Is it possible to achieve zero energy demand while rebuilding multi-dwelling buildings?

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Introduction

In the newly recast directive on the energy performance of buildings (2010/31/EU), there is a demand that "nearly zero-energy buildings" are to be a requirement for the construction of new public buildings from 1 January 2019 and for all new buildings from 1 January 2021. In addition, the member states are to undertake the measures needed to ensure that when buildings undergo a major renovation, the energy performance of the building, or the renovated part of the building, is improved so that it meets the minimum requirements regarding energy performance to the extent that this is technically, functionally and economically feasible. The requirement is to be applied to the renovated building, or the renovated unit, as a whole. The member states are to stimulate the transformation of buildings that are being renovated into nearly zero-energy buildings.

In order to achieve such a change, a number of measures that promote this aim are needed, as well as a stricter set of guidelines for construction and rebuilding. The Swedish Energy Agency has developed a strategy for the implementation of the recast energy directive that was submitted on 18 October 2010 to the Ministry of Enterprise, Energy and Communications. In the strategy, target levels are proposed for the promotion of nZEB (nearly zero-energy buildings) for major renovations of buildings in accordance with **Table 1**. The levels refer to the highest permitted energy use.

Electrically-heated buildings are buildings in which the installed electric power for heating is greater than 10 W/m². Installed power is the total electric power that can be received by the electrical heating appliances that are needed to maintain the intended indoor climate, domestic hot water production and ventilation when the maximum power needs of the building prevail, that is, during the design outdoor winter temperature.

Table 1. Proposed levels for the highest permitted energy performance in renovated flats, the so-called nZEB requirements (kWh/m², year).

Building	Annual energy use for heating, comfort cooling, domestic hot water provision and other shared services in the building (kWh/m²)		
	Climate zone		
	I	II	III
Flats that have a heating system other than electric heating	105	90	75
Flats with electric heating	70	55	40

At the same time, the National Board of Housing, Building and Planning has produced new building regulations that are to apply when changes are made to buildings. These regulations are currently under consideration. Demands are made in part at the component level and in part for the entire building during major renovations.

Rapid change is needed in the renovation concept

Taken together, the above entails a large and rapid change for the construction and real estate sector, together with its suppliers of components and energy. In order for the sector to be able to prepare effective renovation concepts with relevant energy-efficiency measures in combination with effective heating techniques, a thorough impact analysis is needed of some representative existing multi-dwelling buildings. Based on the results of such an impact analysis, different renovation concepts can be developed for the building types that represent substantial parts of the existing stock. The impact analyses is financial supported by The Swedish Energy Agency's R&D program for resource effective cooling- and heating systems, called EFFSYS+.

Many of the modernist, multi-dwelling buildings built in the boom years between the end of the Second World War and the start of the oil crisis require and are awaiting substantial renovation work. The next opportunity after this for profitable rebuilding may not be available for another 40 years. To motivate complete renovation concepts in place of separate component measures, new

renovation concepts need to be developed that manage a renovation down to the nZEB level.

If new renovation concepts down to nZEB are used during all rebuilding works involving multi-dwelling buildings until 2020, there is an energy-saving potential of 1–2 TWh annually. The technical potential, that is, the potential with an increased pace of rebuilding, is considerably higher.

Multi-dwelling buildings in Sweden

About half of the population of Sweden lives in multi-dwelling buildings. These contain approximately 2.4 million flats, with a total of about 180 million square metres. In 2009, the multi-dwelling sector used about 26 TWh for heating and domestic hot water provision. Heating was dominated by district heating, which represented 84% of the total heated area. Of the total energy use for heating and domestic hot water provision, 91% is from district heating, 5% is from electricity, less than 2% is from oil and the remainder is from natural gas and biofuel.

Just over half of the multi-dwelling buildings were built between 1950 and 1975. Most of these are today, or will soon be, in need of renovation. Multi-dwelling buildings can differ greatly regarding size, shape, materials, building technique, etc. The most common types are low-rise apartment buildings, high-rise blocks of flats and tower blocks.

Low-rise apartment buildings have been the dominant building type from the 1930s and onwards. They are often 3 to 4 stories high and are built as long, detached structures. Each story can be reached by several stairwells, often without an elevator. During the 1960s and 1970s, high-rise blocks of flats became very common as a part of the industrialized construction of the million homes programme. These high-rise blocks of flats are multi-story buildings, with an elongated form, usually 8–9 stories high, built on a rectangular ground plan and equipped with elevators. Tower blocks are free-standing buildings with a stairwell located in the core of the building. Tower blocks began to be used in the 1930s and were four to five stories high, but they became common first in the 1940s. Since the 1950s, the height of the buildings has increased, and often includes eight to ten stories.

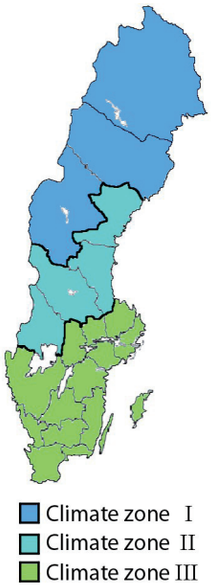
Impact analysis

An impact analysis has been carried out of the energy-efficiency measures that are needed in combination with different heating systems to meet the new demands during major renovations. The impact analysis has been conducted by different types of buildings being combined with different packages of energy-efficiency measures and different heating systems. The energy performance of each combination has been calculated and compared with the proposed nZEB demands during major renovations.

Figure 1. Example of low-rise apartment building.

Figure 2. Examples of high-rise blocks.

Four building types were investigated: low-rise apartment buildings, high-rise blocks of flats, tower blocks and a small multi-dwelling building containing 6 flats. The building types were located in Sweden's three different climate zones, and three building ages were investigated. There were thus thirty-six different combinations considered. U-values (heat transfer coefficients) varied depending on the age of the building and its geographical location. The estimated



heating requirements in these different types of buildings were compared with the national statistics for measured values.

In order to investigate how the energy performance of the buildings can be improved, the following energy-efficiency measures were examined: measures addressing electricity use for shared services in the building, measures addressing domestic hot water provision, loft insulation, window replacement, facade renovation and the installation of a heat recovery system between the exhaust air and the supply air. The measures were investigated in twelve different packages of measures, and an analysis was then made of which heating systems could meet the remaining energy needs. Four different heating systems were examined. These were retaining district heating, complementing district heating with an exhaust air heat pump, converting to a ground-source heat pump or an air-to-water heat pump.

The target levels are different for the different heating alternatives. For the exhaust air heat pump, a size was chosen with an installed power of less than 10 W/m², which entails target levels of 105, 90 and 75 kWh/m² in the respective climate zones, that is, the same target levels as apply for district heating. For ground-source heat pumps or air-to-water heat pumps, the target levels for electrically heated buildings apply, that is 70, 55 and 40 kWh/m² in the respective climate zones.

Measures addressing electricity use for shared services in the building include a package of efficiency measures for lighting, electricity for countering ice formation in gutters, etc. Measures addressing domestic hot water provision contain a package of measures to improve efficiency by having better fittings, individual gauges or solar heating.

Heat pumping technologies can be the solution

The results show that heat pumping technologies will be important in the renovation of multi-dwelling buildings. The larger multi-dwelling buildings, low-rise apartment buildings, high-rise blocks of flats and tower blocks, give largely the same results. The type of building has little importance in determining which package of measures in combination with which heating system will meet the nZEB requirements during a major renovation. The building age also has little effect. However, the climate zone does have considerable importance in determining which package of measures in combination with which heating system will meet the nZEB requirements during a major renovation.

Heat pumping technologies become more and more advantageous the further north the building is located. This is a direct consequence of the difference being constant between the nZEB requirements during major renovations for flats that are electrically heated and for flats that have another heating system than electric heating.

Largely the same measures in low-rise apartment buildings, high-rise blocks of flats and tower blocks

Retaining district heating in large multi-dwelling buildings such as low-rise apartment buildings, high-rise blocks of flats and tower blocks, requires a substantial package of measures in order to meet nZEB requirements. For buildings that were constructed in the period 1950–1975, all the considered measures must be carried out, that is, measures addressing electricity use for shared services in the building, measures addressing domestic hot water provision, loft insulation, window replacement, facade renovation and the installation of heat recovery. For buildings constructed after 1976, nZEB requirements can be reached during major renovations without the need for facade renovation.

Ground-source heat pumps are most advantageous in climate zone I, where installing ground-source heat as a single measure is enough to meet nZEB requirements during major renovations. The exception to this are low-rise apartment buildings built in the period 1950–1960, which also require measures addressing electricity use for shared services in the building and measures addressing domestic hot water provision. In climate zone II, it is sufficient to install ground-source heat as a single measure for buildings constructed after 1976. For older buildings, ground-source heat pumps must be combined with the installation of heat recovery. In climate zone III, measures addressing electricity use for shared services in the building must be carried out, together with the installation of ground-source heat pumps and heat recovery. Low-rise apartment buildings and tower blocks built in the period 1950-1960 also require measures addressing domestic hot water provision and loft insulation.

Air-to-water heat pumps in climate zone I must be combined with the installation of heat recovery in order to meet nZEB requirements during major renovations. For low-rise apartment buildings and tower blocks built during the period 1950–1960, measures addressing electricity use for shared services in the building and measures addressing domestic hot water provision must also be carried out. In climate zone II, air-to-water heat pumps must be combined with the installation of heat recovery, measures addressing electricity use for shared services in the building, measures

Table 2. Possible packages of measures for buildings of the following types: low-rise apartment buildings, tower blocks and high-rise blocks of flats. (x = always needed, (x) = needed depending on the age or type of building)

Climate zone		Measures addressing electricity use for shared services in the building	Measures addressing domestic hot water provision	Loft insulation	Window replacement	Facade renovation	Heat recovery
I	District heating	x	X	X	X	(x)	X
	Exhaust air heat pump	(x)					
	Ground-source heat pumps	(x)	(x)				
	Air-to-water heat pumps	(x)	(x)				X
II	District heating	x	X	X	X	(x)	X
	Exhaust air heat pump						
	Ground-source heat pumps: alternative 1						X
	Ground-source heat pumps: alternative 2	(x)	(x)	(x)	(x)		
	Air-to-water heat pumps	(x)	(x)	(x)			X
III	District heating	x	x	X	x	(x)	X
	Exhaust air heat pump						
	Ground-source heat pumps: alternative 1	x	(x)	(x)			X
	Ground-source heat pumps: alternative 2	x	x	X	x	(x)	
	Air-to-water heat pumps	(x)	(x)	(x)	(x)	(x)	X

addressing domestic hot water provision and loft insulation. Low-rise apartments buildings constructed during the period 1950–1960 also require window replacement. In climate zone III, the installation of air-to-water heat pumps and heat recovery in combination with measures addressing electricity use for shared services in the building, measures addressing domestic hot water provision, loft insulation and window replacement are needed. Low-rise apartment buildings also require facade renovation.

In **Table 2**, the different packages of measures are summarised that are needed in this impact analysis to meet nZEB requirements during major renovations of low-rise apartment buildings, tower blocks and high-rise blocks of flats.

Exhaust air heat pumps can be the winner

Exhaust air heat pumps are a relatively simple measure that may become advantageous during major renovations of multi-purpose dwellings. By installing an exhaust air heat pump that is less than 10 W/m² and retaining district heating for peak load, nZEB requirements can be achieved during major renovations of flats that have another heating system than electric heating, that is, 105, 90 and 75 kWh/m² in the respective climate zones.

The installation of exhaust air heat pumps meets nZEB requirements during major renovations as a single energy efficiency measure for in principle all of the considered large multi-dwelling buildings: low-rise apartment buildings, high-rise blocks of flats and tower blocks. The alternative however has a considerably greater electricity usage than the package of measures with ground-source heat pumps or air-to-water heat pumps.

Difficult for small multi-purpose dwellings to meet nZEB requirements

It is more difficult for small multi-purpose dwellings to meet nZEB requirements during major renovations. In short, some form of heat-pumping technology or the installation of solar electricity is needed to meet the standards adopted in this impact analysis. The proposed collected package of measures, that is, measures addressing electricity use for shared services in the building, measures addressing domestic hot water provision, loft insulation, window replacement, facade renovation and the installation of heat recovery, in combination with retaining district heating, is not sufficient to meet nZEB requirements during major renovations. Retaining district heating requires a renewable energy source of some type, such as solar cells being installed, in addition to the extensive package of measures. Another alternative is to install exhaust air

Table 3. Possible packages of measures for buildings of the type: small multi-dwelling building (x = always needed, (x) = needed depending on the age of the building).

Climate zone		Measures addressing electricity use for shared services in the building	Measures addressing domestic hot water provision	Loft insulation	Window replacement	Facade renovation	Heat recovery
	Exhaust air heat pump	x	x	(x)	(x)	(x)	
	Ground-source heat pumps	x	x				
	Air-to-water heat pumps	x	x	x	x	(x)	x
	Exhaust air heat pump	x	(x)	(x)	(x)		
	Ground-source heat pumps: alternative 1	(x)	(x)	(x)	(x)		x
	Ground-source heat pumps: alternative 2	x	x	x	(x)		
	Air-to-water heat pumps	x	x	x	x	(x)	x
	Exhaust air heat pump	x	(x)	(x)	(x)		
	Ground-source heat pumps	x	x	x	x	(x)	x
	Air-to-water heat pumps	x	x	x	x	x	x

heat pumps and retain district heating for periods of peak demand. However, even in this case, a package of measures is required, which would need to include the implementation of measures addressing electricity use for shared services in the building, measures addressing domestic hot water provision, loft insulation and window replacement. Small multi-dwelling buildings constructed after 1976 can however satisfy nZEB requirements during major renovations by the use of exhaust air heat pumps, measures addressing electricity use for shared services in the building and measures addressing domestic hot water provision. Air-to-water heat pumps also require an extensive package of measures, including measures addressing electricity use for shared services in the building, measures addressing domestic hot water provision, loft insulation, window replacement, facade renovation and the installation of heat recovery. With a ground-source heat pump and a package of measures including measures addressing electricity use for shared services in the building, measures addressing domestic hot water provision, loft insulation and window replacement, requirements can be met in most cases in climate zones I and II. In climate zone III, the installation of heat recovery is also needed.

Table 3 summaries the different packages of measures that need to be taken to meet nZEB requirements during major renovations of small multi-dwelling buildings of the type considered in this impact analysis.

Life cycle costs can be decisive

The quantitative estimates made in this study provide an indication of the possible packages of measures that could be relevant during major renovations of multi-dwelling buildings. The study uses buildings of different types in order to analyse which solutions can be of interest, which provides results that can differ greatly in particular cases. Technical difficulties have not been taken into consideration, such as that it can be difficult to install heat recovery in tower blocks, or that the flow of exhaust air to an exhaust air heat pump can be difficult to collect in long low-rise apartment buildings.

The studies reported in this article only include the technically possible packages of measures. In order to obtain a complete supporting documentation for decision making, an economic analysis also needs to be made, which takes into consideration the life cycle costs for the different packages of measures. One of the alternatives that was not discussed here is to combine heat pumping technologies with solar cells in the production of electricity. Electricity produced by solar cells placed on or in connection to the building is not included in nZEB requirements.