Very Low-Energy House Concepts in North European Countries
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INTRODUCTION

This booklet is one of the deliverables from the IEE project NorthPass, which aim is to increase the market penetration of very low-energy houses in North European countries. The focus area for the project is new dwellings, both single family houses and apartments.

The purpose of this booklet is to convey knowledge about the significant energy saving potential in the building sector, technical possibilities of energy savings and renewable technologies paired with indoor environment considerations. The target groups are planners and producers, as well as building owners, who preferably will demand more environmental friendly houses in the future.

Information about the project and the deliverables can be found at www.northpass.eu
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WHAT IS A VERY LOW-ENERGY HOUSE IN NORTHERN EUROPE?

Definitions and concepts

There exists a number of different cross-border and national definitions and concepts for low energy and very low energy buildings. Some of them focus also on the renewable energy production on site. All these have in common – and that is what residential very low energy houses are about – a design that enables low energy demand:

- Well insulated building envelope for minimal heat losses
- Compact shape and no thermal bridges for minimal heat losses
- Energy efficient windows facing sun allowing use of passive solar gains
- Good air tightness for controlled ventilation and reduction of heat losses and moisture damages

There are several schemes for labelling and certification of energy efficient and sustainable buildings

Low energy house

Buildings with significantly lower energy demand than buildings just meeting the mandatory building regulations. Typical criteria are 25 – 50 % better than minimum requirements.

Passive house

Buildings with space heating demand lower than 15 kWh/m²/a or heating load below 10 W/m², total primary energy demand lower than 120 kWh/m²/a and air tightness given by $n_{50}$ better than 0,6 1/h. The primary energy criteria concern all energy use in a building, including house hold electricity use. Also some basic requirements for indoor thermal comfort and moisture safety are defined. These are international values defined by Passivhaus Institute in Germany. In Sweden, Norway and Finland the term is used for other, national values, too.
Active house
Buildings with focus on low energy demand, daylight utilization, natural ventilation strategies and renewable energy supply on the building

Zero energy building
Buildings with renewable energy supply on the building, which equals the energy demand in annual balance

Zero emission building
Buildings with renewable energy supply on site, which offsets emissions caused by the production of the materials and the conventionally produced energy consumed by the building

Plus-energy-building
Buildings with renewable energy supply on the building, which more than equals the energy demand in annual balance

Space heating demand around northern Europe
The climatic conditions around the northern Europe are very different, varying from nearly central European conditions in the south to arctic conditions in the north. A longitudinal difference in conditions is also varying from mild and rainy Atlantic weather to cold continental winters and hot summers. Therefore when planning a very low energy house across these very different conditions, one has to either accept:

1. different goals for the space heating energy demand
2. adaptation of the building to the conditions, e.g. lowering U-values in order to obtain the same energy demand.

The illustration shows these two concepts with the resulting space heating demand for a single family house.

Concept 1: A building meeting the passive house criteria in Copenhagen is moved around North European climate zones.
Concept 2: U-values of a building are modified to meet the passive house criteria in each climate zone. Resulting range of U-values for opaque constructions is 0,04–0,12 W/m²/K and for windows is 0,56-0,78 W/m²/K. These values a calculated for a compact single family house with a gross area A = 172 m².
WHY BUILD VERY LOW-ENERGY HOUSES?

There are many reasons why it is important to build very low-energy houses; political, economic and ecological. Here are some arguments why the society should build very low-energy houses:

- To take action against climate change and reduce energy consumption
- Very low-energy houses in general have a lower environmental impact [IVL]
- Lower Life Cycle Costs for very low-energy houses in general with a high energy price [IVL]
- To fulfil political agreements

Action against climate change and reduce energy consumption

There is an increasing awareness that climate change is caused by human activities. The UN’s Intergovernmental Panel on Climate Change (IPCC) assesses global research on climate change. In IPCC’s Fourth Assessment Report [IPCC], published in 2007, they note that the global warming is mainly caused by greenhouse gas emissions from human activities. The principal sources of emissions are combustion of fossil fuels and land use change (e.g. deforestation).

To avoid further global warming it is important to reduce the greenhouse gas emissions. The energy production today is to a large extent based on fossil fuels [IEA]. With reduced energy consumption, less fossil fuel will be consumed and greenhouse gas emissions can be avoided.

Another reason why it is important to reduce energy consumption is that there are resource constraints for oil and gas production, the resources are not as easily accessible anymore.

Lower environmental impact

The report “Economic and environmental impact assessment of very low-energy house concepts in the North European countries”\(^1\) presents the results from Life Cycle Costs assessments, Life Cycle Assessments and Cost Benefit Analysis of 32 conceptual single-family and multi-family buildings – both conventional and very low-energy buildings in Denmark, Estonia, Finland, Latvia, Lithuania, Norway, Poland and Sweden. The report is written by IVL Swedish Research Institute and is one of the publications from the NorthPass project.

The Life Cycle Assessments in the study demonstrate that very low-energy houses in general have a lower environmental impact than conventional houses – they use less primary energy and cause less greenhouse gas emissions for a time span of 30 years. An example from the report can be seen in Figure 1. The diagram shows the assessment of two Lithuanian multi-family buildings, heated by electricity and district heating. As can be seen in Figure 1, the potential contribution to global warming [kg CO\(_2\)-equivalents/m\(^2\)] is larger for the conventional multi-family building than for the very-low energy building.
Potential contribution to global warming for two Lithuanian multi-family buildings, accumulated over the first 30 years of operation [kg CO2-equivalents/m²]

The study indicates that greenhouse gas emissions from energy consumption are more important than greenhouse gas emissions from building material production. A conclusion from the study is that it is important not only to reduce energy consumption but to use renewable energy whenever possible.

Lower life Cycle Costs

A very low-energy house has a lower energy demand than a comparable conventional house. This implies reduced energy costs for the tenant.

In the NorthPass report “Economic and environmental impact assessment of very low-energy house concepts in the North European countries” Life Cycle Costs assessments were performed for very low-energy and conventional buildings. The energy price is important for economic comparisons of this kind. The calculations in the NorthPass report were made for a 30 year time span and for different energy price trend scenarios, a low and a high energy price trend.

The report shows that very low-energy houses in general have lower Life Cycle Costs than conventional houses for a high energy price trend. Figure 2 shows an example from the Life Cycle Costs assessments for two Lithuanian Multi-family buildings. As can be seen in Figure 2, the very-low energy house has lower total costs than the conventional house after 30 years. The payback time for the very-low energy house is approximately 15 years.
Life Cycle Cost for two Lithuanian multi-family buildings for a scenario with high energy price development.

Calculated saving in space heating demand with the 2 very low energy house concepts defined in the NorthPass project compared with the national Building Code demands in January 1st, 2010.

**Concept 1**: A building meeting the passive house criteria in Copenhagen is moved around North European climate zones.

**Concept 2**: U-values of a building are modified to meet the passive house criteria in each climate zone.

By adapting Concept 1 in stead of Building Code minimum requirements, the resulting savings in space heating demand vary between 30 to 90 %, depending on the country and location. By adapting Concept 2 the resulting savings in space heating demand vary between 60 to 93 %.

To fulfil political agreements

The building sector accounts for 40% of the energy use within the EU. There is a great potential of reducing energy use and thereby greenhouse gas emissions. There are many political agreements to improve energy efficiency and to reduce greenhouse gas emissions, for example the Energy Performance of Buildings Directive from the EU. With a more energy-efficient building sector a country becomes less dependent on imported energy.
COMFORT AND INDOOR CLIMATE IN VERY LOW-ENERGY HOUSES

The very low energy house has, beside the obvious benefit of low energy consumption, many benefits in regard to the comfort and the indoor climate. These benefits relates to thermal, atmospheric and acoustic indoor climate. Indoor climate and comfort are parameters by which the very low energy house has improved drastically from the first erected houses until now and is a very good reason for choosing to live in a very low energy house.

The very low energy house has had many myths attached to its name. Some true some not. The main thing to state is that there have been some problems in the initial phase where everybody, from the architects to the engineers, the producers, the craftsmen and the occupants, should learn how to draw, calculate, produce, erect and live in very low energy houses by the required quality, but now the problems seem to be eliminated generally speaking. The myths are however still present and very hard to eliminate in the professionals’ and the prospect homeowner’s mind. Some of these myths, and the facts related to them, are described in the following text alongside the benefits related to comfort and indoor climate in a very low energy house.

Thermal indoor climate

Thermal indoor climate relates to the air temperature, the mean radiant temperature, the air velocity, the humidity and the activity and clothing of the persons in the room.

One of the main reasons that the very low energy house consumes less energy than a standard house is the high level of insulation and air tightness in the constructions. These two factors also have great impact on the thermal indoor climate and the comfort of the residents. In very low energy houses walls, floors, ceilings and windows will be homogeneously warm since the constructions are well insulated and airtight and low u-value windows are used. This means that all surfaces will feel warm and not cold as it can be the case in standard houses, where the insulation and air tightness level is not as high. In the very low energy house you can therefore furnish right up the walls without fearing that mould will grow behind your furniture due to cold surfaces. Since the windows are very well insulated they don’t feel cold either – one can in fact sit in the windowsill and use the space as an extra seat.

The building envelope and quality of this has everything to do with the thermal indoor climate. For a building to be classified as a very low energy house the envelop must, as previously mentioned, be very air tight and insulation level fairly high, but also thermal bridges should be eliminated to avoid moist and cold from penetrating through the constructions and into the building. The elimination of thermal bridges and air leaks (along with the high insulation level and low u-value windows) has the benefit of no draft along the floor or downdraft from windows. In relation to the comfort this means that one can walk barefooted on the floor all year round without feeling cold and can sit in a chair under the window without having cold downdraft falling at the neck.

In a very low energy house the outdoor temperature do not have the same influence on the indoor temperature as in a standard house. The temperature in a very low energy house has less variation over the day and the year because of the high level of insulation, the effective solar shading and the air tightness. This because the temperature can be kept even as the air
change are controlled by a ventilation system and not by the wind and leaks in the building envelope and the building envelope keeps the heat out of the building in the summer and in the building in the winter meaning that the temperature all year round will be comfortable.

**Myth:** Very low energy houses are too hot in the summer.

**Fact:** When the low energy house is optimal designed it will not experience problems with over temperature during summer. On a few very hot days, the very low energy house can however have problems with keeping the temperature within the comfort zone, because the airtight and well insulated building envelope can not release the heat as fast as necessary. This will also be the case with a standard house, where the indoor temperature is even more determined by the outside temperature. The very low energy house will keep the heat out longer than the standard house since it is harder for the heat to get through the well insulated building envelope.

There are three main reasons why the very low energy house can experience overheating. First if the house is not designed with the right solar shading on windows facing east, west and south there can be problems with overheating in the summer. When the heat is in the house it is hard to get it out again, so it is important to design the house with the adequate solar shading and hereby limit solar radiation on warm days. It is about preventing instead of curing.

Another parameter related to the design is the risk of having a too high amount of thermal mass exposed to solar heat. The thermal mass will absorb the solar heat in the beginning, but at some point the mass can not contain more heat and the heat will be released and over temperature can occur. If too much thermal mass is combined with low ventilation flow rate it can result in additional increased indoor temperature.

As these two parameters show the design of a very low energy building can cause problems if it is not done carefully. Even if the design is done right lack of guidance for the occupants in how to control the heat/ventilation system and following possible inconvenient adjustment can influence the temperature. This means that the design of the building, the settings of the mechanical systems and the occupants’ behaviour can all influence the indoor climate, but if everything is done correct there will not be any problems.

**Atmospheric indoor climate**

Atmospheric indoor climate is connected to air pollution from people, furniture, surface materials in the room (paint, carpet, etc.), tobacco, cleaning detergent, dust, moist, mould etc. in combination with cleaning quality and ventilation rates.

In a very low energy house a mechanic ventilation system is necessary to recover the heat from the exhaust air and thereby reach the low energy need and at the same time to control the air quality. In the summer time it is possible to supplement the mechanical ventilation system with natural ventilation since the outdoor temperature is high in the summer and therefore the need for recovery of the heat from the exhaust air is not necessary to uphold the low energy consumption. The natural ventilation is voluntarily and if it is not done by the occupants, the mechanical system will take over and ensure the fresh air to uphold the good indoor climate.
The quality of the air you breathe affects your comfort and by the use of a ventilation system many of the problems which can occur in standard houses can be eliminated. First of all the system changes the air in the house with fresh air from outside when it is needed, so that the occupants never stay in air polluted by odour from persons, furniture, construction materials etc. Secondly the filters in the ventilation system will ensure that pollen etc. can not enter the indoor air and thereby allergies can be reduced and at the same time the system keep the air humidity lower than 45% in the winter meaning that dust mites will not thrive, both signifying that the ventilation system can make the house healthier to live in.

A combination of the ventilation system and the air tight building envelope allows the ventilation rate to be set according to the need inside and not depending on user involvement or the outside wind conditions. This means that the air can be changed often if there are many active persons in the house and less if only one sedentary person is at home, but always ensuring that there are plenty of fresh air for whatever activity is going on in the building.

Another benefit from the mechanical ventilation system which can improve the indoor climate and comfort are the possibility to defined different ventilation rates and temperatures in each room in the building. In this way the indoor climate can be tailored to the specific room and activity and guarantee the perfect conditions depending on the demands.

**Myth:** Very low energy houses cannot breathe through the building envelope because it is too airtight and consequently the indoor climate is bad.

**Fact:** It is true that a building where the air is not changed (breathing of the house) will have a very poor indoor climate and a very low energy house is very air tight, consequently not able to breathe through the building envelope. The reason why the indoor climate is good in a very low energy house is the ventilation system, which is an essential part of the building. The mechanical demand controlled ventilation system ensures the right amount of fresh air for an optimal indoor climate with the lowest amount of energy used. The important difference from a standard house, where the air change is controlled by the outdoor wind speed, the leaks in the building envelope and user involvement, is that in a very low energy house everything can be set according to the demand and controlled mechanically without the involvement of the user. The very low energy house can not breathe by itself but with a mechanical ventilation system it can and the indoor climate is at the same time controlled to fit a given situation optimum.

**Myth:** Very low energy houses have risks of having moisture problems.

**Fact:** A leaky building envelope can result in moisture and mould in the construction and consequently a poor indoor climate. When warm moist air can pass through leaks in the building envelope into the construction it will condensate when it cools. The moist from the condensation will attach to the building materials and here mould can grow as well as destroying the construction and transmitting the mould to the indoor climate. An airtight building, as the very low energy house has to be, will not experience this risk since the moist will not be able to go through the building envelope and into the construction.

Because of the airtight building envelope moist problems might occur inside the very low energy house if there were no ventilation. If the air in a very airtight building is not changed according to the demand there can be moist problem because the moist air will be trapped in
the building. With a ventilation system, as the very low energy house need, the moist air will be changed with fresh air and the indoor humidity controlled to avoid problems with moist and mould. The combination of an airtight building envelope and the integration of a mechanical ventilation system ensure that the very low energy house do not have problems with moist – neither in the constructions nor in the inside rooms.

**Acoustic indoor climate**

Acoustic indoor climate is concerning sound and noise impact such as reverberation time and external noise transmitted through the constructions, ventilations system and other places where there are leaks in the building. It is related to everything one can hear in the building – internal or external sounds.

The acoustic indoor climate in a very low energy house will generally be better than in a standard house because the very low energy house is insulated much more. The better the building envelope is insulated (and air tight) the better the building can reduce the noise from outside. When living in a very low energy house the sounds from traffic, neighbours and other noisy outdoor parameters will not be a problem for the reason that the building envelope will absorb the sounds before it reaches the inside of the building.

The internal acoustic have no relation to whether or not one lives in a very low energy house, but only to the furniture and materials in the building – the conditions are the same for all houses.

**Myth:** The mechanical ventilation system makes a lot of noise.

**Fact:** In very low energy houses there can be issues with the sounds from the mechanical ventilation system – air passing through the canals or the system working. It is not direct noise but sounds which are not present in the standard house why they can be perceived as noise until the occupants have become accustomed to them. Another issue with the ventilation system can be that sounds from one room are transmitted through the air canals in to another. This problems can be solved be installing a silencer between the rooms and also before and after the fan. Meaning that if the ventilation system is correct installed and the air velocity is set correctly the occupants will not experience problems with noise from the ventilation.

**Myth:** Very low energy houses have technology that is too complicated for the users.

**Fact:** The technology behind the concept of very low energy houses is complicated and hard to understand for the common man, but the areas where the occupants need to involve themselves ought to be understandable for the average house owner. It will take some adaptation to get used to the new systems and learn how to control them, but if the directions and information are sufficient and the occupants are willing to learn it will not be a problem. The information to the new homeowner should contain information on when and how his behaviour affects the energy consumption and indoor climate and through this make him aware of any undesirable behaviour and how he can change the settings if the need is there.

The myth is therefore not completely false because it is a complicated technology but as with every other new thing, one will have to get used to living in a very low energy house and learn new habits. The habits are however not complicated and the rules are easy to follow.
meaning that everybody are expected to be able to learn within a short period of time and live a perfectly normal life in an very low energy house.

**Lighting conditions**

In general, regarding electrical lighting, it can be claimed that there should be a difference between very low energy buildings and standard ones. Very low energy buildings should also have low energy lighting, e.g. high quality lighting fixtures (reflection-intensifying specular louvre lights) in connection with high efficient lamps (e.g. T5 tubular fluorescent lamps or for example LED-down lights), energy saving ballasts (electronic) or different control systems for adaption to the necessary lighting level by dimming. Dimming optimizes the daylight use and reduces the electricity consumption. 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.

Concerning very low energy buildings the following aspects might contribute negatively with respect to daylight utilization:

- Better window U-value means lower light transmission of the glazing
- Thicker walls (more thermal insulation) means poorer penetration of daylight

The challenge is to develop solutions for daylighting and solar shading that reduce energy consumption for lighting and cooling and still provide a high quality indoor environment [Arnesen].

White or light coloured interior walls reduce the demand for lighting [Kienzlen].

Løvåshagen cooperative housing, Bergen. The first dwelling block with passive house standard in Norway. Architects: ABO Plan og Arkitektur
HOW TO BUILD A VERY LOW-ENERGY HOUSE IN NORTHERN EUROPE

The challenge for the very low energy building design in northern Europe is the cold winter temperature and less sun in the winter time compared to conditions in Central Europe.

The principles of building a very low energy house in northern Europe can be defined quite 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.

In aiming to reduce the consumption of energy in new buildings, a five step strategy for low energy design is recommended, which was developed within the project ‘Cost effective low energy buildings’ (Dokka 2006):

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

The low energy design is in principle applicable to all low energy buildings. The process is of course to some extent iterative.

The starting point strategy for low energy design is the application of energy efficient measures to reduce energy demand, and then supply the remaining demand with an energy supply system utilising renewable energy sources.
Building site and window locations

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. Broad-leaved trees and planting in front of a building can help to reduce over-heating in summer. The distances between buildings should be optimised in a way that they do not shade each other.

A main window orientation from South-East to South-West enables effective winter time solar utilization. Glass size and type should be selected according to the climate, place and orientation.

In the summer the solar gains through large window areas increase the risk of overheating, which can be prevented by appropriate passive measures: balconies, optimized overhangs of roof structures and external solar shading.

Building shape

The compactness of a building body is one of the main features for a very low energy building. The compactness is given either as

- A ratio of the thermal envelope area to building volume, \( A/V \) [m²/m³] or as
- A ratio of the thermal envelope area to the floor area, \( A/A \) [m²/m²].

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 mean less square meters expensive thermal envelope to be invested in and maintained in the future.

Moreover, a compact building has in general less thermal bridges.

A high \( A/V \) ratio has to be compensated with more insulation at the envelope – or other improvements e.g. better windows and higher heat recovery efficiency.
Well-insulated and air-tight building envelope

A very low-energy house for a cold climate requires a high thermal insulation level. The house can be built of different building systems, and there is no special material dependence. 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.

Very low-energy house design requires accurate knowledge over the properties of building components. The effect of thermal bridges is more crucial in very low-energy buildings than in traditional buildings, because the relative effect of thermal bridges increases when the thermal resistance of the construction is increased.

The effects of thermal bridges need to be included into the calculation of transmission heat losses through the building envelope. Therefore the design bases on more accurate U-value calculations than, e.g., required by the building code. The following indicative requirements for thermal insulation of the building elements can help in the energy design of the house:

- wall ≤ 0.12 W/m²K
- floor ≤ 0.12 W/m²K
- roof ≤ 0.12 W/m²K
- window ≤ 0.8 W/m²K
- door ≤ 1.0 W/m²K

Examples of very low-energy house structures

Air-tightness of the building envelope, especially at connections between different elements (windows, doors) is extremely important due to energy consumption, moisture convection and condensation. The air-leakage of the house at 50 Pa (n₅₀ value) can be measured by means of a blower-door-test. The n₅₀ air-tightness value should be better than 0.6 1/h.
Energy-efficient HVAC systems

Beside the very good thermal insulation of the building’s thermal envelope, the attention must also be paid on the reduction of the heat losses due to the ventilation rate and distribution of heat and domestic hot water.

The ventilation rate is usually given by the building regulations and should provide a good indoor air quality. Typically air exchange rate is $n = 0.5 \text{ h}^{-1}$. As the reduction of the ventilation rate is not generally recommended, the only way to reduce the ventilation heat losses is to introduce the heat recovery of the ventilation. Because of the very low in/exfiltration rates of an air tight building, most the ventilation – and the losses, too – can be controlled. The ventilation loss is therefore the heat, which is not recovered by the air handling unit.

Therefore, the basic principles of the efficient installations in a very low energy house are:

- efficient heat recovery of the ventilation air
- short distribution distances
- well-insulated pipes, pumps and valves
- low temperatures
- systems with high efficiency in order to reduce auxiliary electricity

Cross-section of the top floor at Løvåshagen cooperative housing in Bergen. Solar collectors on the roof. A simple radiator 800-1000 W is placed in the hall that is open to the living room. The bathroom has under floor heating

Thermal mass and temperature zoning

Thermal mass of the building structures combined with sliding set points for heating system helps to utilize passive gains. The indoor temperature can vary freely inside the sliding scale, and structures can store or supply heat according to the indoor temperature. The required amount of thermal mass is not very high: a massive floor in a lightweight building is sufficient. However, the effect of the thermal mass on the energy demand of a building is not dramatic.

When designing a lay-out of a dwelling, it is preferable to place functions with heat production – e.g. kitchen – away from the rooms with major solar gains. In the same way, living areas with a preferable higher temperature should be placed in central areas with solar gains and areas with a preferable cooler temperature to the outer (northern) zone of the building.
COMPONENTS IN VERY LOW-ENERGY HOUSES

The low energy design always has to ensure good thermal and visual comfort. To reduce heating demand and need for cooling the following parameters are crucial:

- Site and geometry of the building
- Thermal envelope
- Solar shading
- Airtightness
- Ventilation
- Heating

Low energy components are important for all the above mentioned parameters.

Key considerations

In order to design and erect residential buildings with a very low energy demand, many or all of the following products are needed:

Envelope components which reduce heat loss and need for cooling:

- Thermal insulation, where the thermal conductivity should not exceed 0.05 W/mK
- Airtightness products of high quality
- Windows, where the U-value should be ≤ 0.8 W/m²K
- Glazing, where the g-value (solar transmittance) should be higher than 0.4 (40 %) and daylight transmittance higher than 0.5 (50 %). These values depend on the glazing area related to the façade and/or floor area.
- Solar shading
- Doors, where the U-value should be lower than 1.0 W/m²K
- Structural frame and construction elements, which minimize thermal bridges.

Examples of low energy wall construction with I-beam compared with the traditional solution. Source: Masonite Beams AB
Ventilation components which reduce heat loss and reduce electricity consumption:

- Balanced ventilation systems with fans (supply and exhaust air systems), where the SFP (specific fan power) should be less than 1.0 kW/(m³/s). The SFP value does of course depend on the design of the whole ventilation. The pressure losses in the ventilation system have to be minimized.
- Balanced ventilation systems with air-to-air heat recovery, where the energy efficiency should be higher than 80%.

Heating components which control and display energy consumption:

- Heat pumps with the ground, exhaust air or outdoor air as a source, where the COP (coefficient of performance) should be higher than 3.0.
- Heat distribution systems, which are suitable for very low energy residential buildings.
- Circulating pumps, with a low use of electricity, the efficiency should be better than 25% for one-family houses and 50% for apartment buildings at least.
- Domestic hot water heaters, with low standby losses.
- Control systems, which are suitable for very low energy residential buildings.
- Tap hot water fittings, which are energy efficient.

Other components which reduce electricity consumption:

- Household appliances, which should be of at least class A.

Components for renewable energy:

- Solar collectors.
- Solar photovoltaic cells.
- Biomass boilers.

Many of these components are needed in residential buildings. For very low energy buildings they furthermore have to fulfil high energy performance requirements, at least the above suggested levels.

**Envelope components**

**Thermal insulation**

The most common materials are mineral wool; fibreglass and cellulose, which all of them are used in low energy residential buildings. They all fulfil the recommended thermal conductivity 0.05 W/m K and are needed to reduce heat losses. The insulation is also applied as loose fill insulation. Polystyrene and polyurethane are used quite frequently in low energy residential buildings, but mostly only as ground insulation and occasionally as roof insulation. There are also some examples of using this material for wall insulation, sometimes alone or in combination with mineral wool. Transparent insulation materials are hardly ever applied. Vacuum insulation panels with a very low thermal conductivity are being tested in some low energy renovation projects. These panels have the advantage of a very low thermal conductivity, which results in e.g. thinner walls. Wall thickness (see figure 7.1) is an important topic, as thicker walls are «steeling» valuable area, indoors or outdoors. A vacuum
insulation panel 2-3 cm thick is equivalent to 10-15 cm of mineral wool. The panels are however currently rather expensive. Another insulation material with low thermal conductivity and higher cost is PIR (polyisocyanurate) insulation.

Airtightness products

Airtightness solutions and products of high quality must be used for vapour/air barriers, windows/doors, joining plastic vapour/air barriers, sill and foundation, sill and wall, floor structure lead-through, pipe through concrete, electrical outlets, spotlights, small pipes, between outer and inner pipes, ventilation ducts, stoves and connections to other materials (see figure 7.2). These products are needed to ensure good airtightness of the building envelope, which is necessary to avoid draft, moisture problems and ensure that all ventilating air passes through the heat recovery system. A study was recently made to survey the availability of airtightness products (Johansson 2010). The study concluded that there are several products and solutions available, but they can be hard to find. There are new and old airtightness products. The new ones are often good at airtightness but their reliability or durability is not always known. Workmanship is important for the final result, so therefore airtightness solutions must be easy to apply on-site.

Example of thick multi-layer construction of a low energy house. Source: efem arkitektkontor

Typical places, where problems with air tightness within a thermal envelope exist. Source: www.puuinfo.fi

Windows

The introduction of passive houses has meant that the availability of low energy windows (U-value less than 0.8 W/m²K) has increased. Low energy windows are needed to ensure low heat losses and to ensure thermal comfort even if there are no radiators below the windows in
low energy residential buildings. Quadruple-glazed windows with a U-value of 0.6 W/m²K, g-value of 0.45 and daylight transmittance of 0.59 are available. Triple-glazed windows with a U-value of 0.7 W/m²K, g-value of 0.50 and daylight transmittance of 0.71 are available. In low energy residential buildings quadruple-glazed windows are rarely used. Windows in low energy residential buildings are mostly triple-glazed.

**Solar shading**

Solar shading systems for the east, south and/or west facing windows are often needed to avoid high indoor temperatures during spring, summer and autumn. The systems can be e.g. Venetian blinds for installation inside, outside or between the panes. The solar shading is most efficient if installed on the outside. In some low energy houses the solar shading is solved with overhangs and/or solar control glazing.

**Doors**

Doors should have a U-value of at least lower than 1.0 W/m²K in order to reduce heat losses. Several door manufacturers sell doors with a U-value, which is better than 0.9 W/m²K. These are typically used in low energy residential buildings.

Structural frame components: These components should minimize thermal bridges in the building envelope, and must be used to arrive at a low overall U-value. Structural frame components, which minimize the thermal bridges are e.g. I-beams of Masonite and wood. Otherwise a very common solution in low energy residential buildings is multi-layer constructions.
Ventilation components

Balanced ventilation systems with heat recovery

The energy efficiency of the air-to-air heat recovery should be higher than 80% in order to reduce heat losses for ventilation. A common air-to-air heat exchanger in passive houses is the counter flow heat exchanger. In low energy apartment buildings rotary regenerative heat exchangers are sometimes used. In a low energy building the ventilation can be a source of an important part of the heat losses, unless heat recovery is installed.

Balanced ventilation systems, fans

The mechanical ventilation system (supply and exhaust air systems) should have a SFP (specific fan power) less than 1.0 kW/(m³/s), to avoid excessive use of electricity for ventilation. This means that efficient fans must be used. The use of electricity does not only depend on the choice of fan, but also on the design of the whole ventilation system. The pressure losses in the whole system have to be minimized. The fans are preferably DC-EC fans. EC stands for Electronically Commutated and it combines AC and DC voltages, bringing the best of both technologies: the motor runs on a DC voltage, but with a normal AC supply. DC motors already have low power consumption but if used in an AC application, the power needed converting AC to DC, using a bulky, inefficient transformer. The EC motor incorporates voltage transformation within the motor.
Heating components

Heat pumps
These are recommended to have a COP (coefficient of performance) higher than 3.0. The heat pumps are either ground-to-water, air-to-air or air-to-water heat pumps. The ground-to-water and air-to-water heat pumps can be used either for domestic hot water or space heating or both. The air-to-air heat pumps can provide space heating. The heat pumps must not be under- or oversized for a low energy building. Heat pumps using outside air as a heat source can be insufficient in the cold climate of North European countries, as there is little heat to gain from cold outside air.

Heat distribution systems
The system should be suitable for very low energy residential buildings, which means it should be possible to supply and distribute the small amount of heat required in low energy buildings. Many of the passive houses are heated by the supply air, which means that the air needed for ventilating purposes is also a heat carrier. Some low energy buildings are heated by one or two radiators per apartment.

Circulating pumps, with a low use of electricity should be installed. In very low energy residential buildings with a hot water central heating system a circulating pump is needed, which should have a low use of electricity. The efficiency should be better than 25 % for one-family houses and 50 % for apartment buildings.

Domestic hot water heaters, with low standby losses should be installed. Standby heat losses during the summer are of little use.

Control systems, which are suitable for very low energy residential buildings must be used. These systems are able to control the small amounts of space heating required in a low energy residential building. No heat should be squandered and thermal comfort should be guaranteed, assuming the building envelope is well insulated and airtight. The user interface must be user friendly.

Tap hot water fittings, which are energy efficient, should be used. Such taps exist since a couple of years, ensuring a reduced use of domestic hot water.

Renewable energy components
Of importance when selecting the energy source is the greenhouse gas emission from the energy source and the use of primary energy. This means that renewable energy sources should be considered.

In a low energy residential building the energy need for space heating is very low. An important part of the energy need can be heating of domestic hot water, which preferably can be done by solar energy (solar collectors). In the Nordic countries at least half of the energy needed for domestic hot water heating can be covered by solar energy obtained from solar collectors installed on the roof.

There is a range of renewable energy components which can be used for heating and generating electricity e.g. biomass boilers, solar photovoltaic cells, which have a low impact on the environment.
**Other components**

Household appliances: These appliances should be of at least class A, in order to reduce the use of electricity and to minimize internal gains during summer.

**Availability of components**

Most components needed for very low energy residential buildings are available on the markets in the participating countries i.e. thermal insulation, airtightness products, windows, doors, solar shading, structural frame components, ventilation systems, heat recovery systems, heat pumps, heat distribution systems, pumps, control systems, household appliances, tap hot water fittings, biomass boilers, solar collectors and photovoltaic. However, in the Baltic States some airtightness products are not yet available. The available components obviously have to better marketed, to ensure that e.g. more designers know that they are available.
EXAMPLES OF VERY LOW-ENERGY HOUSES

Denmark – Komforthusene

In the area of Skibet near Vejle, Isover has built 10 low energy houses in close collaboration with actors from the building sector, Zetra invested and Middelfart Bank. The target for all 10 houses was that they should be certified after the German passive house standard and there should be a particular focus on indoor comfort. One of these houses as described here was designed by architect Jordan Steenberg, built by Lunderskov Nybyg a/s, and Cenergia has been energy consultant.

Technical features

The house is a brick construction of 163 m$^2$ living area in one floor level. The house is insulated with 400 mm insulation in external walls, 500 mm in the ceiling and 550 mm polystyrene floor. Cold bridges of all joints are minimized to a minimum, and the air tightness is 0.5 per hour at 50 Pa pressure.

The house is heated with floor heating and ventilation air via a heat pump with energy from soil pipes and exhaust air. There is amechanical ventilation with heat recovery with preheating of fresh air in 40 m soil channels.

Energy demand

Energy demand has been demonstrated by one year of measurements and shows that the house meets the requirement of passive house standard.

Costs

The house is conceived as a standard house from the contractor's program for roughly the same price. It is a house that could fit into many different housing estates. The first estimate showed 40 % extra cost of technical qualities compared to a standard house, 6 % for additional energy saving measures and 6 % for consultants. The finished house is sold at ordinary market conditions.

Concluding remarks

A simple building concept has been chosen to minimize the risk for thermal bridges. A unilateral pitch has been chosen to get a more modern look and to get the most possible daylight from the south. Generally, the house is built in high quality with an attractive architectural design. There is no solar heat as this was not necessary to meet energy requirement of the passive house.

More information

Finland – Passive house in Hyvinkää, Finland

The house is a traditional house made by the company, Herrala-houses. Its energy performance has been improved to meet the passive house level. The house is located in a new residential area in Hyvinkää, South Finland, and it looks like the other houses in the area.

A family of three persons moved into the house in summer 2010.

**Technical features**

The space heating is provided by electric radiators, because the heating energy need is very low. Heat is recovered from exhaust air, there is a storing fire place and a solar collector is used for heating of domestic hot water. The cooperation of the insulation manufacturer and the Herrala-houses worked well and best available insulations were used. The windows are special low energy windows. They have high-quality composite frames and four glasses. Air-tightness: $n_{50} = 0.6 \text{ l/h}$. 

**Energy demand**

The calculated space heating energy demand 18 kWh/m$^2$ fulfils the Finnish passive house criteria of VTT for South-Finland, 20 kWh/m$^2$.

**Costs**

This house is a traditional wooden house. The investment costs were only 10 % higher compared with a traditional Herrala house without any changes. The construction work needed more time as planned so that the additional costs rose from 5 % to near 10 %. Especially for the good level of thermal insulation and for the air-tightness of the envelope a lot of time was used. If an identical house would be built again, a 5 % additional cost would be achieved along with the experience.

**Concluding remarks**

There are not any complaints about the quality of the house after a short living period. Adequate experience of indoor temperatures doesn’t exist because the house is just built. When the family moved into the house, the weather was very warm but there was even cool in the house. So at the moment it seems that the interior temperatures are not too high in the summer and the cooling with the supply air is enough. The real performance of the house will become evident when the residential experiences are increasing. The passive house has had a very positive influence on the neighbours and also other people. There has been arranged some presentations for neighbours and other people (open days). The house seems to attract a lot of attention.
Norway – Loevaashagen cooperative housing, Bergen

Loevaashagen cooperative housing was constructed in Bergen in 2008. This was the first apartment building with passive house standard to be realised in Norway. The project consists of 28 apartments in two 3-storey building blocks.

Loevaashagen cooperative housing consists of low energy houses and passive houses. The passive houses are seen in the front. Illustration: MIR/ABO Architects

The passive houses have solar collectors on the roof. Photo: ABO Architects

Technical features
- Air tight and super insulated envelope solutions, double wood frame construction (walls) and I-beams (roof), cold bridges avoidance
- Passive house windows, total U-value < 0.8 W/(m²K)
- Vacuum solar collectors, type Apricus (German)
- Simplified water based heating system (Norwegian)
- User friendly demand control system

Main actors involved were Bybo (developer), ABO Architects, CTC (heating system), NorDan (passive house windows), and SINTEF Byggforsk as expert advisers. The project received financial support from The Norwegian State Housing Bank and Enova, a public enterprise aiming for energy efficiency and new renewable energy.

Energy demand
Net total energy demand are calculated to 65 kW/m²/year, of which 13 kWh/m²/year are for space heating. Air leakage of the envelope is measured to n₅₀ < 0.6 ACH.

Concluding remarks
Loevaashagen cooperative housing stands as a successful result of an integrated energy design process. The costs for additional measures compared to conventional building are calculated to 1.000 NOK/m² (~ 122 Euro/m²). The apartments were sold at normal marked price.

The simplified water based heating system is developed in laboratory in Norway, and is applied for the first time in these passive houses.

More information
In Norwegian: [http://www.arkitektur.no/?nid=166292&lcid=1044](http://www.arkitektur.no/?nid=166292&lcid=1044)
Sweden – Värnamo passive house

In Värnamo, 40 apartments, divided in five buildings, have been built, of which two buildings have two floors and three buildings have 2.5 floors. The houses are built according to the Swedish passive house criteria. In a preliminary phase the apartments were planned as traditional apartments regarding energy use, but information about passive houses made Finnvedbostäder interested in building passive houses.

The project was also followed by Lund Technical University and was reported in a doctoral thesis in 2010 by Ulla Janson.

Technical features

The total isolation thickness of the exterior walls is 425 mm. U-value is 0.10 W/m²K. The air tightness target 0.2 l/s/m² (by +/-50 Pa), was met according to measurements. Windows have a U-value of 0.95 W/m²/ °C. Doors have a U-value of 0.60 W/m²K.

Each apartment have an own FTX-aggregator placed in a cupboard. The aggregator has an efficiency of 85 %, in the initial performance. During the cold days, a 0.9 – 1.8 kW electric battery helps in warming the supply air. The electricity is procuced by a wind power plant.

There are 125 m² of solar collectors, which includes 3.1 m² of solar collectors per apartment.

Energy demand

The measured energy use for heating, warm water and electricity is approximately 39 kWh/m²/year (27% solar collectors and 63% electricity). Energy use for ventilation is 7 kWh/m².

The yearly household’s electricity use, including ventilation, has been measured as 34 kWh/m²/year, which is somewhat higher than the assessed 30 kWh/m²/year for multi-apartment building. The total purchased energy is 72 kWh/m²/year. The solar energy contribution in warm water is 10 kWh/m²/year.

Costs

The building costs were approximately 17 900 kr/m² (year 2006), which can be compared with the construction costs for traditional apartments of 15 000 kr/m², according to Finnvedbostäder.

Concluding remarks

A detailed requirement specification was prepared, which made it easier for the contractor to know what was expected. According to measurements, the acoustic level from the ventilation system was rather low, due to the placement of the machinery. The measured energy use for heating is very low. The measured indoor temperature is within the comfort zone, almost the whole year. Too high temperatures are avoided because of the solar shading.
Estonia – Valga kindergarten «Kaseke»

In 2009 the building was reconstructed from a soviet-time energy-wasting panel house from 1966.

Technical features

The building has solar collectors on the roof which provide energy for hot water system and room heating. It is the first time in Estonia that a solar thermal system is the central heating system for the whole building, with additional heating coming from the district heating, also stored into the accumulation tanks if needed.

- Insulation: External walls: 370 mm of glass wool insulation + 25 mm softwood board. Roof: 500 mm of glass wool of different weight. Ground floor: 300 mm of polystyrene boards.
- New ventilation systems were installed with heat recovery (efficiency 82%).
- Static horizontal solar protection screens on south facing windows.
- Measured n50-value: 0.47 l/h.
- The building is heated via fresh air using water to air heat exchangers.
- The central heating system consists of three connected 1500 litre solar accumulation tanks that are heated via solar thermal collectors and city heating grid if necessary.

Energy demand

Before the reconstruction the houses net heating energy demand was approximately 250 kWh/m²/a, with renovation it is calculated with PHPP2007 calculation software to be approximately 40 kWh/m²/a.

Costs

After completion the total costs were compared to the costs for refurbishment according to existing national standards. An increase of the construction costs for about 15–20% was stated, but in return a decrease in the energy demand of 6–7 times was achieved.

Concluding remarks

The main reason why Valga Municipality decided to implement a passive house pilot project is promoting remote area at the border through introduction of an innovative technology. Now Valga has received a lot of attention and positive reputation as competence centre of such an important topic as cutting energy costs and environmental impact.
Latvia – Gaujas 13, Valmiera

A 9-storey building with 36 apartments was renovated in the autumn 2009. The concrete panel building was built in Soviet times and had poor insulation. Renovation was done by Energy Service Company (ESCO).

Technical features

- Wall insulation with 100 mm rock wool.
- Insulation of basement with polystyrene.
- Insulation of attic with 200 mm heat insulation.
- Change of old windows.
- Change of heating system.
- Change of hot water system (decreasing the length of hot water pipes).
- Installing monitoring system.

Energy demand

Energy consumption for space heating and hot water preparation has decreased by 50%. The indoor air temperature has increased by 1 to 2 °C (now reaching 21.5 °C).

Costs

This project was partly financed by EU funds available for improving energy efficiency in residential buildings. The reached energy savings guarantee that economically this project will pay back faster than the period of ESCO contract (20 years).

Concluding remarks

This project was implemented by ESCO. The inhabitants agreed to this project because there was need for new heating and hot water systems and the roof was in need of repair. Further; there was a wish for improvement of the indoor air quality and the visual look of the building. Technologies used in this project were well known in Latvia before, but the goal set for this project was to ensure the energy savings to be greater than in other projects in Latvia.

More information

Lithuania – Renovation project at Žirmūnų street 3 in Vilnius

Comprehensive renovation of an apartment building from 1965. The renovation concerned the external walls, windows, stairs, outer doors, roof, balconies. Inner and outer engineering networks were modernised, and outdoor area were upgraded. The major construction works were carried out from June 2005 to July 2006.

Renovation purposes

- Improve the living environment and comfort.
- Refresh the aesthetic apperiance of the house and its environment.
- Reduce heat losses through external walls, windows, roof and increase heating system efficiency.
- Reduce the absorption of moisture into external walls and prevent the wear of facades.
- Extend the lifetime of the house and increase its market value.
- Provide suggestions for improvement of renovation of other large block construction houses after summarising the renovation results.

Concluding remarks

The progress of the works was complicated by the fact that the dwellers of the house were not moved out during renovation, therefore, difficulties have been experienced as to the coordination of time necessary for entering the apartments. Lack of workforce and possibly lack of experience on the part of the builders were other difficulties encountered during the implementation of the first multi-dwelling house renovation project of that scale. Nevertheless; to summarize this model project it can be stated that all objectives envisaged for renovation have been achieved in substance, and the dwellers received a house of completely fresh quality and comfort.

Dwellers of the neighbouring multi-family buildings, inspired by renovation works at Zirmunu Str. 3, also expressed their wish to participate in the programme «Renovate the housing - Renovate the city».

More information

Poland – Lipińscy Dom Pasywny 1, Wrocław

The first certificated passive house in Poland was built as a demonstration project. The basic goal of the project was adaptation of being in force passive standards to the local climate conditions of Wrocław. A small passive house is added to the international base of Built Passive House Projects and certified according to PHI procedures as a first from Central and East European countries. It also took part in international Passive House Day.

Technical features

Technologies applied in the building are thermal bridges free construction elements, high efficient insulation materials, tripe glazed windows, airtight solutions, mechanical ventilation with heat recovery, solar collectors, air to ground heat exchanger, compact heating tower. Some of these technologies were used for the first time in Poland.

This building causes much lower emission of GHG than in case of standard building. If we assume that in standard building natural gas is being used as heat source, and in passive building electrical energy, the emission will be two times lower. The building uses also renewable energy sources like solar energy for DHW heating and energy accumulated in ground for preheating of ventilation air. Half of the heating energy demand is supplied by solar collectors.

Energy demand

The estimated energy performance of the house is as follows:

- Yearly space heating demand is 15 kWh/m²a. The same house built according to Polish regulations uses 123 kWh/m²a, i.e. eight times more.
- The demand for heating of domestic hot water is 14 kWh/m²a, which is two times lower than a standard house.
- Primary energy demand is 105 kWh/m²a. This amount of energy is enough for space heating, preparation of DHW, lightning, cooking and work of electrical devices. A house built according to standards use about four times more primary energy.

Costs

Unfortunately; the cost-effectiveness evaluation have shown that the difference in construction costs (in this case about 40 %) between passive and standard building, is higher than in West European countries. Therefore it is necessary to find out what is the best energy standard for polish market and climate conditions.

Concluding remarks

The project has shown that is possible to construct a building with very low energy consumption also in colder climate conditions. The project has contributed to the promotion and development of sustainable housing in Poland. The problem was the higher difference in construction costs, which can probably be reduced by optimization of building design.
REFERENCES


