Measurement and simulation of a commercial building in Norway

Matthias Haase, Catherine Grini, and Tore Wigenstad
NTNU, Department of Architectural Design, History and Technology
SINTEF Building and Infrastructure, Buildings department, energy and environment group

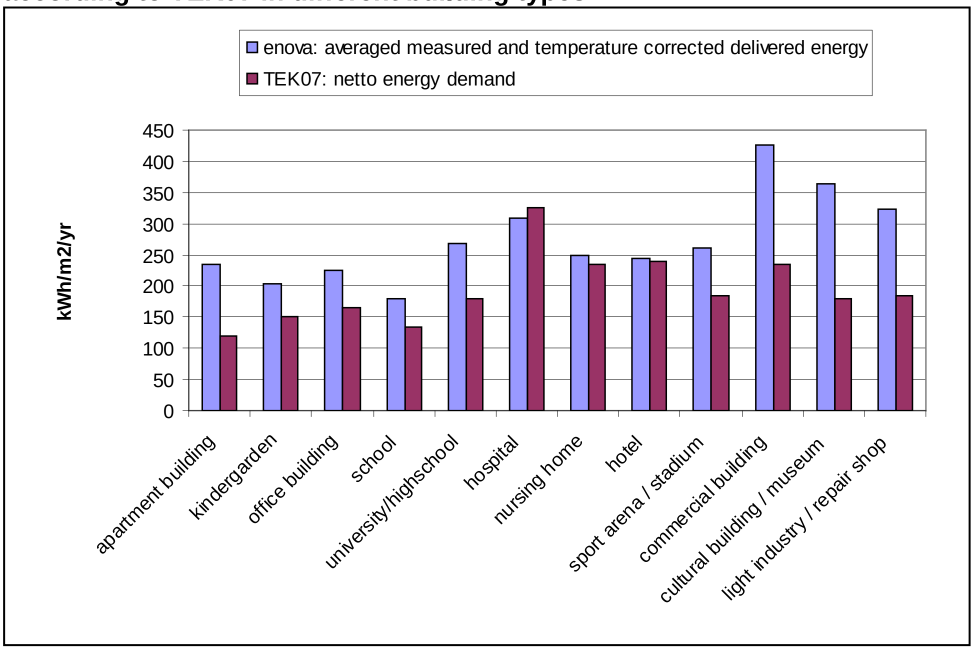
Abstract

A commercial building in Trondheim municipality, renting the entire building and being responsible for further use, was energetically measured over a 3 years period. The building has 6 storeys, 5 above ground level, a basement floor (+ some floor on the 6th floor as management and ventilation plant rooms) and was built in 2001. The building consists of communal offices and shops on the 1st and various offices on 2 to 5 floor. The plan shows a business area in the ground floor and mainly of offices in the other floors while parking is located in parts of the basement. It consists of 2 almost rectangular parts linked together. Gross floor area is approx. 8425m² (heated floor area: 7013m2). The building is compact, with 200mm insulation and windows with an U-value for the entire window of 1.4 W / m². K. External roller shutters, manually controlled, were used as solar controls. The ventilation system consists of balanced ventilation with heat exchanger, manually controlled after outdoor temperature.
District heating and cooling was purchased together with electricity from the local energy supplier. Total energy supply was measured to be 191 kWh/(m^2.a).
The building energy consumption was simulated and a comparison with measured data shows good agreement. The difficulties with modeling the building are described and the recommendations derived from that are discussed. Then it was possible to analyze the energy use in the building in more detail and different measures for reducing energy use could be determined. A cost benefit analysis showed a list of cost effective energy saving measures. Here, it became clear that e.g. the optimized use of the ventilation system is much more cost effective than reducing the U-value of the windows by shifting to new windows.

Introduction

Energy use in buildings varies over different building types. Figure 1 shows delivered energy in different building types in Norway and the net energy frame according to technical requirements TEK07. It can be seen that in office buildings as well as commercial buildings further energy savings are needed.

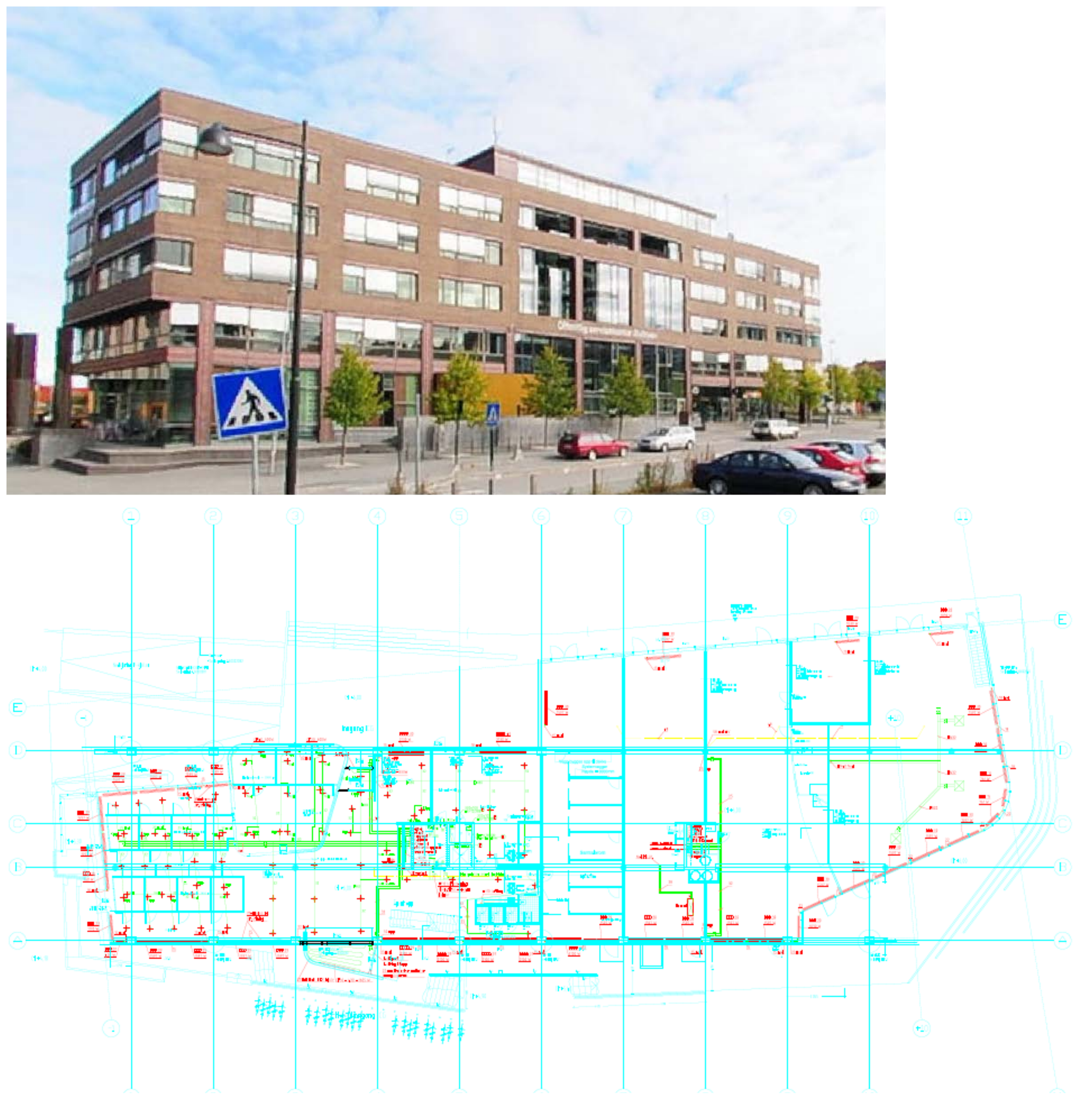
Figure 1: measured and temperature corrected delivered energy and net energy demand according to TEK07 in different building types



Measured energy use

A commercial building in Trondheim municipality, renting the entire building and being responsible for further use, was energetically measured over a 3 years period. The building has 6 storeys, 5 above ground level, a basement floor (+ some floor on the 6th floor as management and ventilation plant rooms) and was built in 2001. The building consists of communal offices and shops on the 1st and various offices on 2 to 5 floor. The plan shows a business area in the ground floor and mainly of offices in the other floors while parking is located in parts of the basement. It consists of 2 almost rectangular parts linked together. Gross floor area is approx. 8425m² (heated floor area: 7013m^2). The building is compact, with 200mm insulation and windows with an U-value for the entire window of 1.4 W / m². K. External roller shutters, manually controlled, were used as solar controls. The ventilation system consists of balanced ventilation with heat exchanger, manually controlled after outdoor temperature.
District heating and cooling was purchased together with electricity from the local energy supplier.

Figure 2: View and plan of the building (picture from www.gulesider.no; plan from Skipnes Arkitekter AS)



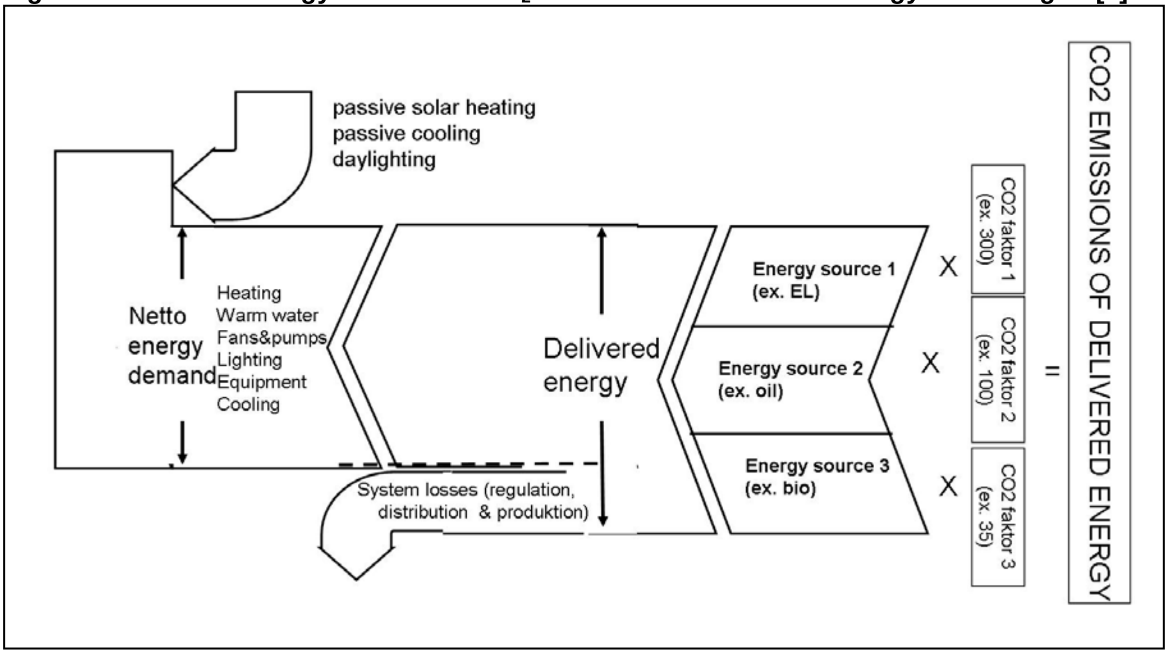
Measured delivered energy for this office building was 191 kWh/(m^2a) in the period 2006-2008. After heating degree days correction (for 2008), the delivered energy is 218 kWh/(m^2·a) for normal weather (average measured in period 1961-1990).

Energy use in commercial buildings in Norway

When looking at energy use in buildings the following three items are important as illustrated in Figure 3:

- Net energy demand (according to TEK)
- Delivered energy (efficiency factors from NS3031)
- CO_2 emissions from delivered energy (factors)

Figure 3: From net energy demand to CO_2 emissions of delivered energy according to [8]



Net energy demand
National building regulations in Norway have been revised and tightened several times since the first numerical requirements were introduced in 1949. The purpose of the recurrent upgrades has basically been to reduce the heating demand, thus reducing the overall energy use in the building.

As a consequence of the Norwegian partnership in the EEC, Norway is obliged to implement the EU Energy Performance of Buildings Directive (EPBD) in the national laws and regulations [3,12]. Thus, the new building codes and guidelines are also revised. While the former regulations concerned building's heating energy demand, the new regulations incorporate all energy needed to operate the building.

The calculation method has been revised in Norway in 2007 [8]. In addition, building regulations were revised [12] introducing two ways to fulfill the energy requirements for a building.

- Energy measure method (Energitiltak)
- Energy frame method (Energirammer)

The so-called Energy measure method (Energitiltak) has to set requirements for certain building elements and installations. The "measures" are listed in Table 1. For code compliance these requirements have to be fulfilled and documented.

Table 1: The new building regulations for commercial and residential buildings [12]

	Commercial	
	TEK 1997	**TEK 2007**
Glass and door area [a]	20 %	20 %
U-value external wall (W/m^2K)	0.22	0.18
U-value roof (W/m^2K)	0.15	0.13
U-value floor on ground (W/m^2K)	0.15	0.15
U-value windows / doors [b] (W/m^2K)	1.6 / 2.0	1.2 /1.2
U-value glazed walls and roofs (W/m^2K)	same as for windows	same as for windows
normalized thermal bridge value (W/m^2)	Included in window	0.06
air tightness [c] (ach)	1.5	1.5
heat recovery [d] (%)	no requirements	70
specific fan power (SFP) ($kW/(m^3/s)$)	no requirements	2.0/1.0 [e]
local cooling	no requirements	shall be avoided [f]
temperature control	no requirements	night set-back to 19°C

[a] maximum percentage of the buildings heated floor area as defined in NS3031

[b] incl. frames

[c] air changes per hour at 50Pa pressure

[d] annual mean temperature efficiency

[e] SFP day/night

[f] automatic solar shading devices or other measures should be used to fulfill the thermal comfort requirements without use of local cooling equipment

Alternatively, if the net energy demand for the building, calculated according to the methodology established in the new Norwegian Standard NS3031 (2007), is within the energy frame for the building's category, the regulations are also satisfied [8]. Here, a holistic approach was chosen, accounting for all energy a building needs (see Table 2 for all components). The frame for aggregate net energy demand for different building types is also shown in the last row of Table 2. Since the frame is based on net specific energy demand per year, the efficiencies of the energy systems are not taken into account. This means that for example the coefficient of performance of a highly efficient mechanical cooling system is not rewarded. However, passive measures that reduce the net cooling demand will contribute to satisfy the energy frame. This has led to a renewed interest in utilizing passive measures to decrease the total energy use in all building types.

Table 2: Energy frame for different building types (kWh/m2 per heated floor area)

	office building	**retail building**
heating	33	45
heating coil	21	34
warm water	5	10
fans and pumps	22	42
lighting	25	56
technical equipment	34	4
cooling	0	0
cooling coil	24	47
sum netto energy demand	164	238
rounded energy frame	165	235

[a] heated floor area according to NS3031

However, there are still minimum requirements concerning the U-values and air tightness of the building envelope which help to maintain a good insulation standard. These are listed in Appendix A, Table 3 of TEK07 [12].

TEK07 is now under revision. A strengthening of the requirements is envisioned [7,14].

Delivered energy
In order to account for delivered energy system losses due to regulation, distribution, and production have to be taken into consideration and allow to link between net energy demand and delivered energy. Annual average energy system efficiencies are recommended to use in Table B9 of [8]. Advanced building simulation tools can help to calculate system losses more accurately.

The only system efficiency that is required to use in TEK07 is the heat recovery system efficiency which directly reduces net energy demand of ventilation air (due to heating of ventilation air).

Table 3: Efficiency factors for different energy supply systems (from Table B9; NS3031)

Supply system	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Supply of heating and hot water	el	oil boiler	gas boiler	district heating	solar thermal	biofuel	PV
efficiency factor	0.98	0.73	0.73	0.84	8.55	0.84	100

It can be seen from Table 3 that a heating system based on electricity has an efficiency of 0.98 while a water based district heating system has an efficiency of 0.84, i.e. the same building with identical net energy demand and two different supply systems shows 14% difference in delivered energy.

Table 4 gives the maximum amount of delivered energy for labeling buildings.

Table 4: Delivered energy in energy labeling system (from energimerking.no)

	delivered energy						
building type	**A**	**B**	**C**	**D**	**E**	**F**	**G**
	<	**<**	**<**	**<**	**<**	**<**	**<**
	kWh/m^2	**kWh/m^2**	**kWh/m^2**	**kWh/m^2**	**kWh/m^2**	**kWh/m^2**	**kWh/m^2**
office building	84	126	168	215	263	395	no limit
commercial building	129	194	258	309	360	540	no limit

Objectives

For a commercial building in Trondheim municipality, total energy supply was measured to be 218 kWh/(m^2.a). It was interesting to calculate the delivered energy with normalized operation parameter and to analyze those building parameters that have the largest influence on further reduction of delivered energy for the building. Especially interesting were those measures that cost effectively reduce net energy demand and could lead to an improved energy labeling (class C, B, and/or A) and the resulting maximum investment of different upgrading options.

Methodology

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 [4]. A detailed description of the building simulation model can be found [6]. 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. This resulted in a second model (MOD2) with total simulated and normalized delivered energy. Results were used together with recommended energy supply system efficiencies from NS3031 in order to determine delivered energy. Different measures were applied that ensure an upgrade from energy label D to C, B, A. This was done by running the normalized model (MOD2).

Then, cost effectiveness (maximum investment costs for saved amount of money NOK/m^2) for different measures were calculated with real operation parameter (MOD1). The 2-model method is described in Table 5.

Table 5: 2-model method

Model	**MOD1**	**MOD2**
Operation parameter for lighting, ventilation, equipment	Real	Normalized (a)
Climate data	Trondheim, TMY (b)	Oslo, DRY (c)
System losses (a)	normalized	normalized
Energy calculation results	Delivered energy	Normalized delivered energy
Used for	Validation (comparison with measured data) Real energy savings	Energy labeling CO2 emissions

Notes: (a) according to NS3031, [8]
(b) TMY, typical meteorological year (averages based on measurements in period 1961-1990)
(c) DRY, Design Reference Year (synthetically configured data set for design purposes)

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

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

with
I = maximum cost effective investment (in NOK/m2) for NPV = 0
B = annual savings (in NOK/(m^{2}a))

$$B = E \times C \quad (2)$$

with
E = annual energy savings (in kWh/(m^{2}a)), calculated from MOD1 for different measures
C = annual energy costs (NOK/kWh), here assumed to be 0.60 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 (www.ssb.no). In addition, electricity tariffs in commercial buildings are very often coupled to maximum power requirements. But here constant energy costs of C = 0.60 NOK/kWh were assumed.

Different measures that were taken into consideration:

- Shifting windows (better U-value, better air tightness)
- Shifting walls (better U-value, better air tightness)
- Shifting ventilation system components (heat recovery unit, ductwork)
- Shifting lighting
- Shifting heating energy supply system (heat pump)
- Adding solar system on roof (solar thermal, PV)

The different options are described in more detail in Table 7 below.

Results

Figure 4 gives the results of the comparison between measured and simulated data. Measured heating energy was adjusted with heating degree days (HDD) as all years appear to have been warmer than normal (measured average between 1961 and 1990). The average of the measured results from 2006-2008 is 211 kWh/(m^2a). The simulated delivered energy is shown in MOD1 and MOD2.

MOD1 is based on average measured Trondheim weather data from Meteonorm with real operation parameter and shows very good agreement with measurements (average) [1]. It can be seen that approximately half of the delivered energy is electricity and the other approximately half is delivered heat from district heating system. Measured average electricity is 86.8 kWh/(m^2a) and simulated electricity use is 86.9 kWh/(m^2a). Measured heating energy is 101.8 kWh/(m^2a) while simulated heating energy is 102.3 kWh/(m^2a). Measured cooling energy is14.3 kWh/(m^2a) while simulated cooling energy is 15.2 kWh/(m^2a). A more detailed analysis is shown in Figure 5 divided into monthly delivered electricity, heating and cooling. It can be seen that heating and cooling fit rather well with R^2 of 0.923 and 0.905 respectively, whereas electricity does not fit well (R^2 = 0.011). This is due to the mainly manual control scheme and implies a certain amount of uncertainty in this analysis.

MOD2 is based on the normalized operation parameter from TEK07 and gives different results. Delivered heating energy amounts to 107.3 kWh/(m^2a), cooling 36.4 kWh/(m^2a), and electricity 111 kWh/(m^2a). The results from MOD2 are now calculated delivered energy for this building according to NS3031 and can be used for assessing the energy label class. When comparing with energy labeling classes from Table 4 this building gets an energy label class E (<263 kWh/(m^2a)). The results were further used to identify energy savings in order to get energy label classes D, C, B, and A as detailed in Table 6 (column 3). It can be seen that energy savings of 40 kWh/(m^2a) are needed to get into energy label class D, 87 kWh/(m^2a) for class C, 129 kWh/(m^2a) for class B, and 171 kWh/(m^2a) for class A.

Figure 4: Measured and simulated delivered energy

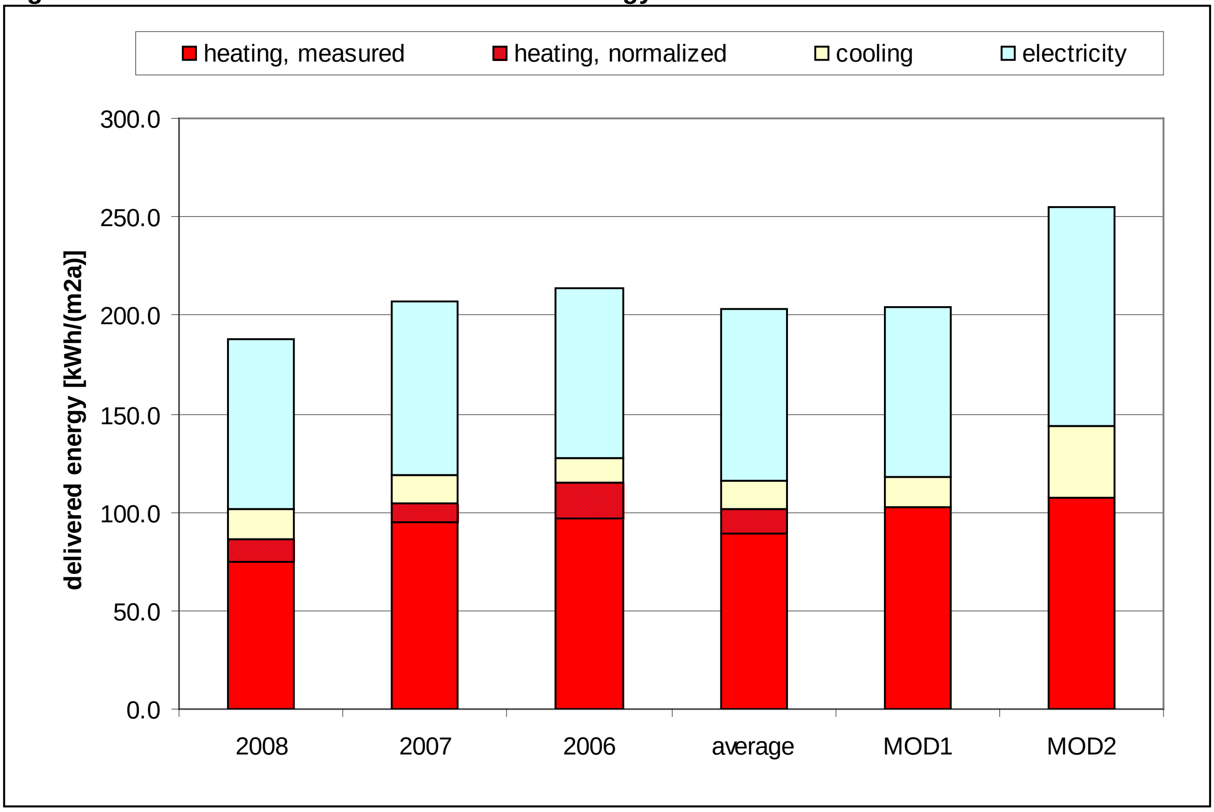


Figure 5: Detailed comparison of measured and simulated delivered energy

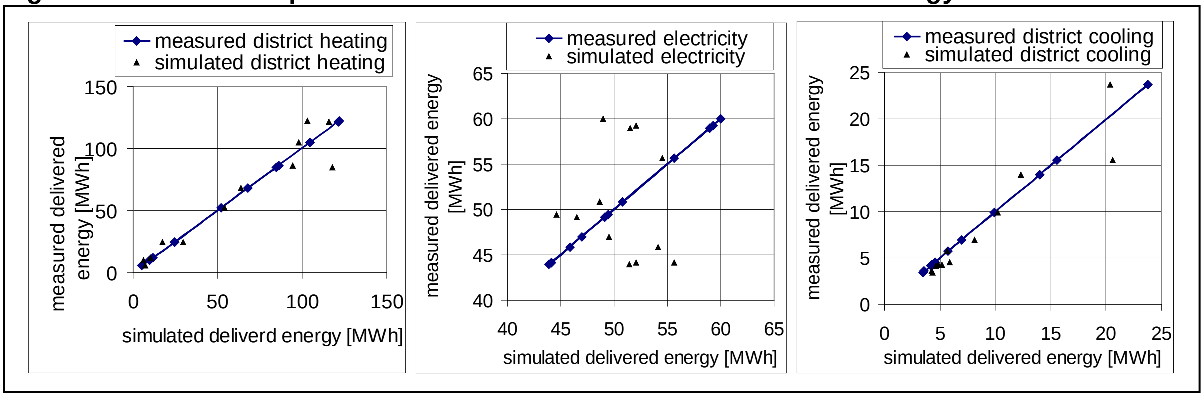


Table 6 shows the maximum investment I to upgrade the building to different labels (C, B, A) calculated from MOD2 as discussed above. It can be seen that upgrading the building to a label D building allows an maximum cost effective investment I = 326 NOK/m^2 or 2,286,763 NOK (with 7011m^2 heated floor area and 20 years live span). This equals to 485 NOK/m^2 façade area (with 4709m^2 façade area).

Table 6: Energy performance, savings and (theoretical) investment for different labels

Label	**Performance criteria (max. delivered energy)**	**Normalized energy savings (from MOD2)**	**Cost savings 0.6NOK/kWh**	**Cost effective investment I(20) (20years)**		**Cost effective investment I (50) (50years)**	
(a)	(kWh/m2a)	kWh/(m^{2}a)	NOK/(m^{2}a)	NOK/ m^2	NOK	NOK/ m^2	NOK
D	215	40	24	326	2286763	516	3614678
C	168	87	52.2	709	4973709	1121	7861925
B	126	129	77.4	1052	7374810	1663	11657338
A	84	171	102.6	1394	9775910	2204	15452750

Notes: (a) heated floor area according to NS3940 [9]

The energy savings that determine cost savings were determined with MOD2. Table 7 shows the results of both delivered energy savings (from MOD1 and MOD2) of the different options for energy reductions measures as described in detail in Table 8. The column on the far right is then showing the ratio of the two results. It can be seen that options 1 and 2 have a ration between 1.47 and 2.2 indicating that real energy savings are higher than predicted with normalized operation data (MOD2). Options 3 and 4 have a ration between 0.55 and 0.79 indicating that real energy savings are lower than predicted with normalized operation data (MOD2). Only options 5 to 7 give a ration of 1 indicating no difference between MOD1 and MOD2. This is explained by options 5 to 7 concerning the energy supply side which does not affect the different operation models (MOD1 and MOD2).

Figure 6 shows the comparison in saved energy for the different options. Here, energy savings are counted positive, while an increase in energy is shown as negative values and are divided into heating, cooling, and electricity. It can be seen that option 1 and 2 reduce heating and increase cooling and electricity slightly with option 2 showing the smallest savings of all options. Option 3 provides the highest energy savings with option 3b providing even more electricity savings. Option 4 reduces cooling and electricity but increases heating due to the reduction of internal heat gains. Option 5 reduces heating and cooling but increases electricity which results in a total reduction of 16.4 kWh/(m^{2}a). Option 6 give rather small savings due to the limited need for hot water (which is 50% of 5kWh/(m^{2}a) in offices). In option 7 a 1000m^2 PV system was added on the roof which provides 11.2 kWh/(m^{2}a) electricity.

In this respect only option 3 provides enough energy savings to upgrade the building to energy label D. It was further interesting to evaluate the maximum investment that accounts for a cost effective investment using equation (1).

Table 7: Description and comparison of energy savings of different measures for MOD1 and MOD2

option		parameter	energy savings		MOD1/ MOD2
			MOD1	MOD2	
no.	description	description	kWh/(m^2a) (a)	kWh/(m^2a) (a)	(-)
1	shifting windows	High efficient windows with insulated frame, U=0.66 W/m^2K	14.4	9.8	1.47
1b	as option 1 with improved air tightness	Air tightening windows to walls, n50=1.0	21.3	13.8	1.55
2	adding 200mm insulation	U=0.17 W/m^2K	1.4	0.7	2.20
2b	as option 2 with improved air tightness	Air tightening of building envelope, n50=1.0	9.4	4.8	1.97
3	shifting heat exchanger	3 new heat exchanger with n=0.8	32.7	41.2	0.79
3b	as option 3 with improved ducts	Improved ductwork in the building, SFP=2.0	37.4	47.8	0.78
4	shifting to energy efficient lighting	Installed lighting power ql=8W/m^2	9.8	17.8	0.55
5	adding heat pump	36 kW with 4000h operation hours and COP=2.5	16.4	16.4	1.00
6	adding solar thermal system on roof	36m^2 solar thermal panels with annual 18000 kWh hot water production, e = 8,55 (b)	2.3	2.3	1.00
7	adding PV on roof	100kWp crystalline silicon cells installed on appr. 1000m^2 roof area at 35° angle facing south with system losses appr. 22% (c)	11.2	11.2	1.00

Notes: (a) heated floor area according to NS3940 [9]
(b) taken from [2]
(c) taken from [5]

Figure 7 give results of the cost effective investment calculations for two different service life spans (n = 20 and 50 years respectively).

It can be seen that option 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 (option 1b) 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 (option 1b). This investment is not enough to shift windows under normal circumstances (i.e. no subsidies or incentives from other refurbishment needs).

Option 2 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 (option 2b) the resulting investment I increases to 121 NOK/m^2 which still makes this option 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).

Figure 6: Detailed comparison of measured and simulated delivered energy

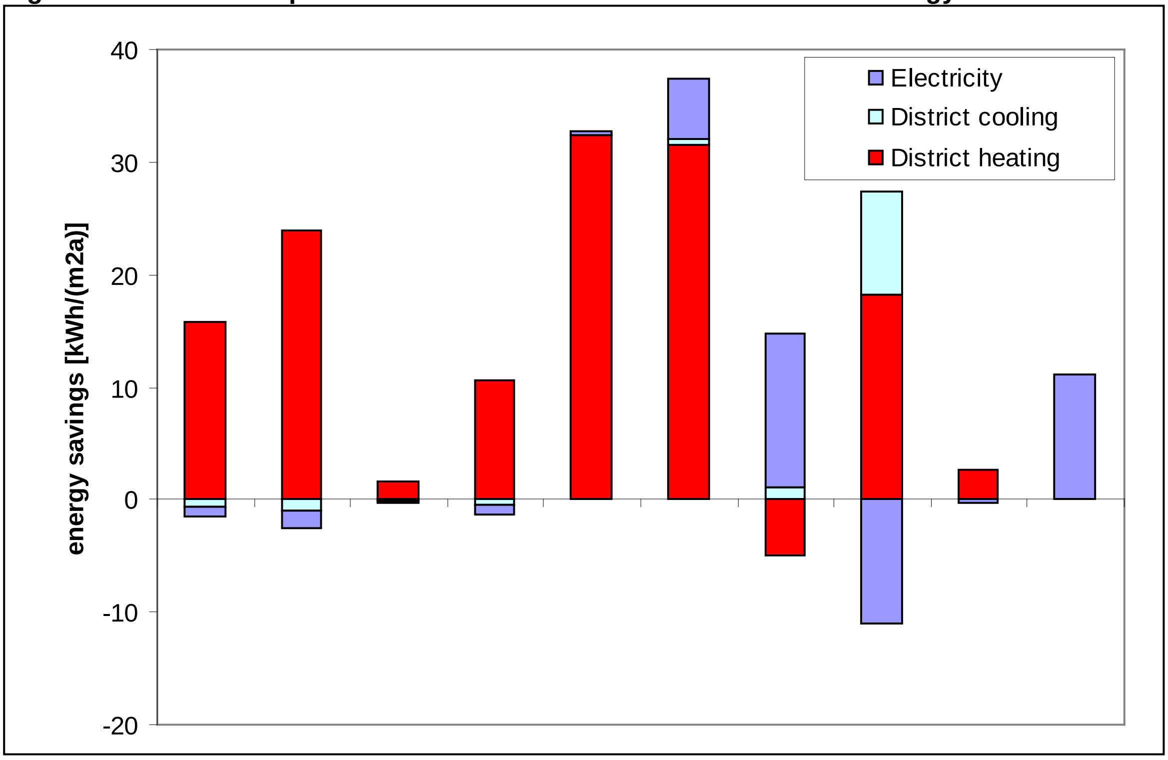
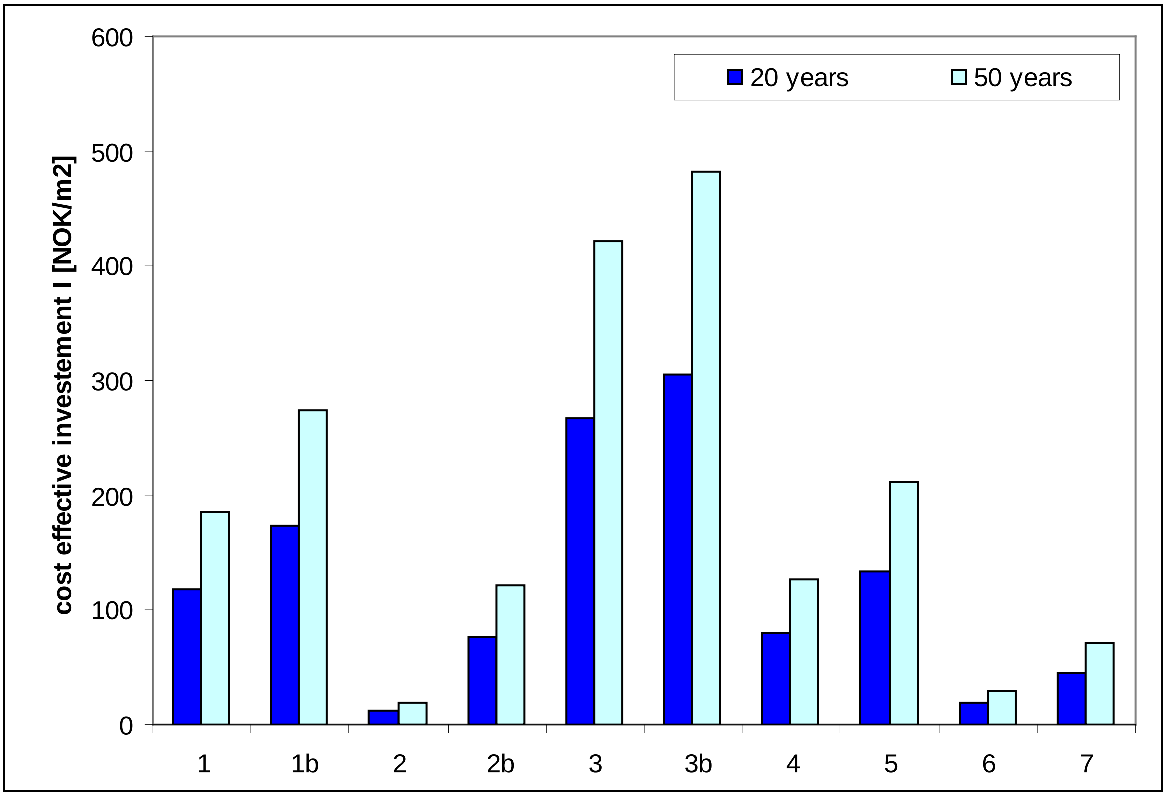


Figure 7: Cost effective investment of different options



Option 3 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 (option 3b) the resulting investment I increases to 305 NOK/m2 which is total 3377085 NOK.

Option 4 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).

Option 5 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.

Option 6 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/m2 (at annual energy gains of 500kWh/m2) [2].

Option 7 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/m2) [11].

Conclusions

The building energy consumption was simulated and a comparison with measured data shows good agreement. The difficulties with modeling the building were described and the recommendations derived from that are that at least two models should be run in order to evaluate not only energy savings based on normalized input data but to take real operation parameter into account. Two models were developed (MOD1 and MOD2) that distinguish between the different operation patterns and give different results for saved energy depending on the energy saving measure applied. Then, it was possible to analyze the energy savings of different measures and to determine cost savings. A cost effectiveness analysis was proposed that showed the cost effective energy savings needed for different energy labels of the building. Here, only upgrading the heat exchangers (option 3) provided enough energy savings to upgrade the building to energy label D. Other options gave energy savings between 0.7 and 16.4 kWh/(m^2a) which is not sufficient to get energy label D.

The evaluation of the maximum cost effective investment I for the different options shows that option 3, 5, 6, and 7 are cost effective. The upgrade of the ventilation system (option 3) is much more cost effective than shifting to new windows (option 1).

A further analysis of combinations of measures should be performed in order to evaluate possibilities for upgrading the building to energy label C, B, and A.

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