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Energy saving potential in retrofitting of non-residential buildings in Denmark

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Abstract

In connection with the "IEA SHC Task 47 - Solar Renovation of Non-Residential Buildings", Denmark has investigated 4 exemplary renovation projects; The Osram Culture Centre, Rockwool office building, Parkvænget office building and Kindergarten Vejtoften. The 4 exemplary projects have demonstrated that deep energy renovation can be achieved for different types of non-residential buildings including protected/historic buildings through combinations of energy efficiency measures and renewable energy measures. This paper provides an introduction to the IEA project and includes results from the 4 Danish exemplary projects with a more detailed description of the renovation of Parkvænget office building.

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Keywords: Energy Saving Potential; Non-residential Buildings; Energy Efficiency Measures; Renewable Energy Sources

1. Introduction

Improving the energy efficiency of buildings represents a key target area in European countries, since 40% of the total energy consumption in the EU is related to the building sector [1]. This implies, among other things, increasing the energy efficiency of existing buildings in order to reduce heat loss through building envelopes and implementing a greater share of renewable energy in buildings.

In Denmark there is a strong focus on renovation of existing buildings and non-residential buildings are a special focus at the moment. For existing buildings the government has developed a comprehensive "Strategy for the energy renovation of the existing building stock". The Strategy for energy renovation contains a number of initiatives to increase the number of energy renovations in the most cost-efficient way. It is estimated that the initiatives in the Strategy will reduce the net energy consumption for heating and domestic hot water in the existing buildings stock by 35% until 2050 compared to today.

Denmark is participating in the "IEA SHC Task 47 - Solar Renovation of Non-Residential Buildings" where the purpose is to develop a solid knowledge base on how to renovate non-residential buildings towards the Nearly Zero Energy Building (NZEB) standards in a sustainable and cost efficient way. Furthermore, the aim is to identify the most important market and policy issues as well as marketing strategies for such renovations. In connection with the project Denmark has investigated 4 exemplary buildings, i.e. a kindergarten, two office buildings and a cultural center.

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The renovation of Osram Culture Centre was initiated in connection with the Climate Change Conference, COP15. The City of Copenhagen initiated a strategic cooperation with a number of Danish enterprises for the purpose of mutual profiling on climate-friendly buildings. The target was to minimize the resources required (and, consequently, the CO_2-emission) both during construction and upkeep.

The main incentives for the renovation of the Rockwool office building were to reduce energy consumption for the 34 year old office building and to establish an attractive and up-to-date working space for 120 employees. Furthermore, Rockwool wanted to focus on the challenges and possibilities there are in raising the energy standard in industrial constructions. The office space was outdated and the energy performance and indoor climate were far below the current standard. After renovation the office building fulfill the Low Energy Class 2015 requirement for new buildings according to the Danish Building Regulations [2].

The main objective of the renovation of Parkvænget office building was to reduce the overall energy consumption of the building while also improving the indoor climate. This was achieved by adding insulation to the facade, replacing existing windows, improving air tightness of the building envelope, replacing the ventilation system and adding solar panels to the facade. After renovation the office building fulfills the Building Class 2020 requirement (NZEB) for new buildings according to the Danish Building Regulations.

The renovation of the Kindergarten Vejtoften aimed at an overall renovation of the existing building, i.e. roof was leaking, windows were worn out and the building was suffering from uncomfortable draught. The energy consumption for heating has been reduced from approximately 37 MWh per year to 14 MWh per year and the electricity consumption has been reduced from 10 MWh per year to 8 MWh per year while at the same time the indoor climate has been improved significantly.

In IEA SHC Task 47 analyses have been made to determine in which building segments the largest energy saving potential within the non-residential sector are found, and how the decision making process for high ambition renovation of such buildings can be achieved. Interviews of key actors were undertaken.

2. Demonstration projects in Denmark

Denmark has provided four exemplary projects to support the work of Task 47; two office buildings, a cultural center and a kindergarten. Figure 1 shows the four buildings before and after renovation.

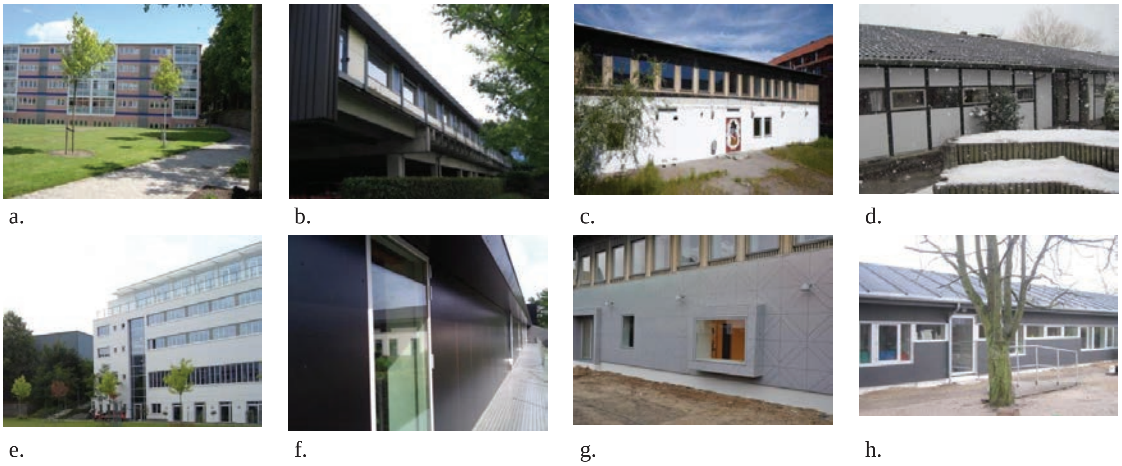


Fig. 1. (a) Parkvænget office, before; (b) Rockwool office, before; (c) Osram Culture Centre, before; (d) Kindergarten Vejtoften, before; (e) Parkvænget office, after; (f) Rockwool office, after; (g) Osram Culture Centre, after; (h) Kindergarten Vejtoften, after.

2.1. Energy efficiency measures in Danish exemplary projects

The 4 Danish projects encompass a wide selection of different energy efficiency measures ranging from traditional retrofitting of energy systems over added insulation to the building envelope to new and innovative solutions for daylight optimization and installation of solar thermal and PV systems.

For the Parkvænget office building the reduction in energy use was achieved through insulation of thermal envelope, exchanging old double-glazed windows with new windows with 2 layers of glass, low emission coating and argon gas filling, installing a new ventilation system with higher efficiency and heat recovery, adding 130 m^2 photovoltaics on the southern facade and installing LED lighting and night cooling.

For the Rockwool office building the energy consumption of the building was reduced by adding new facades, floors and ceilings with increased insulation levels, changing all windows to new windows with 3 layers of glass, replacing the ventilation system with a new system with higher efficiency and heat recovery, changing the existing heating system to heat pumps with 120 m deep wells, adding water based solar collectors and finally installing a photovoltaic system with a 170 m^2 collector area.

The energy savings for the Osram Culture Centre were achieved despite of the buildings status as a cultural heritage, i.e. the entire facade of the building facing the street could not be altered. The facade was insulated on the inside and an extra layer of glass was added to the windows. All other parts of the thermal envelope were insulated, and energy efficient windows replaced the old ones, the building was fitted with energy saving lighting, automatically controlled natural ventilation was installed and solar collectors were added to the roof. In order to increase the daylighting levels in the building roof windows were added and a penetration of the ground floor ceiling created double room height in part of the entrance and made it possible to let daylighting reach the ground floor from the roof.

The kindergarten Vejtoften is 1 in 27 institutions to undergo a similar renovation in the municipality of Høje Taastrup. For the roof 390 mm's insulation was added to the existing 145 mm's and new asphalt roofing was established. The exterior wall had 95 mm's insulation to start with, but this was replaced by a new construction with 280 mm's of insulation and a new cladding of fibre-cement was added. In order to reduce/remove thermal bridge effects at the uninsulated base/foundation of the building 200 mm's of insulation was added on the outside to a depth of 400 mm. The existing traditional double-glazed windows were replaced by generally larger triple-glazed windows and finally the original ventilation system was replaced by a more energy efficient system. The energy savings achieved in the Danish projects can be seen in table 1. Please note that no measurements were performed for Parkvænget Office building before renovation.

Table 1. Energy use before/after renovation in Danish Exemplary projects, kWh/m^2/year.

Name, Type	Parkvænget, Office	Rockwool, Office	Osram, Historic	Vejtoften, Education
Before	-	264.0	288.0	167.4
After	55.4	41.2	153.0	91.7
Savings in %	-	84.4	46.9	45.2

3. Parkvænget office building – detailed project description

The office building has a total heated area of 2,478 m^2 and houses approximately 84 employees. The main incentive for the renovation of the Parkvænget office building was to reduce energy consumption to a level corresponding to the requirement for new buildings in 2015 (Low Energy Class 2015 Buildings) and improve indoor climate in the building, but also to renew the expression of the building to better suit the company's "green" profile. The office building was originally built in 1968 and an energy renovation was carried out in 1991. Still, the building had a relatively poor insulation level and the windows from 1991 were reaching a state where they had to be replaced.

3.1. Thermal envelope

The thermal envelope has been insulated extensively to reduce transmission heat loss. Table 2 shows U-values before and after renovation. Figure 2 shows a horizontal cross section of the exterior wall.

Table 2. U-values in W/m^2K before/after renovation.

Construction	Roof	Facade	Basement wall	Windows
Before	0.20	0.30	2.00	2.60
After	0.10	0.14	0.28	1.00

3.2. HVAC systems and renewable energy sources

Heating of the building is based on district heating (both before and after the renovation). The renovation included changing both the distribution system and the radiators in the building. Domestic hot water production in the building is also based on district heating. The entire system was replaced during the renovation.

The building had no cooling system before the renovation, but as part of the renovation an 80 kW cooling surface was added to the ventilation system that could be used to cool the building before working hours. A separate free cooling system for the server room and individual printer rooms were also added.

The entire ventilation system was replaced during the energy renovation. The new system has a higher level of energy efficiency and a heat recovery rate of 82 %.

130 m^2 PV panels were added to the south façade of the building. They produce only a relatively small amount of electricity compared to the overall electricity use in the building (see figure 3). However, the PV-panels also serve as part of the aesthetic appearance of the building and give the impression of a modern building that also signals the green profile of the company.

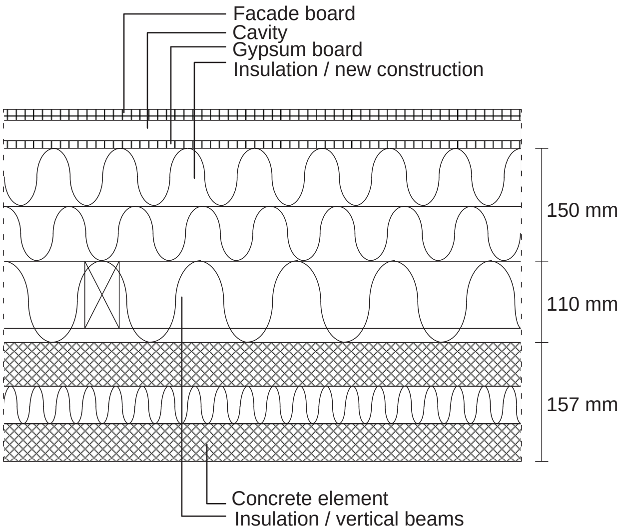
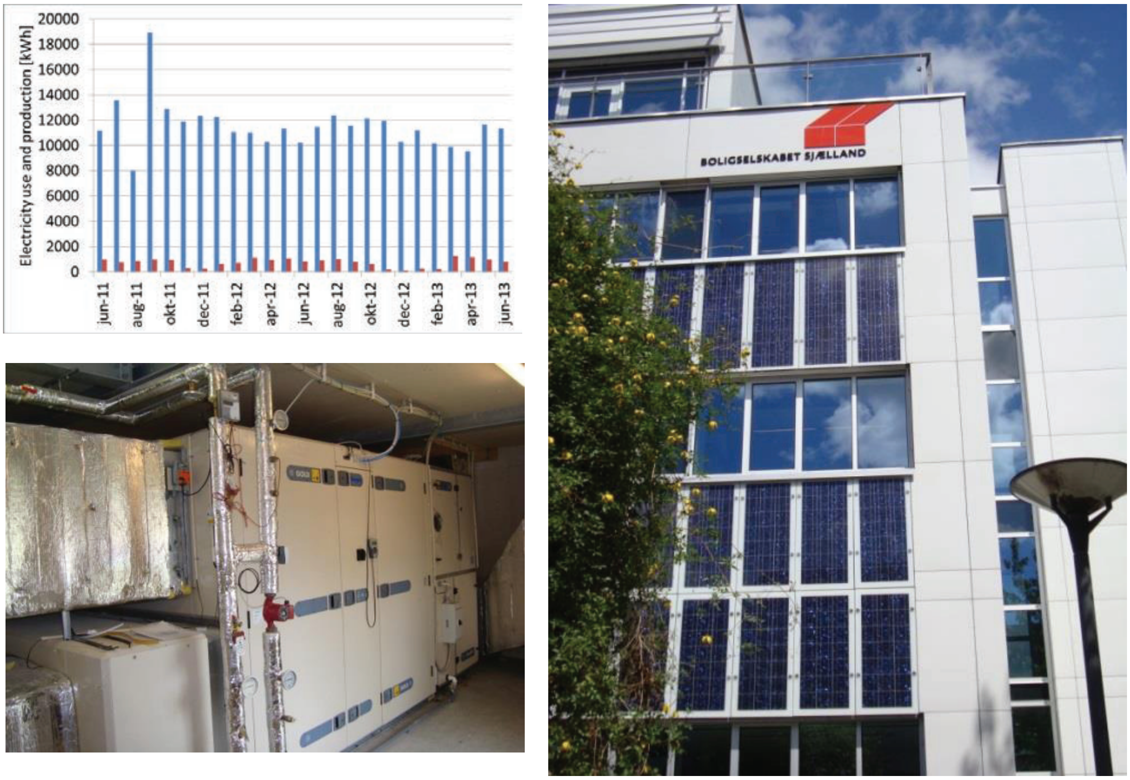


Fig. 2. Horizontal cross section of the exterior wall. 150 mm insulation was added resulting in a total insulation thickness of 310 mm.



a.

b.

c.

Fig. 3. (a) Electricity use (blue) and PV electricity production (red); (b) Ventilation system includes the possibility of delivering 80 kW cooling in the building before working hours, to avoid overheating on hot and sunny summer days; (c) South façade with 130 m^2 PV system.

3.3. Energy numbers

Before the renovation, the expected energy use was calculated. The goal was to reduce the energy use to less than 50.6 kWh/m^2 pr. year, and the calculation showed an expected energy use of 50.3 kWh/m^2 pr. year. This corresponds to a total energy use for the building of approximately 125 MWh/year. Unfortunately, there were no measurements of the energy use before renovation available. Furthermore, the owner of the building – Boligselskabet Sjælland – is a merger of two social housing companies and after the merger the combined administration needed more space, and therefore the renovation/extension of the building was initiated, i.e. energy use before/after renovation is difficult to compare since the use of the building changed significantly in the process. Table 3 shows the measured energy use after renovation.

Table 3. Measured energy use after renovation.

2012	Heat/DHW	Electricity use	Electricity production
MWh	151.1	135.9	9.0
kWh/m^2	61.0	54.8	3.6

The total energy use of 115.8 kWh/m^2 includes auxiliary energy (14.1 kWh/m^2), a refrigeration compressor in the ventilation system (28.2 kWh/m^2), a refrigeration compressor for copy/printer rooms (14.5 kWh/m^2), all of which are normally not included in the calculated results. The measured energy use can therefore be reduced to 55.4 kWh/m^2 (for comparison with calculations).

3.4. Economy

The total cost of the renovation was approximately 4.8 mio. € or 1,932 €/m^2. This is a relatively high price compared to the other projects examined in Task 47, but it reflects the fact that the project had focus on several issues and not just reducing the energy demand of the building, e.g. indoor climate, attractive working environment and signaling the company's green profile.

3.5. Indoor climate and quality of life

The indoor climate in the building has improved significantly because of the renovation.

The renovation included installation of special partition walls that reduce resonation, special rubber coated floors that reduce impact sound and acoustic ceilings. These features have all improved the acoustic indoor climate in the building significantly.

The general insulation/improvement of the building envelope and ventilation system, have reduced the transmission and ventilation heat loss significantly. This has influenced the heat balance of the building to a level where the new radiators are actually redundant, which in turn has led to some problems with draught close to the windows (the radiators could counter the draught, but would then raise the indoor temperature too much).

The quality of life for the building users have also improved. In addition to the improvement in the thermal and acoustic indoor climate, especially the new canteen and the penthouse addition on the roof plus accompanying terrace have given the staff better working conditions.

4. Discussion

The four Danish exemplary projects have achieved reductions in energy consumption from approximately 45 – 85 % through a wide selection of different energy efficiency measures ranging from traditional retrofitting of energy systems over added insulation to the building envelope to new and innovative solutions for daylight optimization and installation of solar thermal and PV systems. The reductions in energy consumption are similar to those achieved by the other countries participating in the IEA SHC Task 47 project.

The Parkvænget office building was renovated to significantly reduce energy consumption and improve indoor climate, but also to renew the expression of the building. The thermal envelope has been insulated extensively to reduce transmission heat loss, i.e. increasing insulation levels in the façade and the roof and replacing the existing windows with new energy efficient ones. Further energy reductions were achieved by replacing the entire ventilation system. The new ventilation system uses less electricity and has a heat recovery rate of 82 %.

The original intention of the Parkvænget project was to reduce the energy use to less than 50.6 kWh/m^2 pr. year, corresponding to a total energy use for the building of approximately 125 MWh/year. The measured energy use after the renovation shows that the building has used approximately 55.4 kWh/m^2 i.e. 9.5 % more than expected.

The indoor climate in the office building also improved significantly due to the renovation. The added insulation/improvement of the building envelope and the new ventilation system, reduced transmission and ventilation heat losses creating a very good indoor climate with no draught.

5. Conclusion

Denmark has contributed to IEA SHC Task 47 with 4 exemplary deep energy renovation projects. The reductions in energy use have been achieved through a wide range of energy saving measures, but typically the first step is to add insulation to the building envelope and replace the windows to reduce transmission heat losses. All projects have also included energy efficient ventilation as well, i.e. reducing the ventilation heat losses.

a.

b.

Fig. 4. (a) The stairwells are much brighter after the concrete facades have been replaced with glass facades. All windows are made with sunscreen to limit overheating; (b) The penthouse has both vertical and horizontal solar shading to avoid high indoor temperatures during summer.

The project that reached the least reduction in energy use, i.e. kindergarten Vejtoften only included the thermal envelope, windows and ventilation system. For the protected building, i.e. Osram Culture Centre insulation of the thermal envelope was more difficult due to restrictions concerning the façade of the building and therefore energy savings could not be achieved as easily. For this building special focus on utilization of daylighting, installation of LED lighting and a solar thermal system was necessary to achieve the far-reaching goals of the project.

The two office buildings achieved the largest reductions in energy use. In addition to insulating the thermal envelope, changing the windows and installing highly efficient ventilation with heat recovery the office buildings also had energy efficient lighting, new heating systems, photovoltaic systems and in the Rockwool building also a solar thermal system. The Rockwool building achieved a total reduction in energy use of almost 85 %; a showcase example on how deep we can go with existing buildings by combining several energy efficiency measures with production of renewable energy, i.e. corresponding to the methodology of the “nearly zero-energy building”-concept put forth in the EU Directive [3].

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