EuroSun 2010 – COST EFFECTIVE ENERGETIC REFURBISHMENT OF OFFICE BUILDINGS IN NORWAY

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Abstract

The energy consumption of an existing office building, built in 2001 in Trondheim in Norway has been monitored over a period of several years. It shows a total specific average energy use of 188 kWh/(m2a). During the next couple of years Norway is planning to tighten the building regulations with regard to heating losses, net energy demand, delivered energy, and share of renewable energy sources. Thus it was important to estimate the measures of different refurbishment strategies. Here, cost efficiency was of major concern as also pointed out by Norwegian authorities and contrasted with additional information about CO_2 emission reductions. The measured office building was simulated using advanced building performance software and validated with measurements. Then, the energy savings of different refurbishment strategies were estimated. The results show the potential of the different measures. Potential energy savings were directly evaluated by cost effectiveness and resulted in maximum investment costs that can be spent. This was contrasted with linked information about CO_2 reductions. A sensitivity analysis of economic parameters was performed.

1. Introduction

Energetic refurbishment of the Norwegian building stock has been pointed out as a major strategy in cutting greenhouse gas (GHG) emissions according to the Kyoto-protocol [4]. The energy consumption of an existing office building, built in 2001 in Trondheim, Norway has been monitored over a period of several years. It shows a total specific average energy use of 188 kWh/(m^2a). An energy labeling scheme has newly been introduced in Norway and will be compulsory from 2012 (www.energimerking.no). During the same period Norway is planning to tighten the building regulations with regard to heating losses, net energy demand, delivered energy, and share of renewable energy sources [13].

2. Purpose of this study

It was important to estimate the measures of an refurbishment that fulfill future requirements with regard to

- Energy labeling system (to be compulsory in 2012), see (www.energimerking.no).
- Revised technical regulations (TEK07) to be expected in 2011, [12,13]
- Minimized CO_2 emissions according to [5,10]

Here, cost efficiency was of major concern as also pointed out by Norwegian authorities [12].

3. Method

A model of the building has been set up and validated with measured data. Cost effectiveness analysis has been applied in order to determine measures to reduce delivered energy (as required in energy labeling scheme) in order to comply with technical requirements and/or ‘energy labeling’.

A dynamic building simulation program (Simien) was used and validated with measured data. [3]. A detailed description of the building simulation model can be found [7]. Here, first net energy demand of the building was simulated with Trondheim weather data (Meteonorm) based on average measured weather data from the period 1961-1990. This model (MOD1) was validated by comparing results with measurements.

TEK07 requires further normalized user profiles to be used. Operation times of ventilation system and lighting are pre-set together with airflow rates of the ventilation system during operation as well as outside operation. These user specific figures were different in the validation model described above. Thus a second model (MOD2) was necessary which gave total simulated and normalized delivered energy. Results were used together with recommended energy supply system efficiencies from NS3031 in order to determine delivered energy. This was done by running the normalized model (MOD2).

Then, the energy savings of three different refurbishment strategies were estimated.

- The first strategy applies several measures in order to reduce heat losses of the building envelope. Here, changing windows, walls, and roof was considered together with air tightness strategies.
- The second strategy applies further measures to enhance energy efficiency and passive solar heat by shifting ventilation components (heat recovery system and ducts) and by shifting the shading system (from manual to automatic) and windows.
- The third strategy identifies measures regarding the energy supply system, applying not only solar thermal and PV systems but also looking at other systems with very low operational CO_2 emissions (wood boiler, heat pump).

With the help of potential energy savings and projected energy costs the maximum investment costs were estimated that result in cost effective refurbishment. Here, an interest rate of 4%, a building life time of 20 and 50 years were taken as basis according to the technical requirements [12].

The equation used for determining cost effectiveness was derived from TEK07 and is based on net present values (NPV) calculations:

$$I \leq B \times \frac{1-(1+r)^{-n}}{r} - NPV \tag{1}$$

with

I = maximum cost effective investment (in NOK) for NPV = 0

B = annual savings (in NOK/a)

$$B = E \times C \tag{2}$$

with

E = annual energy savings (in kWh/a), calculated from MOD1 for different measures

C = annual energy costs (NOK/kWh) for all delivered energy (heating, cooling, electricity), here assumed to be between 0.60 and 1.0 NOK/kWh

r = interest rate of 4%

n = lifetime of building (50 years)

It can be seen from eq. (1) that smaller investments than I lead to a positive NPV indicating cost effectiveness. Equation (2) indicates that both annual savings as well as energy costs have an linear influence on annual savings B. It is assumed that annual energy savings E are constant over lifetime of building (n). When looking at past weather data it can be seen that annual heating demand is linear to outdoor temperatures (or heating degree days). This would in reality result in variations of annual energy savings accordingly but even out over a period of 50 years. Annual energy costs are also not constant but rather raising linear [1]. In addition, electricity tariffs in commercial buildings are very often coupled to maximum power requirements. Here, energy costs C between 0.60 and 1.0 NOK/kWh were assumed. The used interest rate of 4% was taken from recommendations in TEK07 [12].

Table 1. Description and comparison of energy savings of different measures for MOD1 and MOD2.

strategy		**parameter**	**energy savings**	
			MOD1	**MOD2**
no.	**description**	**description**	**kWh/(m^2a) (a)**	**kWh/(m^2a) (a)**
1.1	shifting windows	High efficient windows with insulated frame, U=0.66 W/(m2K)	14.4	9.8
1.2	as option 1.1 with improved air tightness	Air tightening windows to walls, infiltration rate at 50Pa n50=1.0	21.3	13.8
1.3	adding 200mm insulation	U=0.17 W/(m2K)	1.4	0.7
1.4	as option 1.3 with improved air tightness	Air tightening of building envelope, infiltration rate at 50Pa n50=1.0	9.4	4.8
2.1	shifting heat exchanger	3 new heat exchanger with temperature efficiency η=0.8	32.7	41.2
2.2	as option 2.1 with improved ducts	Improved ductwork in the building, specific fan power SFP=2.0 kW/(m3/s)	37.4	47.8
2.3	shifting to energy efficient lighting	Installed lighting power, ql=8W/m2	9.8	17.8

3.1	adding heat pump	36 kW with 4000h operation hours and coefficient of operation COP=2.5	16.4	16.4
3.2	adding solar thermal system on roof	36m2 solar thermal panels with annual 18000 kWh hot water production, efficiency factor e = 8,55 (b)	2.3	2.3
3.3	adding PV on roof	100kWp crystalline silicon cells installed on appr. 1000m2 roof area at 35° angle facing south with system losses appr. 22% (c)	11.2	11.2

Notes: (a) heated floor area according to NS3940 [11]

(b) taken from [2]

(c) taken from [6]

CO_2 emission reductions of different measures were calculated with

$$e = E \times C_{CO_2} \tag{3}$$

with

e = CO_2 emission reduction in g CO_{2eq}
E = annual energy savings (in kWh/a), see eq. (2)
C_{CO2} = emission factor (g CO_2/kWh), taken from [5]
Here, CO_2 factors were taken from [5] and calculated from delivered energy derived from MOD2 (with normalized data) according to Norwegian standard NS 3031 [10].

Finally, CO_2 savings per investment and savings was estimated using CO_2 emissions and comparing them with cost savings.

$$R_{CO_2} = \frac{e}{\left(I - E \times n\right)} \tag{4}$$

with

e = CO_2 emission reduction in g CO_{2eq}
I = maximum cost effective investment (in NOK), see eq. (1)
E = annual energy savings (in kWh/a), see eq. (2)

4. Results

The results show the potential of the different measures in annual energy savings. Potential energy savings were directly evaluated by cost effectiveness and resulted in maximum investment costs that can be spent. This provides helpful information to building owners who want to upgrade their building. In addition CO_2 emission reductions were calculated. A sensitivity analysis of economic parameters (energy costs between 0.6 and 1.0 NOK/kWh) was performed in order to get more confidence in the results [8,9].

Fig. 1 shows the comparison in CO_2 emission reductions for the different strategies. Here, emission reductions are counted positive, while an increase in emissions is shown as negative values and are divided into heating, cooling, and electricity. It can be seen that strategy 1 (1.1 to 1.4) reduces emissions from heating and increases emissions from cooling and electricity slightly with option 1.3 showing the smallest reductions of all options. Strategy 2 provides the highest emission reductions with option 2.2 providing even more reductions from electricity savings. Strategy 2.3 reduces emissions from cooling and electricity but increases emissions from heating due to the reduction of internal heat gains. Strategy 3.1 reduces emissions from heating and cooling but increases emissions from electricity which results in a total reduction of 40 t CO_{2eq}. Strategy 3.2 give rather small savings of 9.5 t CO_{2eq} due to the limited need for hot water (which is 2.5kWh/(m^2a) in offices). In strategy 3.3 a 1000m^2 PV system was added on the roof which provides 11.2 kWh/(m^2a) electricity. This leads to CO_2 emission reduction of 88 t CO_{2eq}.

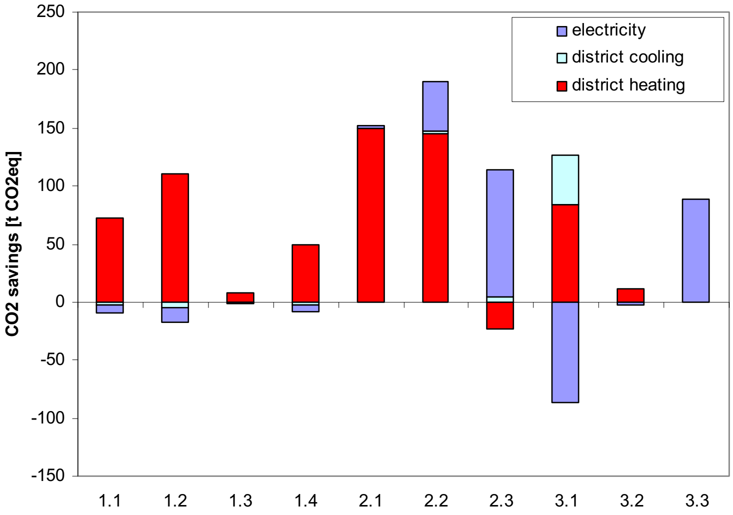

Fig. 1. CO_2 emission reductions of different measures as described in Table 1.

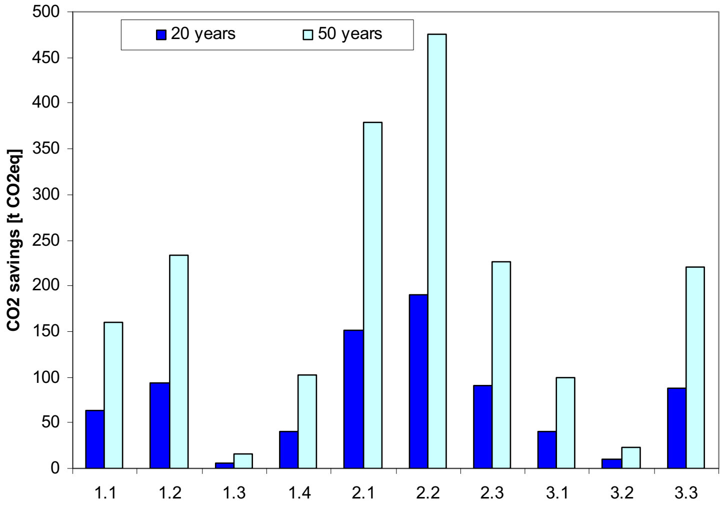

Fig. 2. CO2 savings for different life spans.

Fig. 2 summarizes the CO_2 emission savings for the different strategies for two different life time spans (20 and 50 years). It can be seen that lowest savings are expected from adding 200mm insulation (strategy 1.3) with 6.2 t CO_{2eq} over 20 years and 15.6 t CO_{2eq} over 50 years. The highest savings are expected from shifting to effective heat exchangers and improved ductwork (strategy 2.2) with 190.4 t CO_{2eq} over 20 years and 226.1 t CO_{2eq} over 50 years.

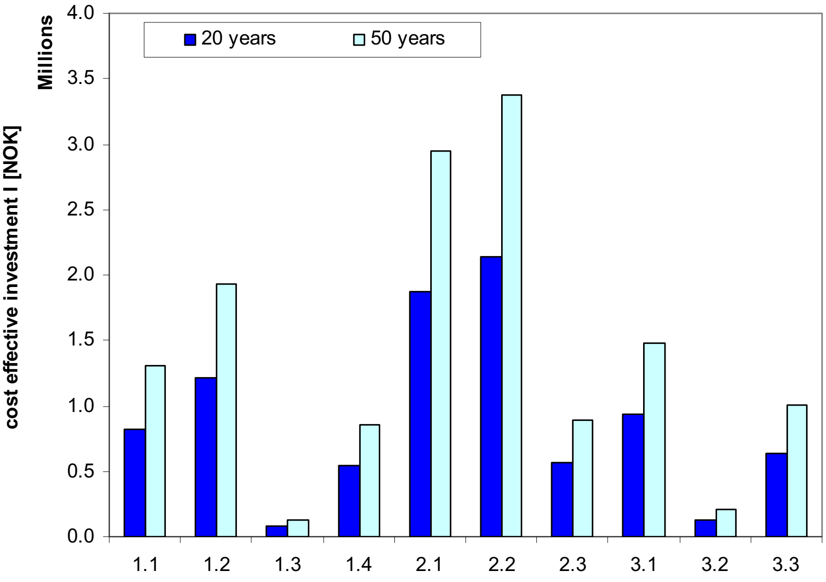

Fig. 3. Cost effective investments according to eq. (1) for different life spans.

Fig. 3 gives an overview of the cost effective investments for all different strategies from Table 1. It can be seen that the results reflect the reduction levels from Fig. 2 with the lowest cost effective investment is expected for adding 200mm insulation to be 82494 NOK (strategy 1.3) and the highest cost effective investment is expected for shifting to effective heat exchangers and improves ductwork (strategy 2.2) with 2.1 million NOK.

It can be seen that strategy 1.1 provides a maximum cost effective investment of I = 117NOK/m^2 (n = 20 years service life span). If an air tightening measure is considered (strategy 1.2) the resulting investment I increases to 173 NOK/m^2 which still makes this option difficult to justify. Window area in this building is 1806m2 (38%) which results in a maximum investment of 456 NOK/m^2 window area, and 674 NOK/m^2 respectively (strategy 1.3). This investment is not enough to shift windows under normal circumstances (i.e. no subsidies or incentives from other refurbishment needs).

Strategy 1.3 provides a maximum cost effective investment of I = 19NOK/m^2 (n = 50 years service life span). This investment is not enough to add 200mm insulation under normal circumstances (i.e. no subsidies or incentives from other refurbishment needs). If an air tightening measure is considered (strategy 1.4) the resulting investment I increases to 121 NOK/m^2 which still makes this strategy difficult to justify. Wall area in this building is 2903m^2 which results in a maximum investment of 45 NOK/m^2 wall area, and 293 NOK/m^2 respectively (option 2b). This investment is not enough to add

200mm insulation under normal circumstances (i.e. no subsidies or incentives from other refurbishment needs).

Strategy 2.1 provides a maximum cost effective investment of I = 266NOK/m^2 (n = 20 years service life span). This is 622474 NOK per unit which should be possible to get (3 air handling units with total of 3 heat exchangers). If an additional measure for improvements of the ductwork is considered (strategy 2.2) the resulting investment I increases to 305 NOK/m^2 which is total 3377085 NOK.

Strategy 2.3 provides a maximum cost effective investment of I = 80NOK/m^2 (n = 20 years service life span). This is definitely not sufficient for a complete shift of all lighting in the building (i.e. 10NOK/W).

Strategy 3.1 provides a maximum cost effective investment of I = 939363 NOK (n = 20 years service life span). This investment I could be considered for installing a 36kW heat pump.

Strategy 3.2 provides a maximum cost effective investment of I = 129609 NOK (n = 20 years service life span). This is sufficient to install 36m^2 solar thermal system at costs of 3500NOK/m^2 (at annual energy gains of 500kWh/m^2) [13].

Strategy 3.3 provides a maximum cost effective investment of I = 318805 NOK (n = 20 years service life span). This is sufficient to install 1000m^2 photovoltaic solar system at costs of 4NOK/kWh (at annual energy gains of 78.2kWh/m^2) [15].

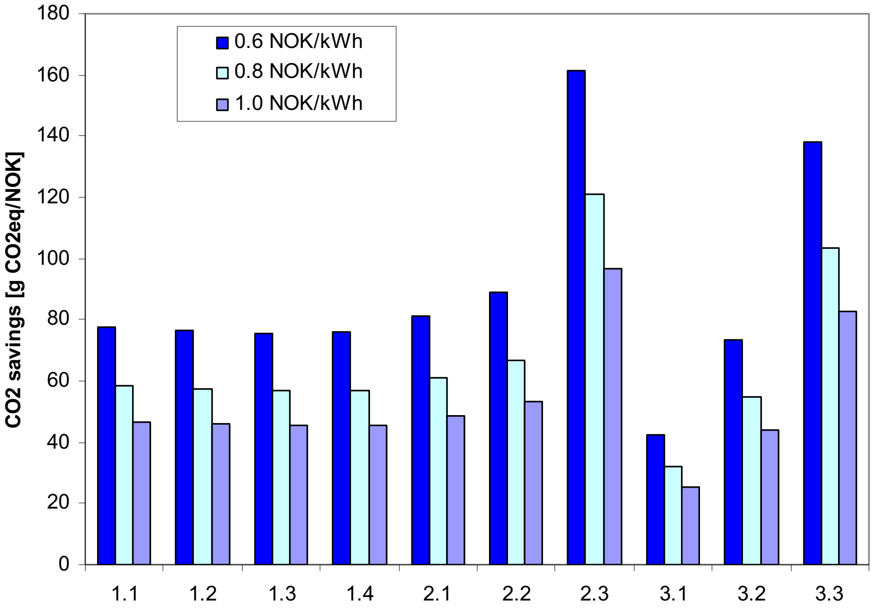

Fig. 4. CO_2 emission reductions per invested NOK for different energy prices (NOK/kWh) at 20 years life time span.

Fig. 4 summarizes the CO_2 emission reductions per invested NOK for different energy prices. It can be seen that higher energy prices reduce the CO_2 savings per NOK. The 100kWp PV system (strategy 3.3) provides the highest CO_2 emission savings per investment followed by shifting to effective heat exchangers and improved ductwork (strategy 2.2). Strategies 1 and 2.3 as stated before does not provide cost effective investment and can thus not be considered.

5. Conclusion

The results show clearly that it is possible to upgrade buildings to reduce CO_2 emissions in a cost effective way. The three steps strategy provides a good help in prioritizing investment costs:

- Refurbishment of the building envelope has to be coupled with air tightening measures.
- Changing inefficient heat exchangers is a very cost effective measure.
- The energy supply system provides a good potential for reducing CO_2 emissions. Cost effectiveness depends on the type of existing system to be replaced.

Building owners will be able to evaluate their building and find those measures that are cost effective and more appropriate to reduce CO_2 emissions. The introduction of public incentives based on the results can help to direct refurbishment work towards GHG emission reductions. This work can help to find practicable and cost effective incentives schemes that help to reduce CO_{2eq} emissions cost effectively.

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