DESIGN AND FUTURE OF ENERGY-EFFICIENT OFFICE BUILDINGS IN NORWAY

Matthias Haase[1] , Inger Andresen[2], Berit Time[1], and Anne Grete Hestnes[2]
[1] SINTEF Building and Infrastructure, Trondheim, Norway
[2] NTNU, Department of Architectural Design, History and Technology, Trondheim, Norway

ABSTRACT

Design of different energy-efficient office buildings in Norway with different energy concepts were studied with a number of different shapes. With the help of dynamic computer simulations of energy and indoor environment for the various building concepts the impact the different parameters on energy use and indoor environment was analyzed. A focus was put on finding those parameter that have the largest potential to enhance future energy efficiency in office buildings.

The results show that significant efforts are needed in order to bring Norwegian buildings up to high energy efficiency levels. In particular, significant improvements of construction details regarding insulation levels and air tightness of the envelope are needed. The importance of climate consideration and level of details became obvious. Here, national and international efforts are needed in order to make building regulations more effective and its implementation successful.

INTRODUCTION

The design of energy-efficient buildings in Norway has been in focus for some years now(Andresen et al., 2005; Andresen et al., 2008; Dokka and Hermstad, 2006). Significant work has been done in strengthening the building codes towards a reduction of the use of energy in buildings (NS3031, 2007; Wigenstad et al., 2005). Table 1 gives the key data of the new Norwegian building regulations (TEK, 2007). It shows that insulation levels are very strict now with U-values for walls of 0.18 W/m^{2}K and U-values for windows of 1.2 W/m^{2}K. Also air tightness has been strengthened and new office buildings require now 1.5 ach (at 50Pa) which is an infiltration rate of appr. 0.1. This requires the development of new solutions and construction details (Relander et al., 2008).

Various design parameters in the early design phase are unknown or only known with a certain degree of uncertainty (Haase et al., 2008). Normally, assumptions are made in order to limit the number of parameter and to make informed decisions. Here, very often simplifying assumptions which can mislead the designer of a building in the early design stage are chosen (Augenbroe and Hensen, 2004; de Wit and Augenbroe, 2002; Hensen and Nakahara, 2001).

Table 1 The new building regulations for commercial and residential buildings

TEK 2007	commercial	residential
Glass and door area [a]	20 %	20 %
U-value external wall (W/m^{2}K)	0.18	0.18
U-value roof (W/m^{2}K)	0.13	0.13
U-value floor on ground (W/m^{2}K)	0.15	0.15
U-value windows and doors [b] (W/m^{2}K)	1.20	1.20
U-value glazed walls and roofs (W/m^{2}K)	same as for windows	
normalized thermal bridge value (W/m^2)	0.06	0.03
air tightness [c] (ach)	1.5	2.5
heat recovery [d] (%)	70	70
specific fan power (SFP) (kW/(m^3/s))	2.0/1.0 [e]	2.5
local cooling	shall be avoided [f]	
temperature control	night set-back to 19°C	

Notes: [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 sun shading devices or other measures should be used to fulfill the thermal comfort requirements without use of local cooling equipment.

While the design of building size and shape is limited by site-specific constraints, the technical equipment in a building in Norway is defined in NS3031. For assessment purposes, several assumptions have been made. This includes reference climate data, occupancy and operation schedules, and a detailed description of the ventilation system, including a heat recovery system. This results in a highly technical building design with special focus on the energy budget of the building. It is possible to evaluate in energy consumption terms architectural qualities and design options. However, it would be helpful to know which parameters have the largest influence on energy consumption and comfort.

OBJECTIVES

With the help of dynamic computer simulations of energy and indoor environment for the various building concepts the impact different parameters on energy use and indoor environment was analyzed. A focus was put on finding those parameters that have the largest potential to enhance future energy efficiency in office buildings. Further, it was important to analyze the sensitivity of the parameter towards outdoor temperature.

METHODOLOGY

Here, it was important to try to identify the design parameters that are dominant in determining the total energy consumption of a building.

Main parameters to study were:

- different construction standards of air tightness,
- heat recovery system efficiency, and
- building size and form and its architectural design implications

Sensitivity of input data

The results of sensitivity analyses of various input parameter were reported (Haase et al. 2008). The results showed that energy consumption is very sensitive to external air temperature. Table 1 shows the range of input parameters together with those parameters that are required in the building regulations. Previous studies showed that air tightness, efficiency of heat recovery system, and window size (window-to-wall-ratio) are most sensitive. Consequently, the new building code strengthens those parameters.

The range of implications for energy consumption was analyzed by running the simulation with minimum and maximum data sets as shown in Table 1 for different locations in Norway. Here, SCIAQ Pro, a dynamic building simulation software, was applied (Dokka and Dokka, 2004). A detailed model description can be found in the Appendix. Then, one focus was put on the air tightness and its relation to outdoor average monthly air temperature. The other focus was put on the efficiency of the heat recovery system and its relation to outdoor average monthly air temperature.

Regression of design criteria

In the early design stage the size and shape of a building is not always well defined. Usually, total floor area is specified. Here, eight different sized

Table 2
Input parameter

Description	**unit**	**min**	**max**	**TEK07**	**LE**
Air tightness	[ach] at 50Pa	0.357	5.714	1.50	0.60
U-value floor	[W/m2/K]	0.1	0.2	0.15	0.15
U-value roof	[W/m2/K]	0.15	0.25	0.13	0.13
U-value wall	[W/m2/K]	0.15	0.3	0.18	0.18
U-value window	[W/m2/K]	0.8	2	1.2	1.2
Window size WFR	[-]	0.0873	0.3927	0.1745	0.1745
Orientation	[°]	0	180	26	26
Shading system Fs	[-]	0.4	1	0.5	0.5
Efficiency of heat recovery system	[-]	0.55	0.9	0.7	0.85
Occupancy	[persons /m2]	0	0.15	0.10	0.10
cooling set point temperature	[°C]	22	26	26	26
Heating set-back temperature	[°C]	15	22	18	18
lighting load	[W/m2]	2.5	20	8	8
equipment load	[W/m2]	2.5	17.5	11	11

and shaped buildings were simulated with 6300m^2 floor area as shown in Table 4 and parameter that reduce energy consumption to a low energy standard (LE) are shown in Table 2.

The energy consumption of the different models was calculated and a regression analysis of the following design parameters was conducted:

- Building envelope area (in m^2)
- Footprint factor; defined as the ratio of building length and building width
- Form factor; defined as the ratio of building envelope area and building volume
- Window to floor area (WFR); defined as the ratio of window area to heated floor area

RESULTS

Sensitivity results

The results of the min/max simulations are shown in Table 3 and Figure 2.

Table 3
Total energy consumption in kWh/(m2a) for different locations

location	min input data	max input data	min/ max results	Min comp. Oslo	Max comp. Oslo
Bergen	54.15	146.64	63.1 %	92.9 %	79.5 %
Karasjok	66.03	276.85	76.2 %	113.3 %	150.1 %
Rygge	57.95	182.19	68.2 %	99.4 %	98.7 %
Oslo	58.29	184.50	68.4 %	100 %	100 %

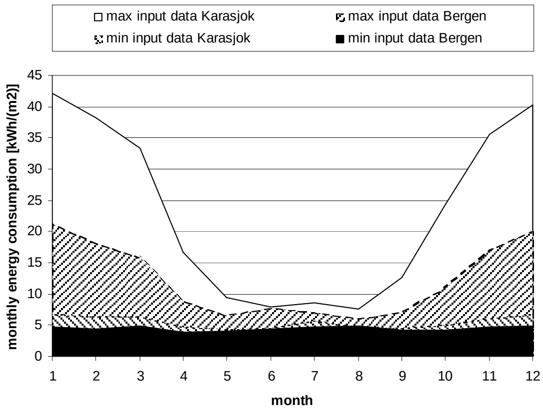


Figure 2 Monthly energy consumption for min/max for different locations in Norway

The results show the large differences in total energy consumption related to the min/max design parameter (between 63% and 76% reduction between max and min input data). Table 3 also shows that designing with Oslo climate data can result in extreme performance differences. But the same is true for the case when designing for extreme climate, like Karasjok for example.

Figure 2 shows the distribution over the year of min/max cases for Bergen and Karasjok. It not only illustrates that differences are larger during winter months but also the ‘optimum’ performances for both Bergen and Karasjok climate which results in very flat energy use curves. Table 5 summarizes the differences.

In column 2 to 5 the monthly energy consumption is shown. Column 6 and 7 show the differences in percentage between min/max data for Bergen and Karasjok respectively. The last two columns show the differences between Bergen and Karasjok in percentage for max/min data. It shows that the differences between Bergen and Karasjok are higher during the winter months for both, min and

Table 4
Geometries of LE models

model	floors [-]	length [m]	width [m]	height [m]	ground floor area [m^2]	facade area [m^2]	total floor area [m^2]	A/V [m^{-1}]
1a	2	116.0	27.15	7	3150	2004	6300	0.377
1b	2	174.0	18.10	7	3150	2689	6300	0.408
2a	3	116.0	18.10	10.5	2100	2816	6300	0.318
2b	3	77.34	27.15	10.5	2100	2194	6300	0.29
3a	4	87.0	18.10	14	1575	2943	6300	0.276
3b	4	58.0	27.15	14	1575	2384	6300	0.251
4a	5	69.6	18.10	17.5	1260	3070	6300	0.254
4b	5	46.4	27.15	17.5	1260	2574	6300	0.231

max data respectively. During the summer months the differences are rather small, in August even negative. This means that energy consumption in Karasjok in August is smaller than in Bergen (for min input data).

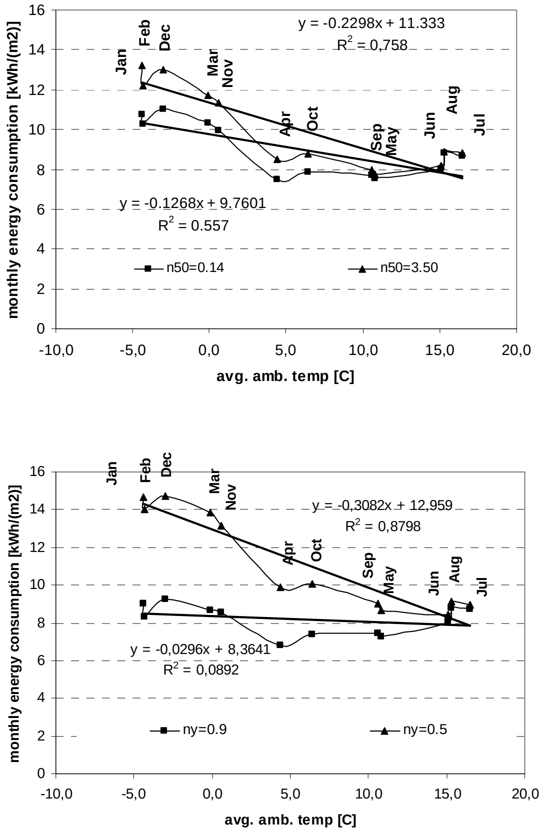


Figure 3 Sensitivity of air tightness (top) and heat recovery efficiency (below) over monthly average ambient temperature

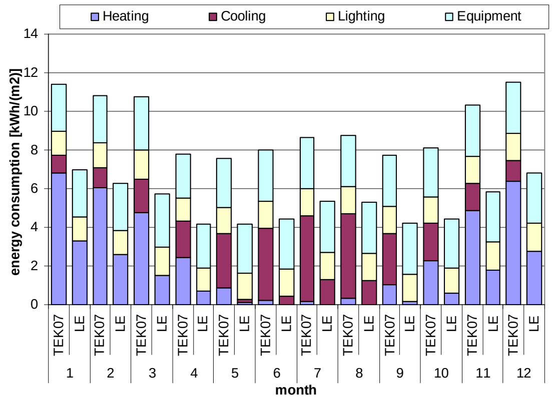


Figure 4 Monthly energy consumption for TEK07 and LE model

Figure 3 shows the sensitivities of air tightness and efficiency of heat recovery over monthly ambient temperature. In the upper graph the energy consumption for a very air tight and a very leaky construction is shown, while the lower graph shows the energy consumption for different efficiencies of heat recovery system. The differences are the energy savings potential for each month. It shows that this potential increases with a decrease in monthly average ambient temperature.

Figure 4 shows the monthly energy consumption for two construction standards; .for TEK07 standard (top) and LE (below). It illustrates that LE has reduced energy consumption for heating and cooling compared with TEK07 standard which is due to different cooling set-points.

While TEK07 requires cooling all year, in LE cooling is only required from May until August. Hence, it was important to analyze the temperature distribution for LE which is plotted in Figure 5. It

Table 5
Monthly energy consumption in kWh/(m2a) for different locations and different input data

Month	max input data		min input data		(max-min) / max		(Karas.-Bergen) /Karas.	
	Bergen	Karasjok	Bergen	Karasjok	Bergen	Karasjok	max	min
January	21	42	5	7	78 %	84 %	49 %	31 %
February	18	38	4	6	76 %	83 %	52 %	30 %
March	16	33	5	6	69 %	81 %	53 %	23 %
April	9	17	4	5	56 %	71 %	46 %	18 %
May	6	10	4	4	37 %	54 %	32 %	6 %
June	8	8	4	5	44 %	43 %	2 %	3 %
July	7	9	5	6	33 %	33 %	18 %	18 %
August	6	8	5	5	21 %	38 %	20 %	-2 %
September	7	13	4	5	39 %	64 %	44 %	5 %
October	11	24	4	5	61 %	79 %	55 %	16 %
November	17	36	5	6	72 %	83 %	52 %	23 %
December	20	40	5	7	75 %	83 %	50 %	27 %
sum	147	277	54	66	63 %	76 %	47 %	18 %

illustrates the sum of operative temperature in all 3 floors.

It can also be seen that the share of energy spent on equipment becomes dominant (see also Figure 6 for annual data).

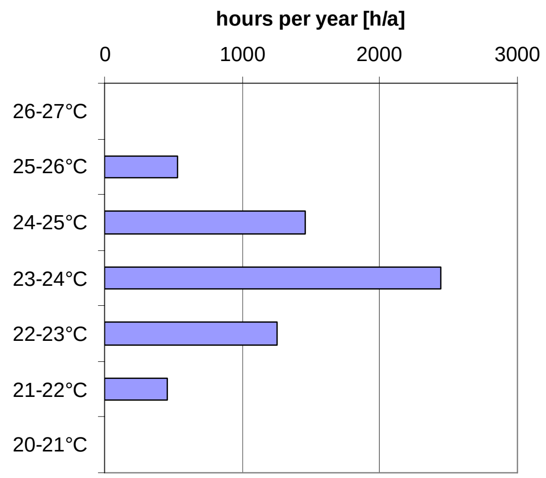


Figure 5 Annual operative temperature during office hours for LE model (all 3 floors)

Regression results

Figure 6 shows the annual energy consumption of the different LE standard models. Energy consumption ranges between 60.2 and 63.4 kWh/(m2a). Equipment share ranges between 48% and 51%.

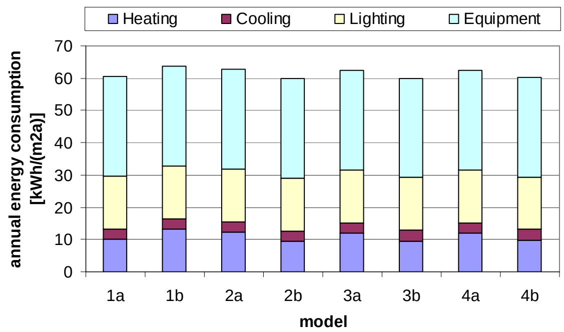


Figure 6 Annual energy consumption for different models

Figure 7 shows the results from the regression analysis. It can be seen that footprint factor and WFR have the highest R^2 (0.7432 and 0.5384 respectively), indicating a good statistical match although it should be noted that the sample size is rather small for statistical analysis. The steepest line is the form factor, indicating the relative importance of compact building design.

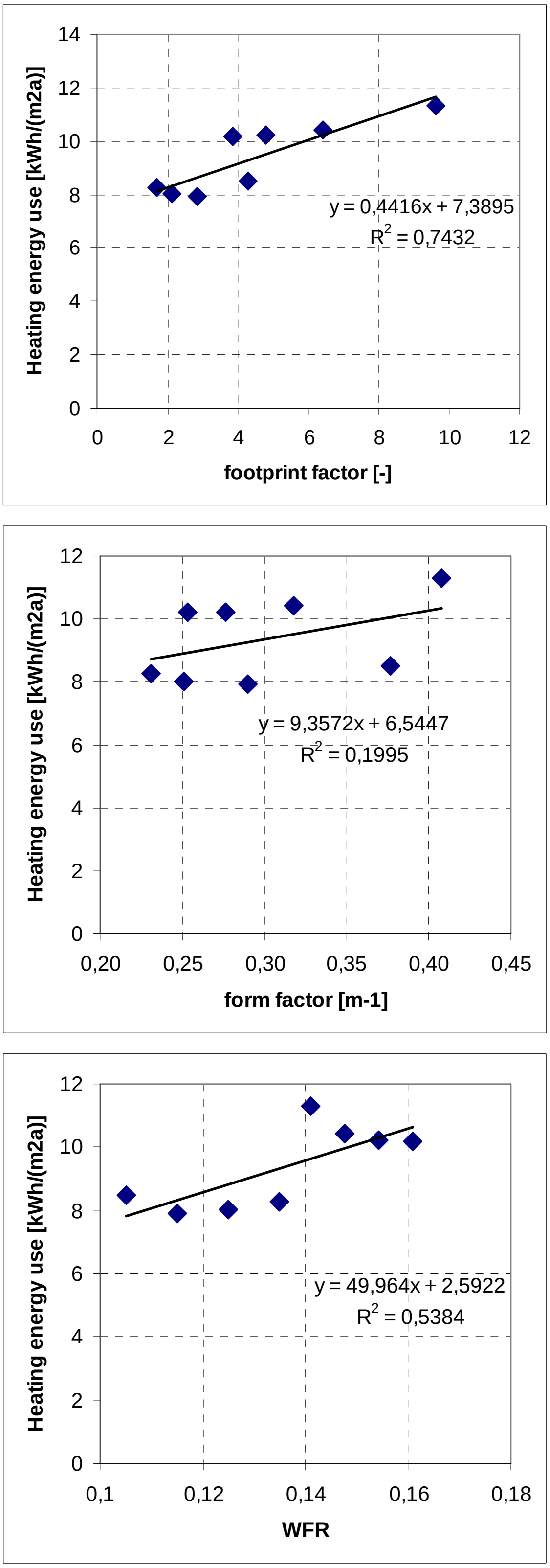


Figure 7a Regression of footprint factor, form factor, and window-floor-ratio (WFR)

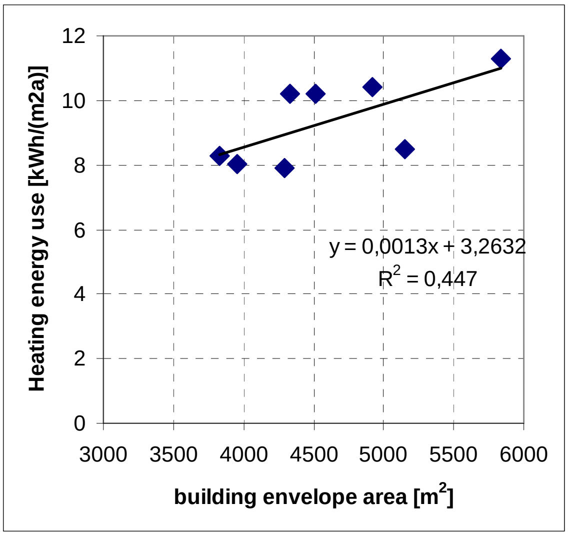


Figure 7b Regression of building envelope area

CONCLUSION

The results show that significant efforts are needed in order to bring Norwegian buildings up to high energy efficiency levels. In particular, significant improvements of construction details regarding insulation levels and air tightness of the envelope are needed.

The external air temperature is an important factor when determining energy consumption of buildings. Specific local climatic data can help to design better buildings that are optimized for their location. Today, the Norwegian building regulations require compliance control with Oslo weather data. But the results show that local differences in outdoor temperature have a large influence on energy use for heating.

Cooling energy is becoming a more and more important factor in Norwegian office buildings due to regulations that require more air tight and insulated building envelopes. If we want to optimize especially low energy buildings we have to take the specific climate into consideration. This can help to reduce or avoid cooling energy.

The results showed that further incresing air tightness is very effective in helping to reduce losses. Especially during cold winter periods this strategy can help to reduce heating energy consumption. It is not so effective during summer.

Also, effective comfort criteria have to be adopted to a changing and enhanced building performance. Results of increased operative temperatures have to be communicated effectively. Here, the level of simulation will have an influence on the results.

Design considerations of building size and shape do not have a big influence on energy consumption level. But they provide potential for reducing cooling energy consumption and improving thermal comfort.

Energy consumption of equipment and lighting become significant in LE buildings. Thus, a special focus should be put on developing strategies for reducing equipment and lighting loads in low energy office buildings.

The design of energy robust, energy efficient, and comfortable buildings depends on building simulation. Accurately predicting the building performance is an important step towards a more sustainable building stock in Norway.

ACKNOWLEDGEMENT

This paper has been written within the ongoing SINTEF strategic institute project "Climate Adapted Buildings". The authors gratefully acknowledge the Research Council of Norway.

REFERENCES

Andresen, I., Aschehoug, Ø., Bell, Thyholt, M., 2005. Energy-Efficient Intelligent Facades. A state-of-the-Art, in: SINTEF (Ed.). SINTEF Building and Infrastructure, Trondheim.

Andresen, I., Dokka, T.H., Lexow, T.E., 2008. New Norwegian Standard for Low Energy and Passive Houses, 1st Passivhus Norden conference, Trondheim, pp. 250-255.

Augenbroe, G., Hensen, J., 2004. Simulation for better building design. Building and Environment 39, 875-877.

de Wit, S., Augenbroe, G., 2002. Analysis of uncertainty in building design evaluations and its implications. Energy and Buildings 34, 951-958.

Dokka, K.A., Dokka, T.H., 2004. User Guide SCIAQ version 2.0, SCIAQ Pro – Simulation of Climate and IndoorAir Quality.

Dokka, T.H., Hermstad, 2006. Energieffektive boliger for fremtiden – En håndbok for planlegging av passivhus og lavenergiboliger, SINTEF Byggforsk. SINTEF Byggforsk, Trondheim.

Hensen, J.L.M., Nakahara, N., 2001. Energy and building performance simulation: current state and future issues. Energy and Buildings 33, vii-ix.

Haase, M., Andresen, I., Time, B., Hestnes, A.G., 2008. Sensitivity analysis in the design of climate adapted building envelopes in Norway, ANZAScA conference, Newcastle, Australia.

NS3031, 2007. Calculation of energy performance of buildings – Method and data. Standard Norge.

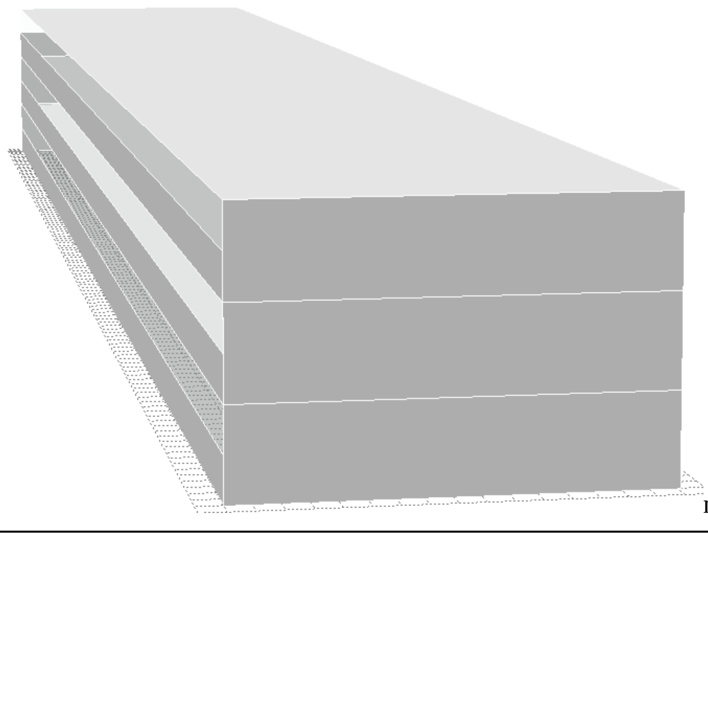
Relander, T.O., Thue, J.V., Gustavsen, A., 2008. Air tightness performance of different sealing methods for windows in wood-frame buildings, in: Rode, C. (Ed.), 8th Nordic

Symposium on Building Physics, Copenhagen, Denmark.
TEK, 2007. Energi – Temaveiledning, in: StatensBygningstekniskeEtat (Ed.). Norsk Byggtjenestes Forlag.
Wigenstad, T., Dokka, T.H., Pettersen, T., Myhre, l., 2005. Energimerking av næringsbygg. SINTEF Building and Infrastructure, Trondheim.

APPENDIX

Detailed modell input description

Location	Oslo (latitude 60.4”N, longitude 10.5”E)
Building type	Office building
Dimensions	118 m x 18.1 m; 3 storeys above ground
Areas	- Total heated floor area = 6300 m^2 - Window-to-wall ratio = 0.44 resulting in window-to-floor-ratio = 0.1745
Heights	- floor-to-floor = 3.5 m - window height = 1.5 m
Constructions of building envelope	(a) External walls (spandrel portion of curtain wall) U-value: 0.18 W/m^{2}K - Absorption coefficient outside: 0.4; Thermal capacity outside: 5 Wh/m^{2}K; emissivity outside surface: 0.85 (b) Roof U-value: 0.13 W/m^{2}K - Absorption coefficient outside: 0.5; Thermal capacity outside: 4 Wh/m2K; emissivity outside surface: 0.85 (c) Floor U-value: 0.15 W/m^{2}K (d) Windows according to Norwegian building code 2007 - U-value: 1.2 W/m^{2}K; glazing factor: 0.8; dir. solar transmission factor pane: 0.65; total solar gain factor pane: 0.75 - Solar shading system: venetian blinds, outside, light color, automatic
Constructions of internal structure	- Medium weight furniture; medium weight partition construction; - Thermal capacity: 12 Wh/m2K
Operating hours	- Mon. to Fri.-0800 to 1600 hr - Sat. and Sun. and Easter and Christmas holidays-closed
HVAC design parameters	(a) Building load - Occupancy density = 0.1 person/m2 (seated working (1.2 Met); normal office clothing (1 clo)) - Lighting load = 8 W/m^2 ; equipment load = 11 W/m^2 - Infiltration = 1.5 ach - Heating set point temperature 22 °C during operating hours (18 °C outside operating hours) - Cooling set point temperature 22 °C (off outside operating hours) (b) HVAC system Minimum 3.6 m3/hm^2; maximum 10 m3/hm^2 - Throttling range = 1 °C - operating hours 0600 hr to 1800 hr - HVAC system type = VAV Ventilation (c) Heating: capacity: 50 W/m^2; convective share delivered heating: 0.5 - operating hours 0600 hr to 1800 hr (d) Cooling: capacity: 40 W/m^2; convective share delivered heating: 0.5 - operating hours 0600 hr to 1800 hr



modell rendering