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Renovation of a detached single-family house into an energy efficient low energy house

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KEYWORDS: *Energy renovation, façade system, air tightness, natural ventilation, mechanical ventilation*

SUMMARY:
In order to obtain the political goals for national and international energy savings of reducing CO_2 emissions and avoid climate changes, renovation projects for dwellings are becoming increasingly more important.

This paper describes the results attained from an extensive renovation of a detached single-family house built in the early nineteen seventies. The old house was renovated in accordance to the best Danish low energy class (class 1). The project was followed by detailed measurements of the indoor environment (temperature, relative humidity and CO_2 levels) and energy consumption for room heating and hot water supply. Measurements were carried out before and after the renovation in order to compare results and see whether the ambition for a 78% reduction in the energy consumption was reached.

The paper will describe some of the most important factors regarding the energy renovation, which will include construction of a new façade for the house, test of air tightness before and after the energy renovation, and installation and use of ventilation system in an existing building.

1. Introduction

New buildings are often the ones in focus when energy consumptions in buildings are being discussed, but new buildings only count for one per cent of the entire building market in Denmark. Therefore, renovation of existing buildings needs much more attention. The focus for this paper originates from the project “EnergiParcel – new energy to your home” which started in 2008. The project concerns the renovation of four detached single-family houses built in the nineteen seventies. The reason for this choice of period is the fact that 53% of all detached single-family houses in Denmark built from 1850-1998 are built between 1960 and 1980 (Wittchen, 2008). This period, therefore, has great saving potential in energy consumptions.

This paper describes the most ambitious renovation in the project where the objective for energy saving was a 78% reduction of energy consumption in the house after the renovation. Unfortunately, the calculated energy demands, and thereby savings, often differ from the measured values. This is part of the reason for the measurements of the energy consumption and the indoor environment of the house. These measurements were made both before and after the renovation, and were (amongst others) used to keep check on the obtained energy savings.

Several aspects must be considered in order to do this comprehensive renovation where an old, leaky house from the nineteen seventies is turned into a modern, air tight and energy-efficient building. This includes everything from air tightness of the building, building materials and ventilation principles to attention to daylight conditions and other qualitative measures. These considerations are the ones, which will be described in this paper.

2. Methods used for the extensive renovation

The following sections will describe some of the most important parts in a successful energy renovation where air tightness, energy savings and indoor environment are some of the main parameters.

2.1 Construction of a new façade for the house

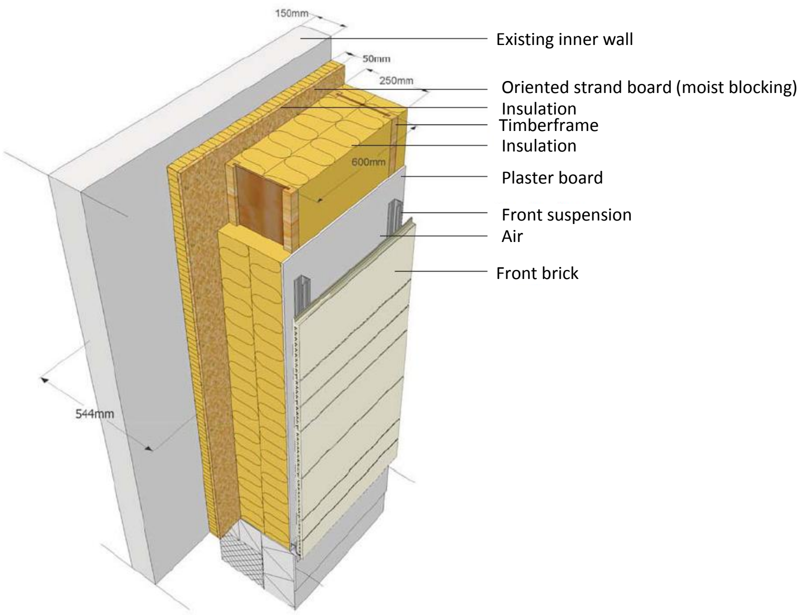
To minimize heat loss through the building envelope, it was decided that the house should have an optimally insulated and airtight façade. Following the initial studies on the stability of the house and discussions of the desired outer wall maximum thickness, the outer part of the cavity wall was torn down and an entirely new façade was constructed on the outside of the bearing inner wall. The wall thickness could, thereby, be minimized and, at the same time, a good insulation level would be achieved.

In connection to the energy renovation, it was essential that the house reached the Danish low energy class 1. For the actual house, this corresponds to 41.1 kWh/m^2 year. In order to obtain this, it was necessary to apply a maximum level of insulation material to both exterior walls and roof, and to install new energy efficient windows.

To optimize the construction process, a façade principle was developed in consultation with the contractor. The entire outer wall was delivered in storey-high prefabricated wooden elements, which were mounted on the outside of the existing inner wall. This allowed the carpenter to seal and insulate the entire façade in just a few days' work.

FIG 1. Construction of the new building façade in a controlled environment.

The elements were manufactured off-site in a heated hall under optimal working conditions where the airtight layer could be secured without holes (see FIG 1). The new airtight layer was created around the building envelope (exterior walls, roof and gables) outside the existing structure and taped to the existing foundation. The attached, prefabricated elements had a thickness of approx. 400 mm with which the total thickness for the wall ended at approx. 550 mm and an overall U-value of 0.117 W/m^2K. A cross section of the elements is seen in FIG 2a.



a.)

b.)

FIG 2. a.) Cross section of the façade elements. b.) Element mounted to the existing inner wall.

The items were delivered on-site without windows, insulation or façade finish since the prefabricated elements would become too heavy otherwise. By keeping the weight down, the carpenter was able to lift the components and assemble the entire system quickly and accurately, see FIG 2b.

The U-values for the entire construction are shown in TABLE 1 together with a description of the amount of heat loss caused by each part of the construction and the achieved reduction in heat loss.

TABLE 1:U-values for construction parts before and after renovation.

Construction and Windows	**Before renovation**			**After renovation**			
	U-value	Spec. Heat loss	Heat loss façade	U-value	Spec. Heat loss	Heat loss façade	Reduction in heat loss
	W/m²K	*W/K*	*%*	*W/m²K*	*W/K*	*%*	*%*
Outer wall	0.42	40.7	17%	0.117	11.3	10%	72%
Roof	0.31	35.3	14%	0.092	13.7	12%	61%
Existing Floor	0.3	22.6	9%	0.3	22.6	21%	0%
Floor in bathrooms	0.3	1.2	1%	0.11	0.,5	0%	63%
Windows (mean)	2.8	131.0	53%	0.96	50.0	46%	62%
Skylights (mean)	2.8	14.8	6%	1.2	11.5	10%	23%
Mean/Total	0.72	245,7	100%	0.28	109.5	100%	55%

2.1.1 *Importance of air tightness*

In order to achieve low energy consumption while ensuring a good indoor comfort level for the residents, it was an ambition from the very beginning when the building was designed to attain air tightness below 1.0 l/s per m² tested at 50 Pa pressure difference (according to DS/EN 13829), which is approx. 33% below the Danish building code requirements. Prior to the renovation, a blower door test showed an air infiltration rate of 6.4 l/s per m^2, and consequently the objective of reaching 1.0 l/s per m² was quite ambitious. Therefore, the tightness requirement was an important point from the very beginning and throughout the design and building process so as to ensure that the building could meet the requirements for a low energy class 1 building.

To illustrate the importance of air tightness, the energy calculation from the renovated building was compared to the total energy consumption of the building. The results are seen in FIG 3. The result for the blower door test was in this case 0.97 l/s per m², which is very impressive for an existing house. FIG 3 also shows that air tightness is a parameter, which can easily make energy consumption vary with 14% from the level corresponding to passive house standard to Danish house standard realised as of from December 2010.

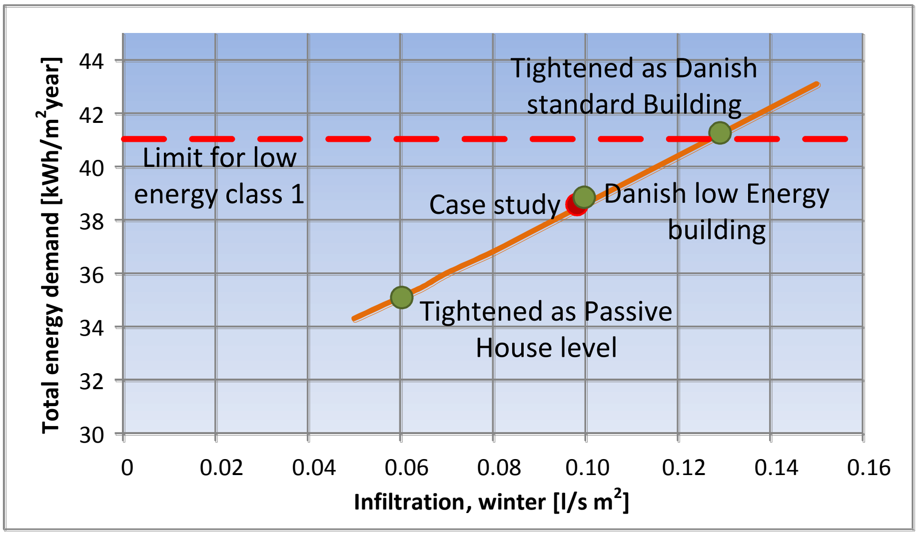


FIG 3. The total energy demand as a function of infiltration (and thereby air tightness).

2.2 Installation and use of a ventilation system in an existing building

Since the air tightness of the building envelope is at a level similar to new low energy houses, it has been possible to maximize the impact of the installed ventilation system. The ventilation system contributes positively to an improved indoor climate while saving on energy consumption for heating. A highly effective ventilation system was chosen and installed in a 60x60 cm closet with connections on top of the unit. The heat exchanger was a 1 m long counter flow heat exchanger with a dry efficiency of approx. 90% and with a minimal pressure drop. Measurements resulted in SFP values around 0.4 to 0.5 kJ/m^3 with an external pressure drop of approx. 55 Pa for the installations in the house. The unit is not equipped with any pre or post heating due to the high efficiency of the exchanger.

2.2.1 Challenges with mechanical ventilation in existing buildings

When applying mechanical ventilation in an existing building, one of the great challenges is to place the ducts in the house in a way, which will result in low pressure loss and at the same time make sure that the ducts fit naturally into the house interior. In this case, the mechanical ventilation unit was placed in a newly designed technician cupboard in the scullery from where the ducts could be allocated to the individual rooms. Since the house has two floors, it was necessary to install a cabinet on the first floor to enable a vertical transmission of the ducts to the first floor rooms.

At the ground floor, a central, integrated installation wall was designed where the supply ducts to the individual rooms were placed and hidden. The installation wall is a floor to ceiling cabinet wall in the kitchen. The ducts for supply and exhaust air were positioned over the cabinet. All the ducts in the renovated house have thereby been possible to hide and the only indications of the new ventilation system are the air vents in each room, see FIG 4.

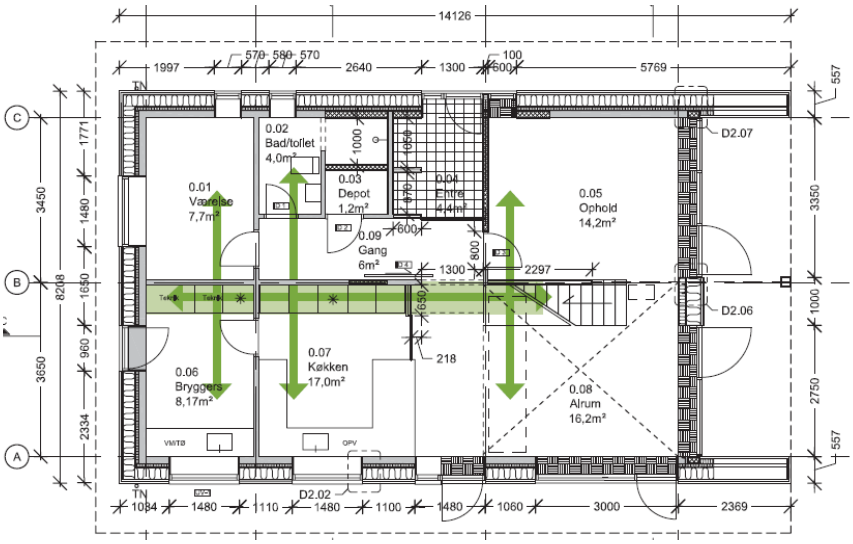


FIG 4. Ventilation principle at the ground level. (Pluskontoret)

2.3 Strategy for use of natural ventilation

In order to save energy for mechanical ventilation in periods when the outside air temperature is suitable as ventilation air, natural ventilation has been adapted as a secondary ventilation strategy. The overall ventilation system is designed to exploit the mechanical ventilation in the heating period maximizing the passive heat recovery and, during the transition periods and summer, use natural ventilation by buoyancy forces in the kitchen and family living room where a solar chimney for the polluted return air is installed. The principle for natural ventilation is shown in FIG 5a and the solar chimney is shown in FIG 5b.

a.) b.)

FIG 5. a.) Principle for natural ventilation, b.) Solar chimney. (Pluskontoret)

When outdoor temperatures are above 16-18 °C, fresh air is supplied through a by-pass in the ventilation system, the skylight located inside the solar chimney is opened, the extract air fan in the unit is stopped and the return air goes through the solar chimney. This reduces the electricity for fan operation by 50% when the system goes into "natural ventilation mode”. To ensure sufficient ventilation in the bathrooms, moisture sensors have been installed to ensure that the extract air fan starts up and removes moisture when necessary. Otherwise, the users are able to turn on the extract fan for approx. 20 min by pressing a switch in the kitchen area or bathrooms where needed.

The solar chimney ensures that the venting system also works with the skylight when it is raining outside or the wind is blowing at high speeds, where before the skylight was forced to close in these cases. The solar chimney may also increase the ventilation effect when the sun heats up the air inside the chimney.
The ventilation unit only stops the extract air fan when the skylight located inside the solar chimney is opened by users. The rest of the roof windows will not affect the ventilation system, and thus it is envisaged that the residents themselves will help ensure low energy consumption in the house.

3. Results

The main objective for the renovation project was saving energy, but it was also important to consider the indoor environment in order to avoid creating an unhealthy environment as a side effect of the airtight energy-friendly house. Therefore, the project was followed by detailed measurements of the indoor environment (temperature, relative humidity and CO_2 levels) and energy consumption for space heating and hot water supply. The measurements were carried out both before and after the renovation in order to see whether the objective of 78% energy saving was obtained.

3.1 Obtained energy savings

The results of the measurements are seen in FIG 6. The results based on the first six months after renovation show a reduction in the total energy consumption of 69%. Even though it is lower than the stated objective, it is still very impressive considering all the challenges of the project.

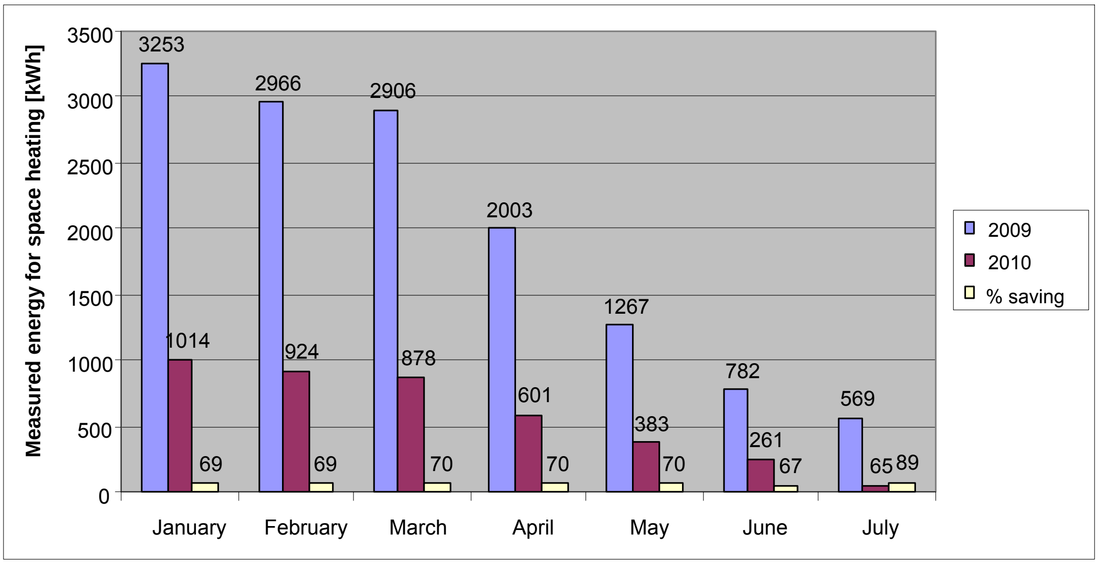


FIG 6. Measured energy consumption for space heating before (2009) and after (2010) the renovation (Larsen, 2010).

3.2 Improvement of the indoor environment

Prior to the renovation, the house was only ventilated by a large infiltration caused by leakages in the house and by windows being opened by the occupants. After the renovation, the mechanical ventilation system should take care of this and hopefully result in an improved indoor environment. The indoor environment was evaluated after the specifications found in CR 1752 (1998). The objective was to achieve category B, which for temperatures corresponds to 23-26°C during summer and 20-24°C during winter. For the CO_2 level, category B stands for <1030 ppm (with outdoor conditions corresponding to 370 ppm). Finally, the relative humidity should be between 30% and 70%. The results from the measurements are shown in FIG 7. Here, indoor temperatures and CO_2 levels have both improved after the renovation. The relative humidity did not change significantly.

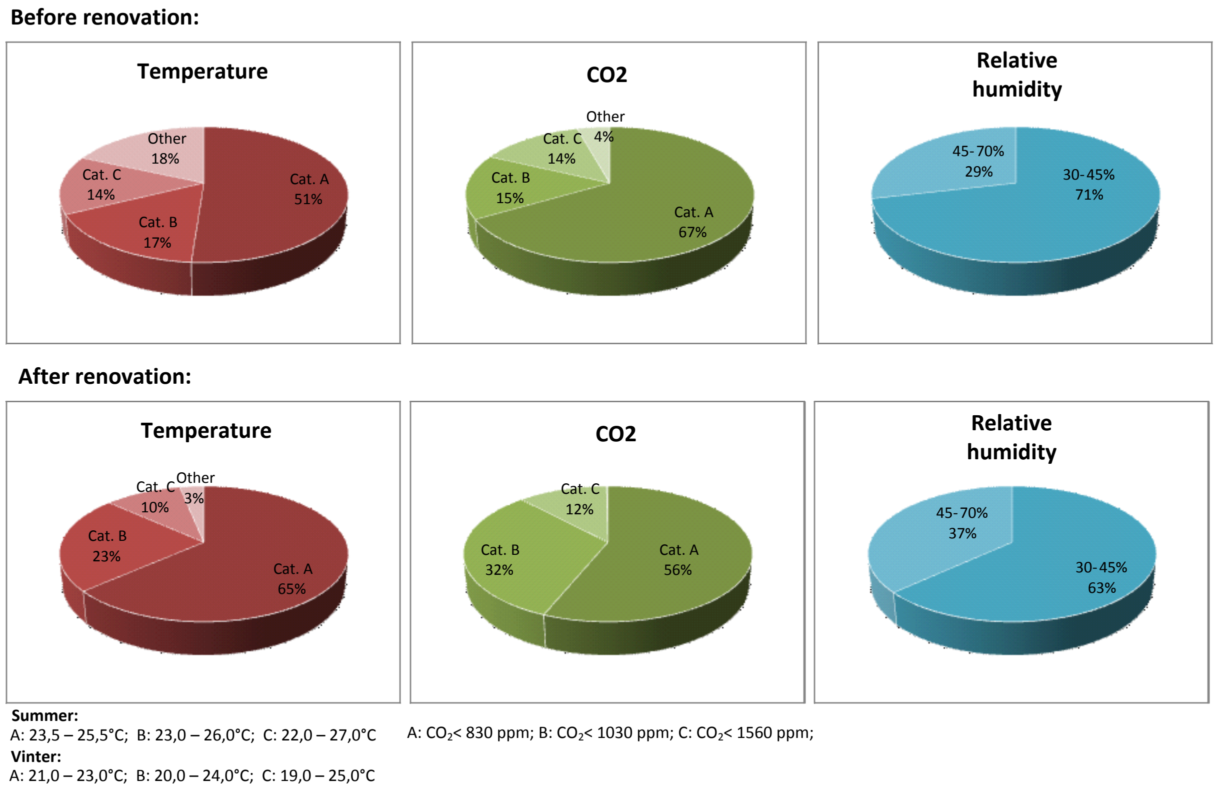


FIG 7. Results from evaluation of the indoor environment (Larsen, 2010)

4. Conclusions

During an extensive renovation of a detached single-family house constructed in the beginning of the nineteen seventies, the objective was to achieve a 78% reduction in energy consumption. In order to reach this ambition, new strategies for renovation was taken into use. A new façade system was designed, which was mounted on the outside of the inner wall of the old house. This solution improved the air tightness of the house, which in the final blower door test had improved from 6.4 l/s per m^2 to only 0.97 l/s per m^2, which corresponds to the new Danish low energy houses standards. In addition, the energy efficiency of the house was improved further with a high level of heat recovery by installing a mechanical ventilation system, with a high level of heat recovery. The mechanical ventilation system was combined with natural ventilation during summer and transition periods in order to increase the energy savings further.

The project was evaluated based on measurements of energy consumption and indoor environment, which showed a reduction in energy consumption of around 69% after the first six months. Moreover, the indoor environment had improved, so the objective for both energy savings and improvement of indoor environment was accomplished.

5. Acknowledgements

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