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Energy consumption in an old residential building before and after deep energy renovation

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Abstract

Denmark is participating in IEA EBC Annex 56 “Cost Effective Energy and Carbon Emissions Optimization in Building Renovation”. The housing complex Traneparken has been chosen as a Danish case study for the project. It has been retrofitted with new facades, new windows, additional insulation, mechanical ventilation with heat recovery and a photo-voltaic installation on the roof. The measured energy consumption for heating and domestic hot water before and after renovation was 736 MWh/year and 506 MWh/year respectively. Hereby, the project has demonstrated that the renovation resulted in significant energy savings.
This paper presents results from the Danish case study.

Keywords: Energy retrofit; residential building; indoor climate; analysis; monitoring

1. Introduction

The main objective of IEA EBC Annex 56 is to provide tools, guidelines, recommendations, best-practice examples and background information for policy makers, designers, users, owners and promoters that help cost-effective minimization of greenhouse gas (GHG) emissions and primary non-renewable energy consumption in the existing building sector. The project started on 1.5.2011 and will last approximately 4.5 years until 30.12.2015.

Traneparken consists of 3 multi-story blocks of flats situated in the village of Hvalsø, 55 km west of Copenhagen. Each block has 3 stories and a total of 66 flats. The residents are an average of the Danish population – except that 48 % are single (small flats). However, there is a big turnover of residents every year in Traneparken. Traneparken was built in 1969 and the gross heated floor area is 5293 m^2. It was retrofitted with new facades, new windows, additional insulation, mechanical ventilation with heat recovery and a PV installation on the roof. The owner is Hvalsø Boligselskab (Building Association Hvalsø) and

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administrator is Boligselskabet Sjælland (Building Association Zealand). The buildings in general were in very poor condition and needed renovation - especially the concrete facades were worn down.

The overall intentions were to:

- Renovate buildings because they needed it
- Reduce energy consumption (insulation – windows – doors - ventilation)
- Improve indoor climate
- Improve flats by adding an external balcony
- Improve outdoor recreational areas

The renovation was performed based on the requirements in the Danish Building Regulation [1].

2. Construction and systems of the building before renovation

2.1. Building envelope

The buildings were typical 1960s buildings made with prefabricated enforced sandwich concrete elements with approx. 50 mm insulation. Some of the façade consists of panel walls with 45 mm insulation Floor insulation to basement was approx. 45 mm. The roof was insulated with approx. 190 mm. Windows were double-glazed with U-value of 2.4 W/m^{2}K.

Fig. 1. Two of the three blocks at Traneparken. The photo shows the end wall of one block being renovated and the facade of the other which has not yet been renovated.

2.2. Heating, ventilation, cooling and lighting systems before retrofit

The buildings are heated by district heating let into the basement of one of the blocks to a 200 kW plate heat-exchanger and from there it is distributed to the other blocks. There were pre-insulated domestic hot water tanks in each block. In total, there were 8 tanks holding 300 liters each.

The flats were ventilated by a mechanical exhaust air system from bathroom, toilets and kitchens.

There were energy-saving bulbs in all indoor lights on the staircases. They were equipped with automatic switch-off controls with presence detectors. The outdoor light had automatic daylight switch-off.

The buildings seemed rather “grey and boring” and had problems with facades, windows, roofs, etc. The indoor climate was unsatisfactory and the energy consumption was unacceptably high. The intention was that the renovation project would make Traneparken more attractive for both existing and new residents.

3. Energy retrofitting measures

Traneparken has undergone a thermal rehabilitation process where 190 mm insulation material is added to the outside of the exterior walls. The original construction of the exterior wall was prefabricated concrete elements consisting of 100 mm concrete, 50 mm mineral wool insulation and 140 mm concrete. The concrete facades were worn down and had to be renovated. The 190 mm insulation was continued below ground level to reduce/remove any thermal bridges. Furthermore, the roofs and panel walls have also been insulated and windows have been replaced with triple-glazed energy efficient windows. In addition to the energy renovation of the facade, a new ventilation system and solar photo voltaic panels have been installed.

Traneparken has undergone a retrofitting process and the panel walls now consist of 285 mm insulation plus exterior solid standard bricks. The external insulation was continued under ground level to reduce/remove any thermal bridges. Furthermore, the roofs were also insulated and windows were replaced by triple-glazed low-E windows with low U-values.

Table 1. Renovation measures for one block. Calculations of U-values are done in accordance to Dansk Standard 2011; DS 418:2011 [2].

Element	Area, m^2	U-value before renovation, W/m^2K	U-value after renovation, W/m^2K	After renovation, description
Exterior walls	486	0.66	0.15	Plus 190 mm insulation plus exterior standard bricks, now totalling 240 mm
Panel wall	106	0.7	0.11	Plus 285 mm insulation plus exterior standard bricks, now totalling 330 mm
Windows, doors	205	2.4	0.8	Triple-glazed low energy windows with aluminium-wood frame
Roof	333	0.2	0.09	Plus 250 mm insulation, now totalling 435 mm

Mineral wool was used for the insulation of the external walls and the roof. Mineral wool is produced at high temperatures with some energy consumption, but when compared with the energy saved by its use, this is close to negligible. It has a very high durability and will last for the rest of the buildings lifetime.

Plastic window frames have been the object of some debate over the years. However, today the quality of plastic windows has greatly improved so their lifetime is now comparable with that of other types of windows. Unlike wooden windows, they need no protective treatment every 5 - 7 years. The windows can be completely taken apart and materials recycled after end-of-service-life. Thereby the plastic can be recycled for new plastic products – for example plastic windows.

Fig. 2. (a) The external insulation (EPS) of the basement walls; (b) Lower corner of a plastic triple-glazed low energy window; (c) New balcony doors – plastic with energy-efficient glazing.

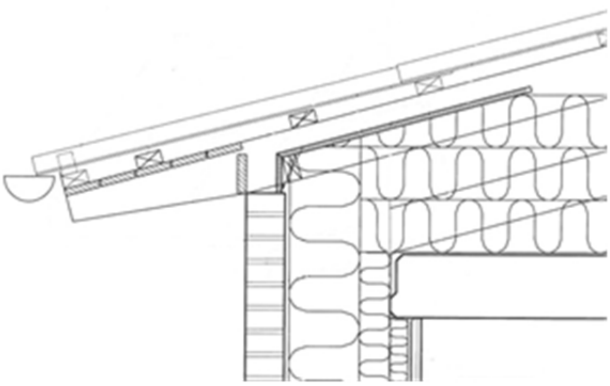

Fig. 3. The insulation in the wall was increased by 190 mm and the insulation in the roof by 250 mm. In the joint between external walls and the roof the insulation is continued in full thickness to minimize thermal bridges

Nothing was changed concerning the heating and lighting systems. After renovation, a balanced mechanical ventilation system with heat recovery was installed. The air was supplied to the living rooms and bedrooms and exhaust air from bathroom, toilets and kitchens. For the installation of the new demand-controlled balanced mechanical ventilation system with heat recovery, the existing exhaust air ducts were reused – thereby minimising costs and material use. Available space was identified and utilised for the supply air system. A PV system was installed on the roof to produce electricity.

Fig. 4. The 33 kWp south-facing PV system and the coverings for the new mechanical ventilation systems located above each stairway.

4. Energy calculation and measurements

The energy consumption for heating and domestic hot water (DHW) before and after the energy retrofit has been calculated and measured.

Table 2. Energy consumption for heating and DHW before and after renovation.

Calculated energy consumption including domestic hot water:			
Before renovation:		728	MWh/year
After renovation:		502	MWh/year
Calculated savings:		226	MWh/year
Measured energy consumption:			
Before renovation:	2011 – 2012	736	MWh/year
After renovation:	2012 – 2013	506	MWh/year
Measured savings:		230	MWh/year

The calculated energy savings achieved through reduced heat losses from the building envelope amount to 120 MWh/year and the energy savings achieved through reduced ventilation loss amount to 106 MWh/year.

The PV electricity is intended for use mainly in the common laundry. Any extra electricity production is used for common lighting. The PV system was expected to produce 30.000 kWh per year, but measurements show that from 1 September 2012 until 1 September 2013 the production was 38.159 kWh (the summer of 2013 was extraordinary sunny).

4.1. Renovation costs

It was important for the economy that the buildings were renovated due to beginning deterioration. Therefore, a large part of the renovation project could be financed from funding available for improving the present situation – a Danish fund for social housing was used for this purpose: “Landsbyggefonden”.

Table 3. Overview of the cost of renovation for the 3 buildings in total.

	Costs € million	Costs €/m^2
Craftsmen/contractor	5.1	1,003
Consultants	1.5	298
Total cost	6.6	1.302

The exterior walls were retrofitted with supplementary insulation added to the outside. The external insulation was continued to the base of the building to reduce any thermal bridges. The total cost of this measure was 1.60 million € (incl. VAT).

The roofs were renovated and insulated and the total cost of this measure was 0.56 million € (incl. VAT).

The windows and doors were replaced with triple-glazed low-energy windows and the cost was 0.11 million € (incl. VAT, excl. installation). These figures are included in the overall economy in table 3.

The increased running costs for the ventilation system were 13,333 €/year. The expected PV electricity production was 30,000 kWh per year, and with an electricity price of approx. 0.29 €/kWh this corresponds to savings of 8,000 €/year.

Fig. 5. Traneparken after renovation.

4.2. Influence on tenants rent

The economic consequences for the tenants were as follows: rent before: 93 €/m^2/year; rent after: 105 €/m^2/year. The increase in rent was therefore 12 €/m^2/year. If the energy savings were 226 MWh/year as calculated, and the energy price was set at 93 €/MWh, the savings would be 226 x 93 = € 21,018 = 4 €/m^2/year, i.e. approximately one third of the increase in rent would be covered by the energy savings. For the 12.9 % (8.6 % net) increase in rent, the tenants have received a better indoor climate, apartments that are easier to organize and balconies overlooking the renovated outdoor recreational areas.

5. Tenants satisfaction with the results

A questionnaire survey was conducted in October 2014 among 65 tenants. The survey was carried out by sending letters to the tenants by regular mail with a brief description of the project and an invitation to participate in the survey. A total of 25 tenants answered, corresponding to a response rate of 38 %. The respondents constituted 72 % (18) women. Among the tenants, 50 % moved into their apartment in the period 2010 to 2014 and 27 % in the period 2005 to 2009. The questionnaire survey focused on the occupants' overall satisfaction with how the retrofitting had been carried out and the final result of the retrofitting, including e.g. perceived indoor climate before and after the retrofit. A preliminary analysis of the results shows that the tenants are generally satisfied with the retrofit. A majority find that the retrofitting meets their expectations and they would recommend energy retrofitting of flats to others. The perceived indoor climate is better after the retrofitting especially for the parameters temperature, draught and air quality. A little less than half of the tenants express that the temperature in their flat is higher after the retrofitting, indicating that some of the energy saving has transformed into better comfort.

6. Lessons learned

The renovation and the energy retrofitting project carried out for Traneparken resulted in a series of lessons learned which might be useful for upcoming renovation projects. One of the great challenges was to do renovation work while the tenants were still occupying the buildings. It takes longer time to plan and carry out a renovation work than building a new construction, mainly because the flats were inhabited.

It is cumbersome to carry out work in dwellings, where people live and the craftsmen need to be considerate. There can be conditions in the individual dwellings, which are not known beforehand, so the project has to be adapted to these and there has to be room enough in the budget for this flexibility. In this particular case, there was sufficient financial flexibility for specific considerations in the individual dwellings – and to solve unexpected problems – which will always occur in a renovation project.

The security at the building site has to be the very best. It has to consider the tenants and especially the children living on the building site. In this respect the consultants and the contractor succeeded in the Traneparken project. The project has already shown that the energy retrofit results in large energy savings, but also the non-energy benefits are very important. The tenants received new balconies, new green surroundings and an improved indoor climate due to a new ventilation system with heat recovery, carefully adjusted supply temperature as well as less heat loss and draught through walls, windows and doors. A majority of the tenants, who answered the questionnaire, find that the retrofitting meets their expectations and they find the perceived indoor climate better after the retrofitting.

7. Conclusions

The added insulation and new ventilation systems improved the thermal comfort and air quality in the flats. The warmer walls and windows make it easier and more comfortable to utilize all square meters of the apartments. All flats now have a balcony overlooking the also refurbished green areas of the courtyard surrounded by the blocks of flats.

A PV system on the roof of one of the blocks helps reducing the energy consumption of the common laundry facility. The overall energy demand and energy bill for heating is reduced by 31 %. The electricity demand for ventilation has gone up, but the electricity production from the PV system covers around 60 % of this increase.

It was considered to be important that the tenants received what they expected, so from the beginning a great deal of effort was spent on making sure that the expectations were adjusted to what could be realised in practice. The inhabitants/tenants had to be part of the decision-making process (tenants' democracy is mandatory in Denmark). The time schedule is important as the tenants need to know when something is going to happen in their dwelling!

Traneparken has become a significantly more attractive place to live with a relatively low increase in rents and therefore it will be easier to find tenants for the flats in the future. It is also expected that the tenants will take better care of their homes and surroundings after the renovation process.

The IEA EBC Annex 56 project in Traneparken will continue with more measurements of the energy consumption and the indoor climate.

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