THE IMPLEMENTATION AND EFFECTIVENESS OF AIR INFILTRATION STANDARDS IN BUILDINGS

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A CONSEQUENCE ANALYSIS OF NEW NORWEGIAN BUILDING REGULATIONS ON AIR INFILTRATION

Sivert Uvsløkk and Bjørn Vik
Norwegian Building Research Institute
PO Box 322
Blindern
N-0314 Oslo 3
Norway

SYNOPSIS

In 1981 Norwegian building regulations introduced quantitative requirements to air leakages in different types of buildings. The requirements were formed as maximum allowed air changes per hour at 50 Pa pressure difference according to the pressurization method.

To evaluate the consequences of these new requirements imposed to Norwegian building industry a model proposed by the Nordic Committee for Building Regulations (NKB) was used.

The average air leakages of residential buildings, built before the new requirements, are known through a research project performed in 1979. Average air leakages of other buildings are not known.

Energy losses due to air infiltration are calculated with the computer program ENCORE.

Extra costs for achieving necessary tightness in detached houses are estimated to be NOK 1000,- in average per house, and the resulting energy saving is estimated to be 1200 kWh/year corresponding to NOK 360,- per year.

For block flats the new requirements are supposed to have none or little practical influence. For other buildings the influence is not known.

The most evident negative consequence is the possibility of reduced and too low air change rate in detached one storey houses with natural ventilation systems. In some of these houses it may be necessary to introduce mechanical ventilation systems to achieve air quality control.

DEFINITIONS

Air change rate:
- Air supply to a room/building divided by the volume of the room/ building (m^3/m^3h).

Air leakage coefficient n_{50}:
- Measured air changes of a building at 50 Pa pressure differences (m^3/m^3h).

0. INTRODUCTION

This consequence analysis uses a model proposed by the Nordic Committee for Building Regulations (NKB) in 1983[1]. The model is generally used for all kinds of building regulation proposals, and may perhaps seem too extensive in this connection. The stringent system of the NKB-method may be of value also for others, and the chapters in this paper are therefore in correspondance with this method.

1. GOAL

In January 1981 the Norwegian building regulations[2] got a new chapter 54 dealing with heat insulation and air tightness of buildings. The main purpose of the new chapter 54 was to give a technical background for energy saving in buildings. Therefore increased requirements were introduced with regard both to heat insulation and air infiltration. The part goal as to air infiltration is to reduce heat losses from buildings due to air leakages.

2. FULFILLMENT OF GOAL

To fulfill the above mentioned goal, the Norwegian building regulations have introduced quantitative and controllable requirements to air tightness of building components and buildings. Earlier regulations contained only qualitative and hardly controllable requirements.

3. SPECIFICATION OF REQUIREMENTS

Qualitative and quantitative requirements regarding air tightness are assembled in chapter 54 of the building regulations, but some qualitative requirements are also found in chapters dealing with e.g. external walls, roofs and floors. The superior requirement says that buildings which are meant to be heated, should be insulated against heat loss and should be air tight in a way that maintains a good indoor climate without unnecessary energy consumption and risk of moisture damage . Connections and joints should be air tight to prevent annoying draughts and moisture problems.

The maximum allowed specific air leakages measured according to NS 3206 at 50 Pa pressure difference are:

Wall-, roof- and floor constructions:	0,4 m^3/m^3h
Windows (and doors in detached houses):	1,7 m^3/m^3h

The maximum allowed air leakage coefficients n_{50} of buildings measured according to NS 8200 at 50 Pa pressure difference are:

Buildings, more than 2 storeys	1,5 m^3/m^3h
Buildings, until 2 storeys	3,0 m^3/m^3h
Detached houses	4,0 m^3/m^3h

For detached houses the volume for air change calculation should be the volume of primary parts of the house (according to NS 3940) and for other buildings the heated volume.

4. PERFORMANCE ANALYSIS

The air barriers of walls, roofs and floors have two energy related functions. The prevention or reduction of air infiltration is taken care of in the new building regulation requirements. The prevention or reduction of cold air streams from the outside into the insulation is, however, not taken care of.

Laboratory measurement of air leakage through windows is done in accordance to Norwegian Standard (NS 3206). This method is originally developed and valid for windows, but is also used for doors, walls and roof constructions. At the Norwegian Building Research Institute (NBI) it is possible to perform measurements on building components up to 3,0 x 3,0 m.

Adequate equipment for testing air tightness of building components in situ is not available in Norway. This kind of testing is therefore very comprehensive, expensive and is hardly done.

Total allowed air leakages through the individual building components amounts to only 10-15 % of the allowed over all leakages through the building. The situation may then easily arise, that a building fulfills the over all requirement while e.g. the external walls have unacceptable air leakages. This could give some interpretation problems about which of the joints and connections that should be included in the building component.

The Norwegian Standard NS 8200 gives the instructions for the testing of a complete building. The capacity of available equipment in Norway gives a practical limit to the size of buildings that could be tested. Detached houses with floor area until 450 m2 and larger buildings until 1000 m2 may be tested within standard procedures. Larger buildings may be tested by extrapolation from low pressure differences or by using the ventilation system. These are not, however, standard procedures, and are therefore only seldom used. Air tightness control is in practice performed mainly on detached houses.

The definition "volume of primary parts" of detached houses gives interpretation problems, while e.g. the basements in new Norwegian houses very often are left uncompleted but heated, until the owner gets economy to fit up a second living room, trim room or similar. We have seen cases where different testing people have come to different results, which have given unnecessary juridical disagreement.

5. EXISTING PRACTICE

Most Norwegian producers of windows and doors have already adapted to the new requirements through their participation in a voluntary control organization driven by NBI. The most common wall- and roof- constructions also fulfill the new requirements, on the assumption of reasonable good craftmanship. Experiences through moisture damages, complaint cases and thermography show that the main part of the air leakages is found in connections between different building parts and components.

In 1979 NBI examined 61 detached houses and 34 block flats between 1 and 5 years old at that time[3]. Their air leakage coefficients are shown in figures 1 and 2. 40 % of the detached houses had an air leakage coefficient lower than 4 m^3/m^3h and 20 % more than 6 $m^3/m3h$. 70 % of the block flats were already more air tight than prescribed in the new building regulations.

For larger buildings we have no statistical material. A few single control tests indicate that the deviaton in air tightness may be considerable.

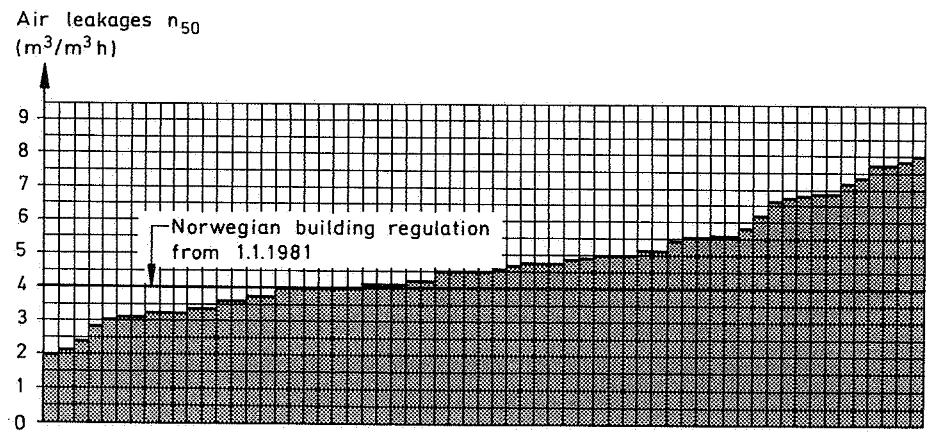

Figure 1. Air leakage coefficient n_{50} of 64 detached houses on different places in Norway. The measurements were performed by NBI on 1 to 5 years old houses in 1979.

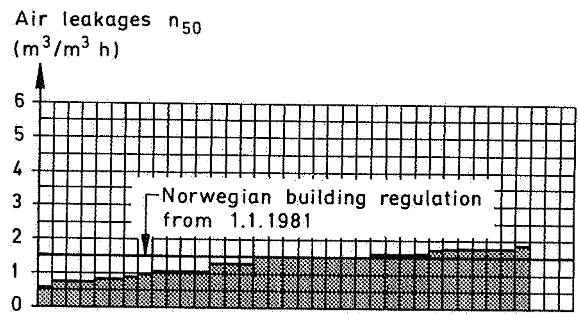

Figure 2. Air leakage coefficient n_{50} of 34 block flats on different places in Norway. The measurements were performed by NBI on 1 to 5 years old buildings in 1979.

6. NEW PRACTICE

The new air tightness requirements will scarcely have any effect on the basic construction principles for windows, doors and the common wall-, floor- and roof constructions.

A change of polyethylene film thickness from 0,04 mm or 0,06 mm to 0,15 mm is partly due to the new air tightness requirements. The thicker polyethylene film is less exposed to damages during the building period .

Some constructions with no separate water vapor barrier, like some metal wall systems, are not likely to fulfill the new requirements unless the jointing problems could be better solved.

The traditional Norwegian apartment building with in situ concrete and timber framework facades has sufficient air tightness, and no changes are necessary.

Detached houses must in general have a slight improvement of the air tightness, but no dramatic changes in building practice is necessary. A reasonable good craftmanship and avoidance of severe faults is of most importance. Several research projects have shown that thorough clamping of all joints and edges of the wind- and water vapour barriers gives an over all air tightness far below the new requirements.

We have no statistical material showing the air tightness level or the occurance of very leaky houses built after 1.1. 1981. A survey on new dwellings is planned, and will probably give the answer to this question.

A similar survey on larger buildings should be very comprehensive and is therefore not possible with the available resources.

7. IDENTIFICATION OF NEGATIVE AND POSITIVE CONSEQUENCES

Consequence field	Example	Influence
Planning	. Freedom of choice	-
	. Routines	0
Building process	. Wages	-
	. Materials	-
	. Capital	-
Building materials	. Limitations	-
	. Product development	-
Control	. Building authorities	-
	. Production control	-
	. Testing procedures	-

Consequence field	Example	Influence
Administration and maintenance	. Energy costs	+
	. Running	+
	. Maintenance	+
	. Damages	+
Use of building	. Quality	+
	. Health	?
	. Safety	0
	. Fire hazards	0
Community	. Social costs	0
	. Employment	0
	. Balance of payments	0
	. Environment	0
	. Diversion of production	+

8. DIRECT MEASURABLE CONSEQUENCES

8.1 Building costs

The cost increase for simple detached houses will be very moderate. For more complex houses there will be some cost increase. These houses are, however, also the most leaky ones, and considerable energy savings should be expected. We have no Norwegian experiences where extra costs are related to air tightness level. Figure 3 shows some Swedish experiences.

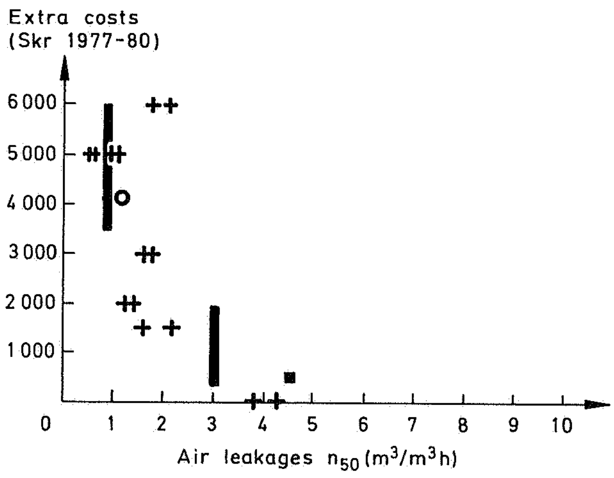

Figure 3. Extra costs related to air tightness level for Swedish detached houses.

The following table is based on figure 3 supplemented with some Norwegian experiences from field and laboratory measurements. Within these extra costs we assume that most dwellings could be built within the new air tightness requirements:

Extra costs per dwelling (NOK)

	Planning	Constructing	Windows and doors	Materials	Total sum
Block flat	0	0	0	200	200
Simple detached- and row house	0	0-600	0	400	400-1000
Complex detached- and row house	0-1000	0-2000	0	400-1000	400-4000

8.2 <u>Energy costs</u>

If we assume that figure 1 gives a representative picture of the air tightness level of new Norwegian detached houses before 1.1. 1981, it will be necessary with an average reduction of the air leakage coefficient by 1,0 m3/m3h to make most new houses fulfill the requirement. This corresponds to a certain reduction in the air infiltration heat loss depending on:

- air leakage coefficient n_{50}
- ventilation system
- number of storeys
- outside temperatures
- wind

By means of the computer program ENCORE, following energy savings are calculated under the above mentioned conditions. The table is valid for houses with natural ventilation, which is the most common system in Norway, and a building size of 120 m2 floor area:

Calculated air infiltration heat loss reduction (kWh/year) by reducing n_{50} from 5,0 to 4,0 m3/m3h

	1 storey	2 storey	3 storey
Oslo	700	1000	1200
Trondheim	900	1300	1500
Tromsø	1200	1700	2000

The energy price in Norway (electricity) is approximately 0,30 NOK/kWh. If we assume that the average heat loss reduction per detached- and row house is 1200 kWh, the corresponding cost reduction is 360 NOK/year.

9. OTHER CONSEQUENSES

The new air tightness requirements could cause financial implications other than building costs and energy savings. We have not sufficient information to take these aspects into account, and the most important other consequences are therefore only shortly described in the following:

9.1 Ventilation system

Most Norwegian detached houses from the 70's have natural ventilation system with an extract fan over the stove. Increasing attention to air tightness and ventilation problems will probably lead to more mechanical ventilation systems in the future, like the trends of e.g. Sweden. This means extra costs, but also the possibility of installing heat recovery systems. In very air tight houses (n_{50} < 2 m^3/m^3h) heat recovery systems are normally profitable.

9.2 Control activities

To day only approximately 0,5 % of the total annual production of dwellings is controlled. A higher control rate would probably influence the building quality and thus be profitable for the nation. A control rate of 5 % would give an extra cost per dwelling of NOK 100-200.

9.3 Energy costs

Reduced air infiltration could lead to secondary energy saving effects, through e.g. better possibilities of reducing indoor temperatures and the reduction of cold air streams into the insulation.

9.4 Building faults

Air leakages have caused condensation and lots of moisture damages, especially in roof constructions. The costs of such damages may be considerable in single cases, but the frequency is not known. Better air tightness would undoubtedly bring savings for the country.

Reduced air leakages could on the other hand give reduced ventilation and an increased risk of condensation and mould growth.

10. QUALITATIVE AND SOCIAL CONSEQUENCES

10.1 Comfort

Reduced air leakages lead to less draught problems and thus a better thermal indoor climate.

Airtight houses may lead to problems in connection with open fireplaces, which are very common in Norway. During the last years we have had an increasing number of cases where smoke has come into the room. The problem may, however, be solved at some extra cost, e.g. by means of separate air ducts to the fireplace.

10.2 Air quality

The indoor air quality is dependent on the air change rate of the single rooms and of the building. In older leaky houses air leakages must be considered as an integral part of the ventilation system, and the risk of having a too low air change rate has been minimal. In new airtight houses planning and construction of an adequate ventilation system and the use of the building is of vital importance for the indoor air quality. At the same time we have an increasing number of new materials involving volatile and hazardous gases in building components and furniture.

In buildings with a balanced ventilation system all extra air infiltration is undesirable, and air leakages should be kept as low as possible. An air outlet or inlet should be placed in each room.

In buildings with extract ventilation an air tightness level lower than building regulation requirements would have little influence on the average air change rate.

In buildings with only natural ventilation the air change rate will vary with outside temperatures and wind. To achieve a good ventilation it will be necessary to extensive open and close vents according to the weather conditions. At times one must expect that outlets function as inlets. In summer and partly also spring and autumn it will be necessary to ventilate through windows and doors in order to achieve the generally recommended air change rate of 0,5 m3/m3h. In these buildings air leakages may be considered as desirable, but even very leaky houses will have too low air change rates during most of the year if windows and doors are closed.

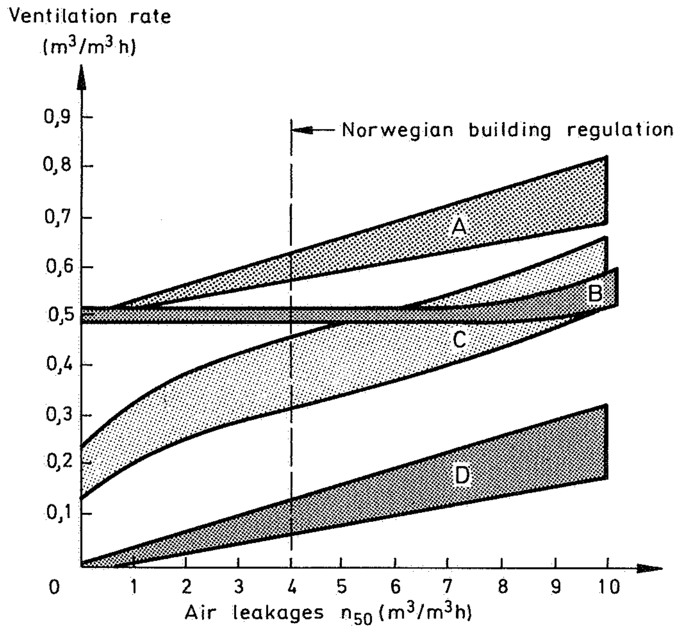

Figure 4. Calculated air change rates in a 2 storey detached house by + 10 oC outside temperature and no wind.

A: Balanced ventilation
B: Extract ventilation with open air inlets
C: Natural ventilation with open outlets and inlets according to building regulations minimum requirements.
D: Air infiltration only, all vents closed.

11. COMPARISON OF POSITIVE AND NEGATIVE CONSEQUENCES

Due to the lack of reliable information, only building costs and energy savings as a result of air infiltration reduction are compared. Costs are based on mean values from chapter 8 and the following assumptions:

. investment	1000 NOK
. life time of construction	30 years
. interest	7 %
. annual energy saving	1200 kWh
. energy price	0,30 NOK/kWh
. detached or row house, floor area	120 m2

	Annual amount (NOK)	Years	Dis-counting factor	Now-value (NOK) Positive	Negative
Direct consequences:					
1. Investment	1000	1	1		1000
2. Energy	360	30	12,34	4450	
Indirect consequences:					
Information not available					
Balance				+3450	

Because of Norwegian tax rules in connection with bank loans and interests, the private profitability of investments should be better than shown above. If other indirect consequences also were taken into account, the result would probably be even more positive.

12. COMPARATIVE ANALYSIS

The consequence of alternative building regulation requirements is not evaluated.

13. ERROR ANALYSIS

There are involved large areas of uncertainty in the assumptions. The table below indicates the amount of uncertainties and their consequences for the calculations. The limits of the total balance is calculated for each parameter, while the other parameters are left constant.

Parameter	Assumption	Uncertainty	Limits	Now-value Balance (NOK)
Extra cost	-1000 NOK	+1000 NOK	0 NOK	+4500
		-1000 NOK	-2000 NOK	+2500
Energy cost	360 NOK/year	+ 100 NOK/year	460 NOK/year	+4700
		- 100 NOK/year	260 NOK/year	+2200
Energy price	0,30 NOK/year	+0,05 NOK/kWh	0,35 NOK/kWh	+4200
		-0,05 NOK/kWh	0,25 NOK/kWh	+2700
Life time	30 years	+10 years	40 years	+3800
		- 5 years	25 years	+3200
Interest	7 %	+ 2 %	9 %	+2700
		- 2 %	5 %	+4500
		- 4 %	3 %	+6000

14. CONCLUSION

New building regulation requirements from 1.1. 1981 concerning air leakages are quantified and in principle controllable. Because of limitations in testing methods and available testing equipment it is possible to control only small buildings in situ and building components only in laboratories.

The economical consequences are calculated only for dwellings. The new air tightness requirements should give insignificant change in building practice for new apartment buildings, and thus modest economical consequences. For new detached and row houses extra costs are estimated to less than NOK 1000 per dwelling in average. This extra cost is compensated by a wide margin by energy savings estimated to a now value of NOK 4350 in average.

Better air tightness will lead to less complaints due to draught problems, less moisture damages and a tendency to increasing numbers of mechanical ventilation systems.

The risk of getting low air change rates and reduced indoor air quality in certain periods of the year will increase with better air tightness of the buildings. One storey houses with natural ventilation only will be especially vulnerable. Appropriate mechanical ventilation systems will eliminate these problems.

15. REFERENCES

1. Nordic Committee for Building Regulations (NKB): "Konsekvenser av bygningsbestemmelser. Forslag til analysemodell med tre eksempler på anvendelse". Progress report, April 1983.

2. Kommunal- og arbeidsdepartementet (Department of Labour and Municipal Affairs): "Byggeforskrifter av 1. august 1969 med endringer sist av 22. juli 1983". Oslo 1983

3. Brunsell, Jørn T., and Uvsløkk, Sivert: "Boligers lufttetthet. Resultater av lufttetthetsmålinger av nyere norske boliger". Arbeidsrapport 31. Norwegian Building Research Institute, Oslo, 1980.

4. Jonson, J.Å.: "Villa 80 fjorton energisnåla småhus i Umeå, 1. byggskedet". R 47:1978, Swedish Council for Building Research, Stockholm 1978.

5. Elmroth, A., Nylund, P.O. and Bengtsson, S.: "Lufttät ytterhölje sparar energi". Byggnadsindustrin 17/1978. Stockholm 1978.

6. Harrysson, Chr.: "The Choice of Airtightness and Ventilation System for Single Family Houses", Air Infiltration Review, vol. 4 No. 3 May 1983, Air Infiltration Centre, Berkshire, Great Britain.