear that a nZEB status can indeed be achieved in the Finnish climate and can still be a reasonable choice for a residential house. The energy efficiency measures from PHS and VLEH proved to be sufficient for a nZEB in cold northern climate. From the two that were simulated, both DH and GSHP heating methods proved to be a possible choice. Even though a GSHP demonstrated better results, that was to be expected as GHSPs are generally known to be a more efficient but also a more expensive heating alternative. As far as on-site renewable energy systems go, if we don’t count geothermal energy from a GSHP, PV systems and unexpectedly ST systems are the best choice. The latter however, requires special considerations in the early design phase of the heating system of the building as specific moderations would be required in order for ST systems to be usable.

The initial hypothesis raised in the beginning of this work has been confirmed. A well-insulated, airtight building with a moderate amount of RE systems can reach an nZEB status relatively easily throughout Southern, Central and Northern Finland.

Regardless of what where the results of this simulation, there is still a lot of work that needs to be done and questions to be answered before transitioning to nZEBs. In my personal opinion, nZEB energy performance levels were so easily achievable in this work due to two reasons. First, more variables should have probably been included in the simulation rather than changing only the insulation levels of the building concepts. This is because it is unlikely that a nZEB owner would neglect the importance of good thermal insulation and would still install the efficient and expensive HVAC equipment that we're chosen for the highly insulated building model. The second reason in my opinion is that the requirements are not very strict. Finland as well as other EU countries should be advancing towards eliminating human footprint on the environment even faster. The EU already has the technology and capabilities to start transitioning even towards the net-zero energy building concept, therefore more initiative needs to be taken to accelerate this progress. Even being in a less fortunate position in terms of climate suitability for energy efficiency, Finland, together with other Scandinavian countries have already demonstrated a high level of determination and mutual understanding that we need to take action to save our environment. This is why Finland should keep striving for progress in this area and be a good example to other EU member countries.

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Appendix 1

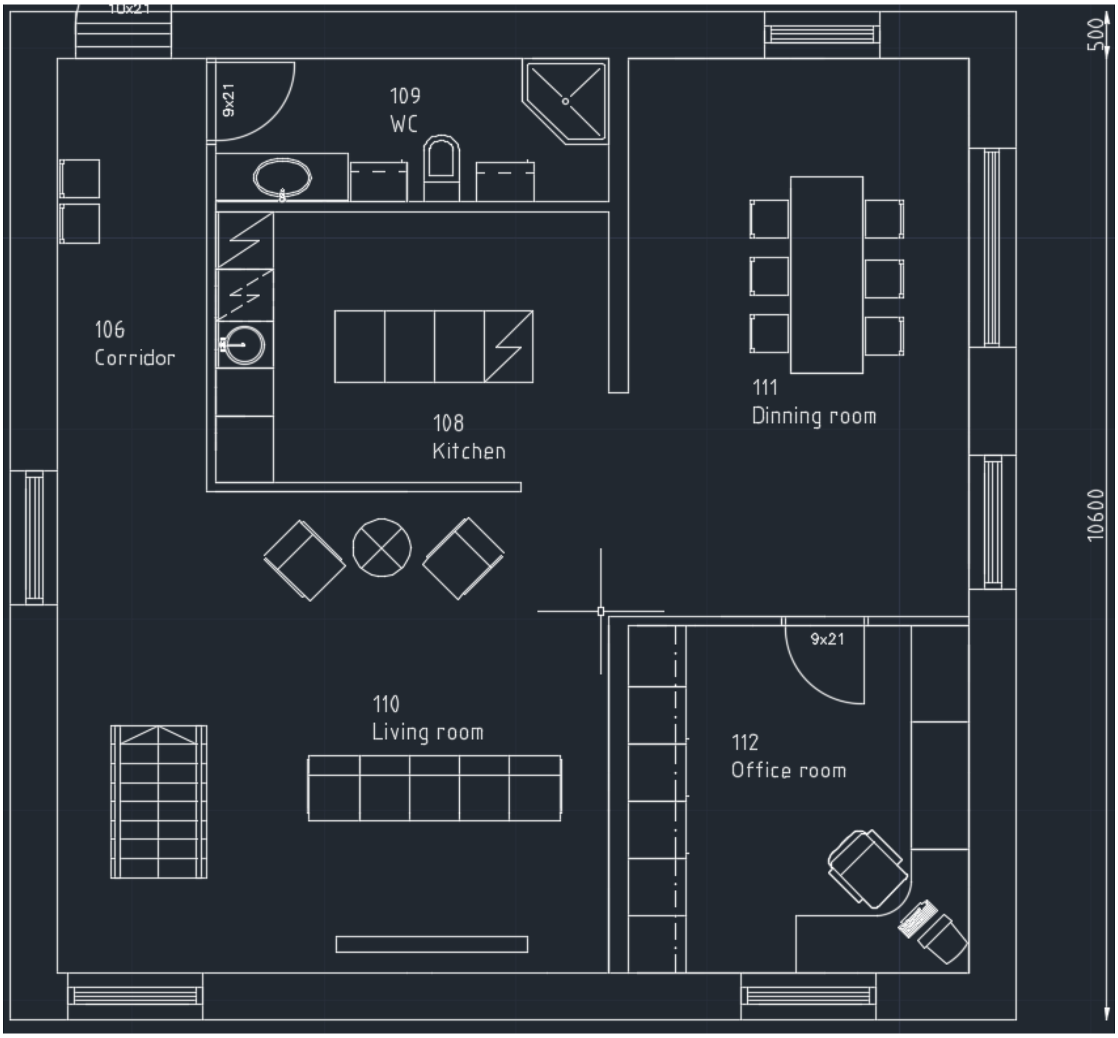
Boundary conditions, acceptable certification criteria and efficiency classes for glazing

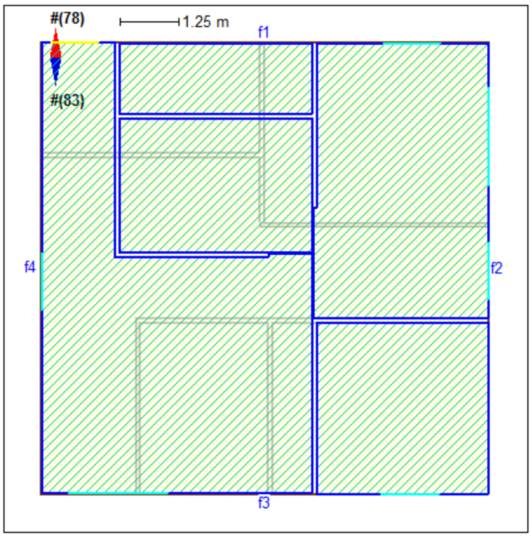
Region No.	Name	Boundary condition for hygiene criterion	Hygiene criterion			Ambient temperature for comfort criterion [°C]	Maximum heat transmission coefficient					Solar-factor	Glazing efficiency classes For each class, Ueq* must be less than		
		Ambient external design temperature T_e	Relative humidity internal RH_i	Internal surface temperature T_{si}	Surface temperature factor f_{Rsi}		Orientation (tilt) angle	[°]	$U_{w,installed}$	U_w	U_g	S	A	B	C
1	Arctic	–34	0.40	9	0.80	–50	vertical	90	0.45	0.40	0.35	0.70	–0.10	–0.05	0.00
							inclined	45	0.50	0.50	0.50				
							horizontal	0	0.60	0.60	0.60				
2	Cold	–16	0.45	11	0.75	–28	vertical	90	0.65	0.60	0.55	1.00	–0.15	–0.07	0.00
							inclined	45	0.70	0.70	0.70				

Appendix 2(1)

Simulation model first floor layout

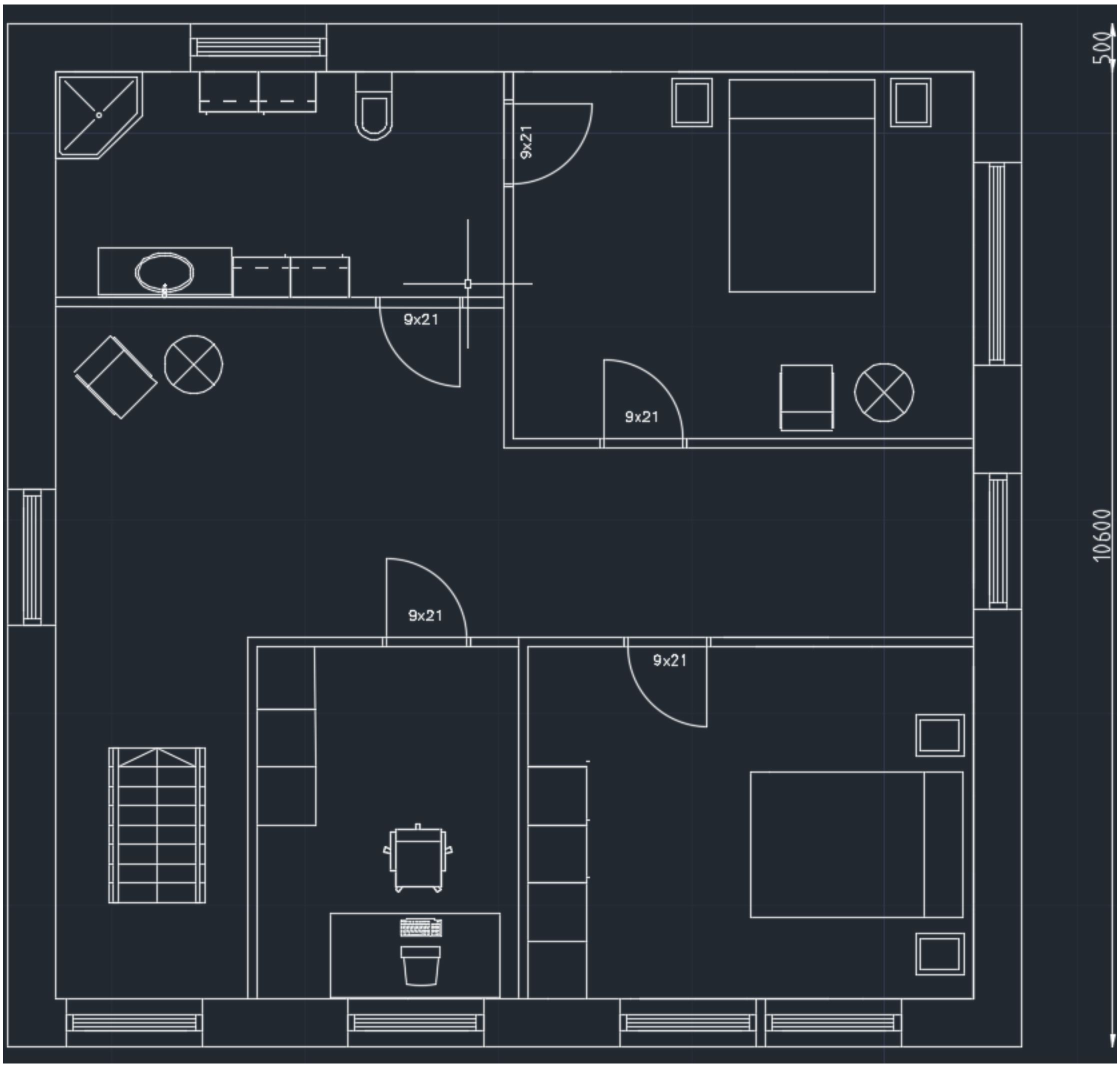
First floor

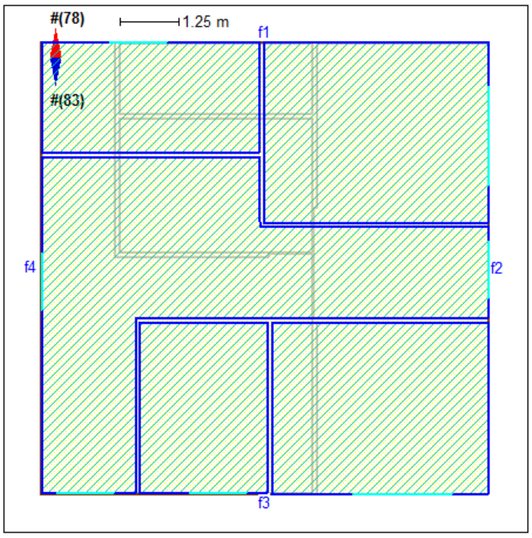




Simulation model second floor layout

Second floor





Jyvaskyla

	Used energy		**Purchased energy**		**Primary energy**	
	kWh	**kWh/m^2**	**kWh**	**kWh/m^2**	**kWh**	**kWh/m^2**
DHL 1.0	20013	107.7	20013	107.7	14145	76.2
DHL 2.0	21312	114.7	21312	114.7	13038	70.2
DHL 3.0	19286	103.8	19287	103.8	10607	57.1
DHL 4.0	19220	103.5	19220	103.5	10528	56.7
DHH1.0	14395	77.6	14395	77.6	11341	61.1
DHH2.0	15670	84.5	15671	84.5	10224	55.1
DHH3.0	13644	73.5	13646	73.6	7793	42
DHH4.0	13578	73.2	13580	73.2	7714	41.6
GSHPL 1.0	9721	52.5	9721	52.5	11666	63
GSHPL 2.0	9285	50.1	9285	50.1	11144	60.1
GSHPL 3.0	7699	41.6	7699	41.6	9239	49.9
GSHPL 4.0	5675	30.6	5676	30.6	6810	36.8
GSHPL 5.0	5609	30.3	5608	30.3	6730	36.3
GSHPH 1.0	8459	45.5	8459	45.5	10151	54.6
GSHPH 2.0	8023	43.1	8023	43.1	9627	51.7
GSHPH 3.0	6435	34.6	6434	34.6	7722	41.5
GSHPH 4.0	4411	23.7	4410	23.7	5294	28.4
GSHPH 5.0	4345	23.4	4344	23.4	5214	28

Sodankyla

	Used energy		Purchased energy		Primary energy	
	kWh	kWh/m^2	kWh	kWh/m^2	kWh	kWh/m^2
DHL 1.0	24842	133.7	24842	133.7	16380	88.2
DHL 2.0	26243	141.3	26243	141.3	15630	84.1
DHL 3.0	24411	131.4	24410	131.4	13432	72.3
DHL 4.0	24376	131.2	24376	131.2	13390	72.1
DHH1.0	17674	95.3	17674	95.3	12798	69
DHH2.0	19046	102.7	19046	102.7	12040	64.9
DHH3.0	17214	92.8	17215	92.8	9842	53.1
DHH4.0	17179	92.6	17180	92.6	9800	52.8
GSHPL 1.0	10893	58.8	10893	58.8	13073	70.6
GSHPL 2.0	10283	55.5	10283	55.5	12340	66.6
GSHPL 3.0	9064	48.9	9067	48.9	10879	58.7
GSHPL 4.0	7233	39	7235	39.1	8682	46.9
GSHPL 5.0	7198	38.9	7200	38.9	8640	46.6
GSHPH 1.0	9282	49.9	9282	49.9	11139	59.9
GSHPH 2.0	8674	46.6	8674	46.6	10408	55.9
GSHPH 3.0	7451	40	7451	40	8942	48.1
GSHPH 4.0	5620	30.2	5621	30.2	6745	36.3
GSHPH 5.0	5585	30	5583	30	6703	36