Implementing zero energy buildings in harsh Nordic climate conditions

Author Pasi Käkelä, SPU Oy, P.O. Box 98, FIN 33500 Tampere. pasi.kakela@spu.fi

Author Antti Viitanen, SPU Oy, P.O. Box 98, FIN 33500 Tampere. antti.viitanen@spu.fi

Author Kenneth Finnäs, SPU Isolering AB. kenneth.finnas@spu-isolering.se

Abstract

Essential part of zero energy buildings is energy production at the building level. However in the northern climate conditions solar power is least available when the demand for heating energy is the highest. Therefore the design of the building envelope as well as design of the HVAC system is critical to minimize energy consumption and keeping the building cost feasible. The paper represents, through real life examples, possible ways to implement zero energy buildings in Nordic climate conditions. Kuopas apartment building in Kuopio Finland is able to generate 98% of total energy demand on-site. The cost difference to a similar building fulfilling the 2010 Finnish building code is 10%. Technical feasibility of zero energy buildings has been verified, but further development of energy production can bring the overall building cost down.

Keywords: Zero energy building, building envelope of zero energy building, zero energy HVAC systems, Kuopio zero energy building

1. Introduction

The EU commission recently adopted the new building energy performance directive [DIRECTIVE 2010/31/EU, 2010]. According to the directive all new buildings have to be built to nearly zero energy level by 2020. In Finland, the Ministry of the Environment has set a roadmap for the development of energy efficiency of buildings. The target is to build only nZEB by 2017, three years early from the 2020 deadline. This roadmap is part of the ERA17 (Energy-smart built environment 2017) project that aims for energy-efficient, low emission, high quality built environment that employs all necessary means to mitigate climate change.

The basic principle of net zero energy building is that it produces the same amount of renewable energy that it consumes during an average year. The building is sill connected to electricity or district heating grids to balance the energy consumption and energy production. In practice in Nordic countries the building produces more energy than needed during the summer months and that energy can be sold to other users through the energy grids. In winter months the energy balance is negative.

Implementing zero energy buildings creates challenges in the northern European climate conditions. Solar power is often used for the energy production at the building level. Nevertheless in the northern climate conditions solar power is least available when the demand for heating energy is the highest. Therefore the design of the building envelope as well as design of the HVAC system is critical to minimize energy consumption. Recent projects in Kuopio [Vartiainen, 2010] and Järvenpää [Simunaniemi, 2010] as well as in Mäntyharju, Finland, introduce the implementation challenges and opportunities very well in Nordic climate conditions. There are also in other Nordic countries good pilot cases which could have been choisen, like Vallda Heberg I Kungsbacka (NCC). Buildings fulfill passive house standards and have many different structure types.

2. Case studies used in this paper

The Kuopas apartment building in Kuopio, Finland was the first commercially built net zero energy building in Finland. It is four storey apartment building consisting of 47 apartments for disabled students. The project was completed in Feb 2011. Similar building in Järvenpää with 44 apartments for elderly people will be used to compare building costs. The Järvenpää building is very similar to the Kuopas building in terms of structures and technical systems and therefore Järvenpää building will not be presented here in detail. Järvenpää building will be completed in May 2011.

Figure 1 Kuopas zero energy building in Kuopio, Finland.

Single family home in Mäntyharju represents an example of a smaller zero energy building in this paper. It will be completed in May 2011.

The energy consumption and balance values of these two apartments presented in this case study are calculated values during the development and designing process. Both apartments are reference buildings and the real energy consumption and balance are constantly monitored in real time.

The main energy calculations were made among the others with IDA-ICE software, a dynamic indoor climate and energy consumption program that offers wide variety of different HVAC and energy simulations. The program is a component based simulation program that is widely used in Finnish energy consumption calculations. The components of the software are developed mainly in Aalto University Finland and Kunglike Teknniska Högskolan.

The real time energy consumption and production values can be observed from projects web-site: http://www.nollaenergia.fi (in Finnish).

Figure 2 The building in Mäntyharju is a single family home with 150,5 m2 of floor space.

3. Building envelope

Since energy production using solar power is very inefficient and expensive in Nordic countries, the minimization of energy consumption is the first design principle.

The basic methods to minimize thermal losses and air leakages of the building envelope are:

- increasing amount of insulation and avoiding thermal bridges, i.e. lower U-value of structures
- lower conductivity-value of windows and doors
- smaller area of windows and doors and window placement
- air tightness of all elements of the building envelope
- paying attention to details, e.g. joints and inlets
- careful implementation

In all examples the U-values used in the wall construction are 0,08 W/m^{2}K and in roof 0,07 W/m^{2}K in Kuopio and Järvenpää buildings and 0,06 W/m2K in Mäntyharju building. Insulation has been implemented using polyurethane boards to keep the structures as thin as possible and to ensure risk-

free hygrothermal performance of the structures. The water vapor resistance of polyurethane boards used in these structures is > 4000 x 109 m2sPa/kgm and water absorption in RH 100% about 0,2 volume% making them ideal for designing risk-free structures. The hygrothermal performance of the structures has been widely studied [SPU 1, 2009 and SPU 2, 2010]. The used structures represent no risk of mold growth. Furthermore they represent no increased risk of moisture problems due to better U-values.

In addition, the closed cell structure and diffusion tight facings of the polyurethane board guarantees same safe hygrothermal performance for both directions of moisture and heat. This is very beneficial in Nordic climate, where weather conditions varies widely from hot summer days to extreme cold.

The wall construction of all buildings is concrete sandwich element and the only thermal bridges are the trusses holding the sandwich elements together. The Finnish building code [Suomen rakennusmääräyskokoelma G1, 2005] defines that in apartments the window area has to be at least 10% of the floor space. U-value of windows used was less than 0,8 W/m2K and windows represent about 10 times higher heat loss per area compared to wall structure, the window area has been kept minimum to about 10%.

Air tightness of the structures and joints was of special attention from the beginning. The air tightness design target of the Kuopio building was n50-value of less than 0,4 1/h and. The measured n50 values were: 0,4 for the Kuopio building and 0,33 for the Järvenpää building. The joints and seams have been made air tight by applying multiple layers of one-component polyurethane foam.

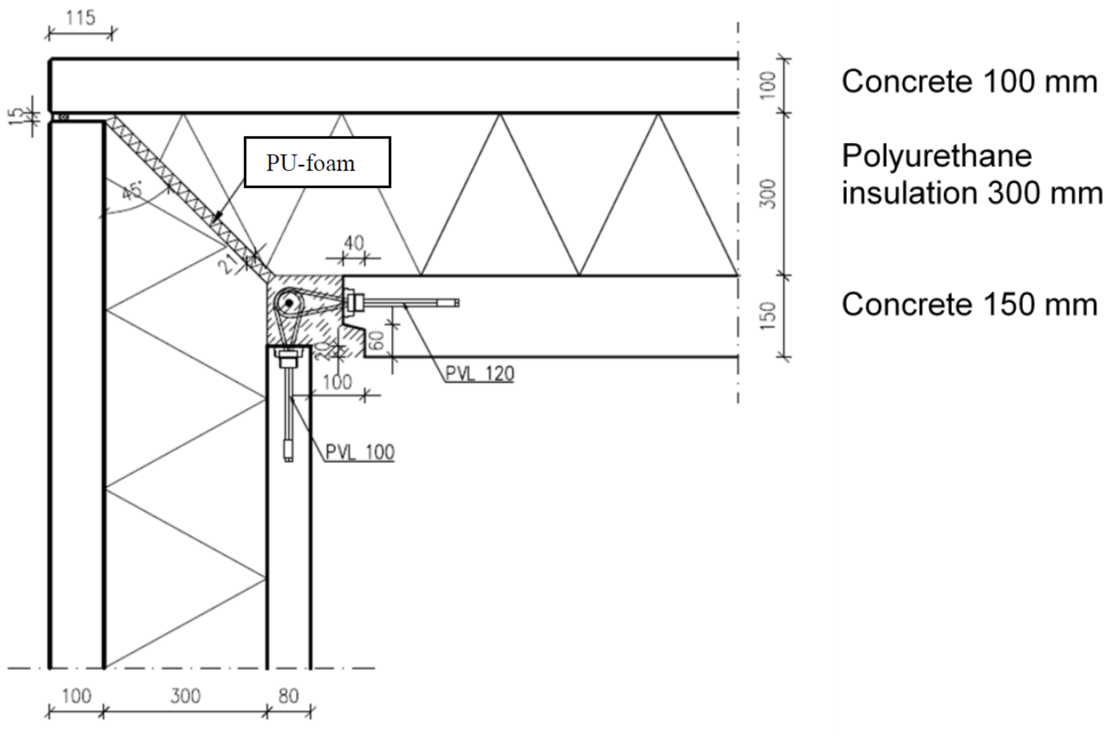

Figure 3 Wall construction used in Kuopas building [Rakennustoimisto Nylund, 2010]

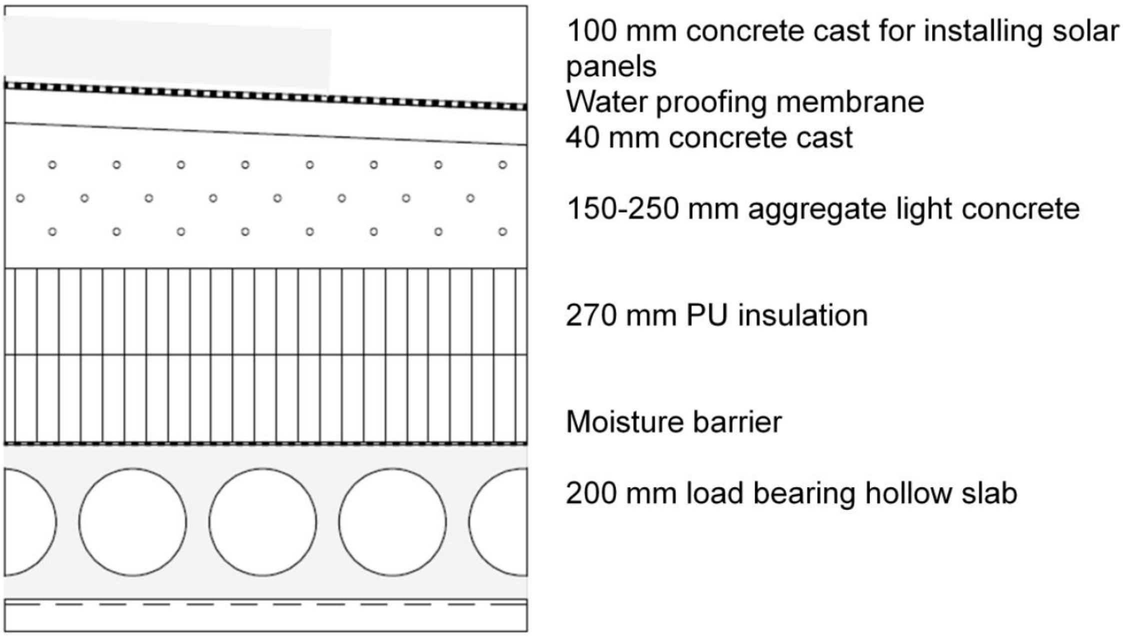

Figure 4 Roof construction used in Kuopas building [Rakennustoimisto Nylund, 2010]

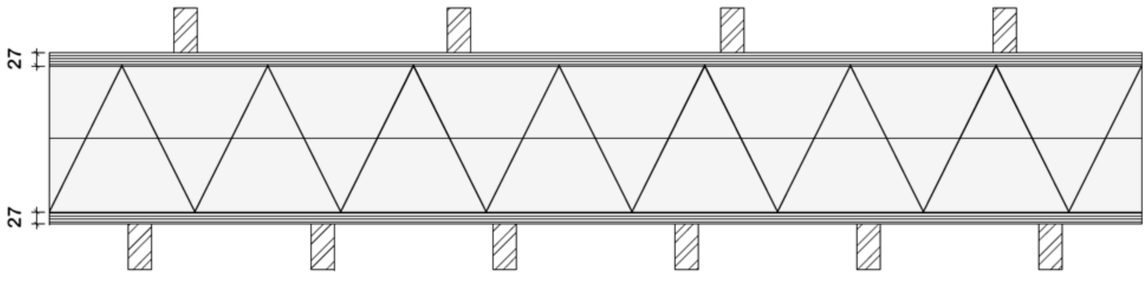

Figure 5 Wooden sandwich roof element used in Mäntyharju building [SPU 3, 2009]. Structure: Kerto S-beam 100 mm - Kerto Q-plate 27 mm - PU insulation 320 mm - Kerto Q-plate 27 mm - Kerto S-beam 100 mm

Roof construction of the Mäntyharju building was made of composite wooden sandwich elements manufactured with 320 mm of polyurethane insulation and completely without thermal bridges.

4. HVAC systems

Ventilation typically represents the biggest portion of heating energy consumption and therefore the design principle is to utilize mechanical ventilation with as efficient heat recovery as possible. Typically the heat recovery is using either rotating or counter-flow plate heat exchanger units. In the Kuopio building the counter-flow plate heat exchanger units are utilized, providing with about 73% heat recovery efficiency. In Mäntyharju building rotating heat exchanger with annual efficiency of 75% unit is used. The actual heating of the apartments is implemented using floor heating and warming the incoming air.

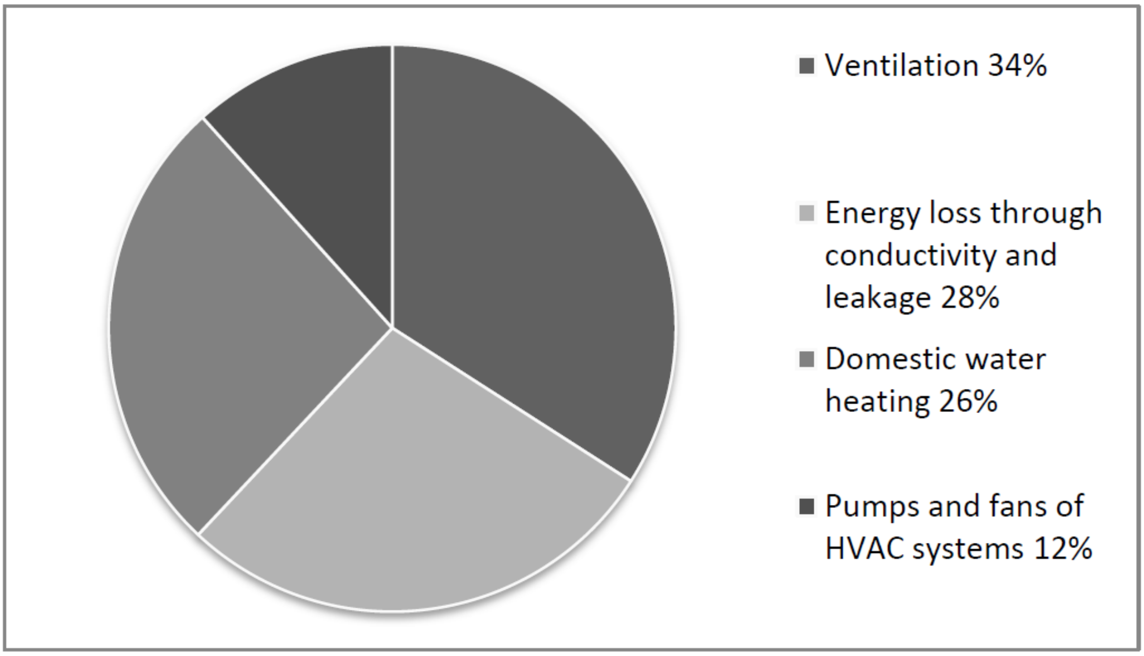

Figure 6 Energy consumption of Kuopas building as a percentage of total energy consumption [Insinööritoimisto A.Mustonen, 2010]

In the Kuopio building domestic hot water heating represents roughly one fourth of the total energy consumption. Key is to reduce the total consumption of domestic hot water by giving residents feedback about their water consumption and bill them for their water consumption. In the Kuopio case it is done by measuring and billing domestic hot water consumption separately in all apartments.

It is also worth noting that electricity represents only 12% and heating energy 88% of total energy consumption in the Kuopio building.

In Kuopio building the space heating demand is 10,6 KWh/ m^2/a and in Mäntyharju building 20 KWh/ m^2/a.

5. Energy production

By definition net zero energy building must produce as much energy as it consumes in an average year. In Kuopio building solar water heating, solar electricity and geothermal heating/cooling are used for energy production. Geothermal energy is used in winter for pre-heating of incoming air to ventilation system and in the summer to pre-cooling of incoming air.

This geothermal system involves no heat pump but only circulator pumps to circulate the fluid in the closed system. Cooling of the building during summer months is done entirely by geothermal cooling.

Altogether 72 pcs, 108 m2 of electricity producing solar panels and 35 pcs, 126 m2 of water heating solar panels are utilized.

In the Mäntyharju building energy is produced by solar water heating, solar electricity and air-to-water heat pump.

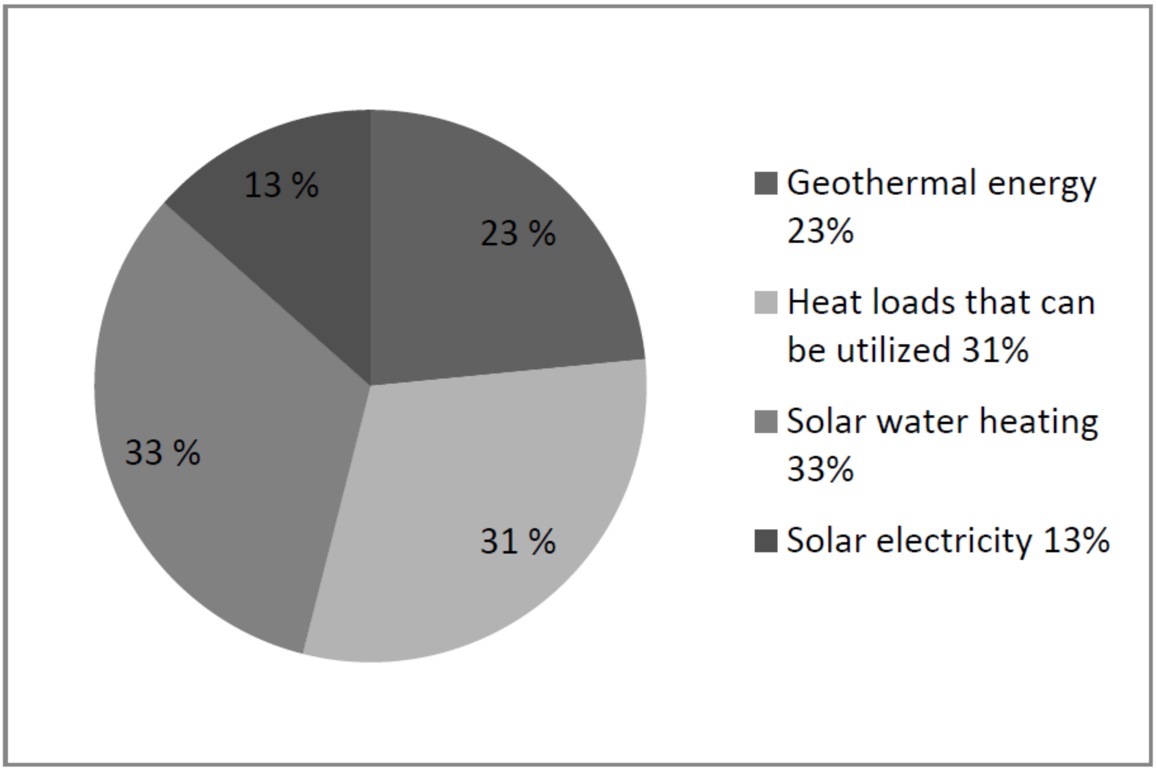

Figure 7 Energy production of different systems of the Kuopio building as percentage of total energy production. [Insinööritoimisto A. Mustonen, 2010]

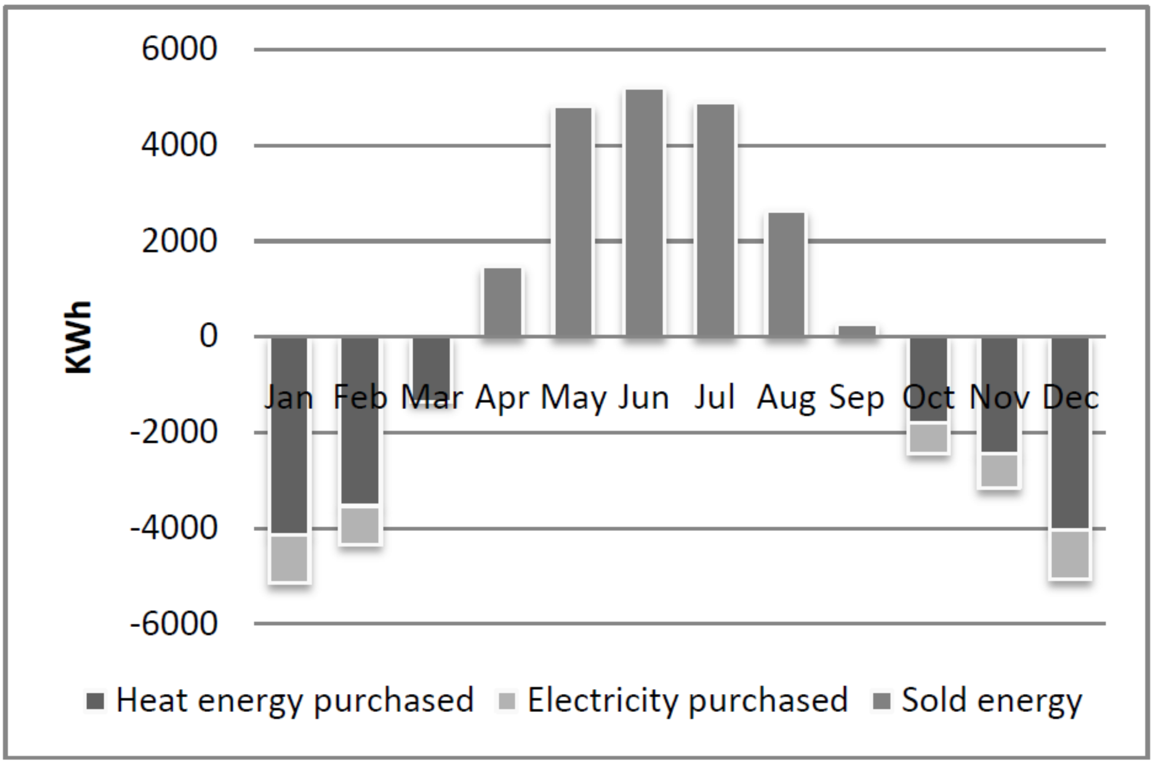

Figure 8 Monthly balance of energy (KWh) produced on site and sold to grids of the Kuopio building during different months of a year. [Insinööritoimisto A. Mustonen, 2010]

Kuopio building is connected to both electricity and district heating grids. Fig 8. shows the balance of purchased and sold energy during different months of a year. Total energy consumption is balance is -2292 KWh per year.

Large scale implementation of such buildings will represent challenges to balancing of energy grids. Based on [Saari A. et al., 2010], many problems of the small scale electricity production can be avoided by feeding the electricity production close to transformer. In terms of district heating grids, one possible solution would be to consider group of buildings as one energy production and consumption block and use buildings different energy usage and consumption patterns to balance energy production and consumption. Warm water storage could be used to balance production and consumption during different times of the day.

6. Cost considerations

According to the owner Kuopas Oy, the building cost of the Kuopio building has been calculated at 2700 €/ floor m2, and comparable building built to fulfil the 2010 Finnish building code about 2450 €/ floor m2. The added cost from zero energy construction was about 10% in the building cost.

In the Järvenpää zero energy apartment building cost was 2870 €/floor m2. In comparison, cost of renovation of 1983 built apartment building for elderly residents next to the new building was 2530 €/floor m2 [Simunaniemi, 2010]

When aiming for zero energy building, the added cost to building envelope is quite small. Since the Finnish building code requires outer wall U-value 0,17 W/ m2K the additional PU-layer required to achieve U-value 0,08 W/ m2K is 150 mm. The cost of this layer can be estimated to be about 20 €/m2. The added cost to windows, when they are upgraded from building code level U-value 1,0 W/m2K to zero energy level U-value 0,8 W/m2K is about 40 €/ m2. These estimates are based on average market prices from several manufacturers, without taking into account potential effects to other building elements.

It can be concluded that most of the cost difference is related to the energy production. It is also important to remember that these projects are pilot projects and therefore the added cost will most likely reduce with the further development and mass production of the concept.

7. Conclusions

Since the buildings account 40% of total energy consumption in EU [DIRECTIVE 2010/31/EU], they represent very significant opportunity to reduce greenhouse gas emissions. Three recent examples of zero energy buildings implemented in Finland show the feasibility of zero energy buildings even in very harsh Nordic climate conditions. The Kuopas apartment building is situated in Kuopio, where the annual average temperature is only less than 3 degrees centigrade [Ilmatieteen laitos, 2010], is able to produce about the same amount of energy that it consumes. Careful design of building envelope to minimize thermal conductivity and air leakage as well as energy efficient ventilation and control of hot water consumption are used to minimize the energy consumption. Renewable energy sources such as solar electricity, solar water heating and geothermal energy can be used to produce energy. Cost of examples also shows that the building cost is about 10% higher compared to a similar building fulfilling 2010 Finnish building code in energy efficiency.

Since most of the added cost is related to the technical systems and energy production, further development and study of these systems is necessary to reduce overall building cost. Possible ideas to study further are, production of energy at building group level and alternative ways to produce renewable energy such as utilizing bio fuels.

It is also worth considering concepts, where energy production is not included from the beginning. Building envelope design can be done according to the zero energy standards and the technical systems can be designed to accommodate energy production, which can be introduced at later stage, when energy production technologies will become more inexpensive. This would allow lower cost of "future proof" buildings.

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