DIVISION OF

BUILDING TECHNOLOGY

THE ROYAL INSTITUTE OF TECHNOLOGY

WELL INSULATED AIRTIGHT BUILDINGS ENERGY CONSUMPTION, INDOOR CLIMATE VENTILATION AND AIR INFILTRATION

by

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SUMMARY

Previous standard requirements in Sweden with reference to outer structure thermal insulation and airtightness have been influenced by hygiene or comfort. There have previously been requirements for thermal insulation but, on the other hand, no requirements for building airtightness.

In Swedish Building Code 1975 the requirements for thermal insulation for different building sections have been tightened up considerably and completely new requirements for a building's airtightness have been introduced. The purpose of these new requirements is partly to reduce transmission losses through the house and partly to prevent too much natural ventilation through the building's outer structure.

The indoor climate - primarily air quality - and energy consumption have been studied in a number of free-standing houses in a group housing area. All these houses were very tight and, when pressure-tested, had an air change rate less than 1 change/h at 50 Pa.

Energy consumption

The annual energy consumption has been calculated theoretically and then compared with the true consumption over a two year period. From the results it can be seen that the measured energy consumption agrees quite favourably with that calculated. The mean consumption for the five houses was, during a period of one year, 18,700 kWh. The corresponding value for a similar house (dormer house with approximately 140 m^2 living area), built before the new requirements for airtightness and insulation were introduced, is approximately 28,000 kWh. Thus the energy consumption as a result of improved thermal insulation and tightness has decreased considerably.

Checking the airtightness of the houses

Measurements of the airtightness of the houses was carried out during the period 1977-1980 (pressure testing at 50 Pa) in order to discover whether this had changed significantly with time. From the results it can be seen that a relatively large increase in air leakage was measured after the houses had been occupied for approximately one year. Later measurements indicated that no

changes had taken place. The cause of the increase in air leakage during the first year is probably the drying out of the timber in the house giving rise to cracks. The measured values after two years are below approximately 1.5 changes/h at 50 Pa - considerably lower than the limiting values recommended by the Swedish Building Code for new-built houses. Thus the houses are still very airtight.

Indoor climate

Apart from the five houses noted above (type A house), two houses (type B house), which when completed had an air leakage of approximately 3.0 changes/h at 50 Pa gauge and negative pressure, were investigated when studying indoor climate. Both types of houses are fitted with mechanical exhaust air systems. From the results it can be seen that the air change rate in the master bedroom in type B houses was very low (5 m^3/h) if the fan was set to its lowest value and the supply air valve (slot air valve) in the room was closed. From a hygienic point of view the air change rate should be at least 25 m^3/h. In the tighter houses (type A houses) a significantly better air change rate was obtained. The measurements carried out indicate clearly that an acceptable indoor climate in all areas can only be achieved if the houses are tight, the slot air valves open and the fan set at a position which corresponds to an air change rate in the whole house of approximately 0.5 changes/h. In houses which have exhaust air ventilation and which were not sufficiently tight, there is a risk of the air supply being concentrated to the gaps in the outer structure. These are often unevenly distributed which means that an uneven air flow is obtained resulting in certain rooms not being ventilated sufficiently neither from hygiene nor technical points of view.

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BACKGROUND

Previous standard requirements in Sweden with reference to outer structure thermal insulation and airtightness have been influenced by hygiene or comfort. There have been requirements for thermal insulation but, on the other hand, no requirements for building airtightness.

In Swedish Building Code 1975 the requirements for thermal insulation for different building sections have been made considerably more severe. For example the requirements for thermal insulation mean, in the case of mineral-wool insulated wooden walls, that the insulation thickness must be approximately 150 - 190 mm (depending on the geographical location in Sweden of the house). In loft ceiling structures a mineral wool thickness of 220 - 260 mm is normally required. These are significant thicknesses which mean more complicated wall and joist structures than those previously used. As a result of the considerable increases in oil prices there is considerable motivation today for insulating to a greater extent than is prescribed by the Swedish Building Code.

Completely new requirements for a building's airtightness have been introduced. The purpose of the new regulations is to prevent too much natural ventilation, as was the case earlier, through the building's external structure. The Code now contains a recommendation for the highest perviousness for the whole building at a pressure difference of 50 Pa in relation to the outdoor air (Table 1).

In order to build airtight houses it is necessary to carefully consider airtightness problems. A well-planned system for how airtightness is to be achieved facilitates practical work. Great importance must be placed on how the different constructional parts are formed and, by no means least, how transitions for installations - electricity, heat, water and ventilation - are to be achieved (see Figure 1).

Objectives

The way in which indoor climate - primarily air quality - and how energy consumption is affected by very good airtightness, as well as good thermal insulation, has been studied in a number of houses in a group housing area. During pressure testing all of these houses had an air change rate of 1 change/h at a pressure difference of 50 Pa immediately after erection. For the sake of comparison the climate has also been studied in a number of houses which, during pressure testing, have had an air change rate of approx 3 changes/h at a pressure difference of 50 Pa. Furthermore the change in the airtightness of the house has been determined during the course of the first few years.

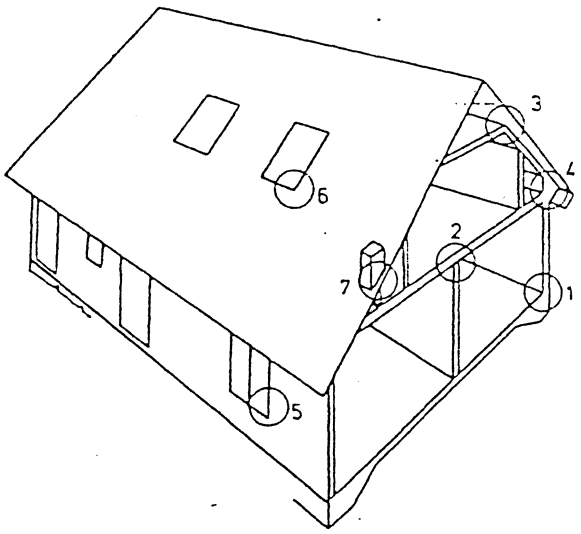


FIG 1. Conncetion and joint details to which a great deal of attention must be paid in order to achieve satisfactory airtightness.

1 External wall - ground floor
2 Loadbearing partition - gable wall/attic floor
3 Attic roof - sloping roof
4 Eaves
5 Joints around windows
6 Joints around windows in the roof
7 Penetrations for services

Table 1. Maximum permitted number of air changes in a completed building

	1 July 77 - 30 June 78 change/h	After 1 July 78 change/h
Detached house or linked house	4,5	3,0
Other building of at least 2 storeys	3,0	2,0
Building of 3 or more storeys	1,5	1,0

Type A Houses

These houses are built on site, designed and erected by Byggnads AB Folkhem, Stockholm (figure 2). The houses are all of the same type and are situated in a group housing area approximately 40 km east of Stockholm.

During the planning stage of these houses considerable effort has been made to achieve good building engineering solutions. A carefully considered system to achieve airtightness has been produced. Furthermore high demands have been placed on work procedures, particularly thermal insulation and airtightness work on the building site. All the houses were pressure tested before occupation and all had an air leakage less than 1.0 changes/h at 50 Pa gauge and negative pressure in the house. The Institution for Building Technology at the Royal Institute of Technology, Stockholm has carefully followed the whole building process and has documented the procedure well (Elmroth A: 1978). Thus the houses are very airtight.

The ventilation system is of an exhaust air type and is fan controlled. Supply air is delivered through special air supply devices (slot air valves) in window frame heads. The slot air valves can be regulated but cannot be closed completely.

The houses are built on ground slabs and are of a dormer design.

Pressure difference between outdoor air and indoor air

To check whether the fan in the house could create a negative pressure in the whole house, the pressure difference in relation to the outdoor air at different facades has been measured.

Measurements were carried out with the fan set at basic speed, 50% of full fan capacity and 100% full fan capacity. When the fan is set at basic speed an air change rate of approx 0.25 changes/h is obtained in the whole house. At full fan capacity there is an air change rate of 0.9 - 1.0 changes/h. Full fan capacity is designed primarily for use during food preparation. Measurements were carried out on two different occasions with different wind speeds. In the first case the wind speed was high (approx 10-12 m/s, southerly) and on the second occasion moderate (approx 3-6 m/s south-easterly). On both occasions the external temperature was approximately $0^{o}C$ and the indoor temperature approx $20^{o}C$.

Examples of measurement results in a type A house are shown in Tables 2 and 3.

Table 2 Results from air pressure measurements in type A houses, trial 1 (slot air valves open). All values indicate that the air pressure is lower indoors than outdoors. Wind speed 10-12 m/s (S)

Facade	Pressure difference Pa with fan set at		
	basic speed	50% of full capacity	100% of full capacity
Longside living room north facing (leeward side)	1-2, 5	4-6	10-11
Longside external door south facing (windward side)	5-6	9-11	19-22

Table 3 Results from air pressure measurements in type A house, trial 2 (slot air valves open). All values indicate that the air pressure is lower indoors than outdoors. Wind speed 3-6 m/s (SE)

Facade	Pressure difference Pa with fan set at		
	basic speed	50% of full capacity	100% of full capacity
Longside living room north facing (leeward side)	2-4	4-6	8-12
Longside external door south facing (windward side)	4-5	4-6	12-14
Upper floor west facing	1-2	4	8-12
Upper floor east facing	0-1	1-2	5-6

All measurements indicated that there was a negative pressure in the houses. The pressure difference changed immediately when the fan's speed was increased or decreased. No significant pressure difference was measured between upper and lower floors in the test houses. An interesting observation is that, with a wind speed as high as 10-12 m/s, there was a negative pressure on both the windward and leeward sides in type A houses with the fan set at basic speed. (These pressures were 5 and 2 Pa respectively). See Tables 2 and 3.

The result of the pressure difference measurements gives a clear indication that the ventilation is controlled to a significant degree by the setting of the exhaust air fan. The external climate has only a marginal effect on ventilation in airtight houses.

Energy consumption

Energy consumption during a normal year has been estimated by registering energy consumption, air change rate, temperature difference between outdoors and indoors and possible solar radiation during a few, relatively short measurements periods (16-19 hours). On the basis of these short-term registrations, transmission and ventilation losses can be approximated for longer periods. Such calculations can be made providing that the houses are unoccupied and that the external climate is stable both during the trial and for a certain period prior to commencement.

Energy consumption for hot water and household electricity in occupied houses has been extracted from a paper by Munter (1974) as have estimated values of the proportion of energy usage constituted by direct losses.

Energy gains from solar radiation to the houses has been approximated as 3200 kWh/year.

The total number of degree hours for Stockholm is shown in Table 4 for different indoor temperatures.

Table 4 Calculated degree hours for Stockholm using normal outdoor climate figures for different indoor temperatures during the heating season. This is assumed to begin when the mean diurnal temperature goes below +12 °C and ends when it again exceeds +10 °C.

Indoor temperature °C	Degree hours °C h
20	110 000
19	103 000
18	97 000

When calculating the energy consumption for ventilation during one year, the air change rates have been assumed as 0.25 changes/h and 0.5 changes/h respectively. The reason for this is that many householders normally set the fan to approx 0.25 changes/h. According to the Swedish Building Code however the air change rate should be 0.5 changes/h.

Theoretical determination of transmission losses

Calculation of k-values have been carried out in accordance with Swedish Building Code 75. Calculations have been carried out so that the total area of framework members, nogging pieces, rest timbers, cross ties etc. is included. See Table 5.

Table 5 Calculated k-values, areas and transmission losses per °C through different building sections in type A houses.

Building Section	k-value $W/m^2\ °C$	Area m^2	k x A $W/°C$
Floor over crawl space	0.29	77.2	22.39
External walls	0.28	206.0	29.68
Roof	0.16	35.0	5.53
Sloping roof areas	0.19	57.1	10.68
Windows	1.90	20.4	38.76
Doors	0.95	5.0	4.75
		$\sum$ k x A =	111.71

The total transmission losses during the year and for 110 000 degree hours amounts to 12 288 kWh. The calculated transmission losses, based on short-term measurement, amount to 13 100 kWh. Thus the difference is only 812 kWh.

The values show good correlation which indicates that, in airtight houses where the air change rate can be expected to be relatively constant during the year, short-term measurements for calculating energy consumption provide good results.

Table 6 shows the calculated energy balance during a normal year for a type A house. The indoor temperature has been assumed to be +20°C and the average ventilation rate 0.5 changes/h. The transmission losses have been calculated using the results from short-term measurements. How the energy consumption changes if the indoor temperature and ventilation are changed is indicated in Table 7.

Table 6 Energy balance for type A house for a normal year in Stockholm's climate with an indoor temperature of +20°C and an average ventilation rate of 0.5 changes/h

Energy losses			
	transmission	13 100 kWh	
	ventilation	6 700	
	household electricity	1 000	
	drainage water (hot water drainage)	3 500	
Total energy losses		24 300 kWh	
Energy gains			
	heating plant	11 000 kWh	
	hot water production	5 000	
	household electricity	3 500	
	solar radiation	3 200	"free energy"
	body heat	1 500	"free energy"
Total energy supplied		24 300 kWh	
Total purchased energy		19 500 kWh	

Table 7 Tabulation of expected demand for purchased energy supply for different indoor temperatures and ventilation rates.

Indoor temperature °C	Ventilation change/h	"Purchased" energy kWh
20	0.5	19 600
	0.25	16 200
19	0.5	18 400
	0.25	15 200
18	0.5	17 200
	0.25	14 200

Comparison between calculated and measured energy consumption

The total energy consumption in five houses was read off from the respective houses' electricity meters. The indoor temperature was checked a number of times during the year. The householders gave an assurance that no changes were made to the thermostat settings on the electric radiators.

The quantity of exhaust air was measured at each reading opportunity from the electricity meter and has been assumed to be constant during the year.

Tables 8a and 8b indicate the true energy consumption over a period of two years in relation to the calculated energy consumption. Calculation of the energy consumption has been carried out in the same way as that which formed the basis for Table 6, wherein the measured values of temperatures and ventilation were used for calculating transmission and ventilation losses.

Table 8a Tabulation of calculated and measured energy consumption between February 1978 - February 1979

House	Measured indoor temperature °C	Measured air change rate changes/h	Energy consumption kWh/year Calculated	Measured
A1	19-20	0.35	17 100-18 000	17 900
A2	20-21	0.50	19 600-20 500	19 450
A3	17-18	0.50	16 100-17 100	16 000
A4	20-21	0.50	19 600-20 500	20 500
A5	19-20	0.50	18 400-19 600	18 900
			Average	18 500

Table 8b Tabulation of calculated and measured energy consumption between February 1979 - February 1980

House	Measured indoor temperature °C	Measured air change rate changes/h	Energy consumption kWh/year Calculated	Measured
A1	19-20	0.45	18 600-19 400	20 800
A2	19-20	0.35	17 100-18 000	18 500
A3	18-19	0.50	17 200-18 600	16 900
A4	20-21	0.50	19 600-20 500	20 400
A5	18-19	0.50	17 200-18 600	17 400
			Average	18 800

Tables 8a and 8b indicate that the measured energy consumptions agree favourably with those calculated. When the indoor temperature and the ventilation rate are known, it is possible to calculate the annual energy consumption with reasonable accuracy and in quite a simple manner. Different living patterns (hot water consumption, household electricity) can explain the differences which are evident between measured and calculated energy consumption.

In well-insulated, airtight houses there is no evidence of dramatic changes in energy consumption unless the mean annual temperature during the year is significantly greater or less than the normal value. Furthermore, the results indicate that natural ventilation is low and varies insignificantly in relation to the outdoor climate.

Monitoring the houses' airtightness

The Swedish Building Code recommends that free-standing single-family dwellings shall have an airtightness of 3.0 changes/h at a gauge or negative pressure of 50 Pa. The five houses described above all had an airtightness of less than 1.0 when the houses were completed.

One constructional requirement is that the houses' airtightness shall remain unchanged. At the Institution for Building Technology, the Royal Institute of Technology, Stockholm, pressure measurements have therefore been carried out to discover whether the houses' airtightness change significantly with time. Table 9 shows the results of airtightness tests carried out both at completion and when the houses had been occupied for one and two years respectively.

Table 9 Results of pressure tests over a three year period

House	Air change rate, changes/h, with a pressure difference of 50 Pa when pressure testing		
	October 1977	February 1979	February 1980
A1	0.8	1.6	1.5
A2	0.7	1.1	1.2
A3	0.7	1.5	1.4
A4	0.7	1.0	1.1
A5	0.8	1.2	1.3

The table indicates that a relatively high increase in air leakage is evident after the houses have been occupied for a year. During the latest measurements, no further change has occurred (the values lie within the measuring equipment's accuracy range.)

The reason for the considerable increase during 1979 is probably the fact that the house dried out during the first year wherein small cracks can have arisen primarily between external walls and intermediate joist structures.

The moisture content of wooden joists adjacent to external walls was very low (6.5-7%) when measured during February 1979 and 1980, which shows that there had been a considerable drying out of the timber since erection. One of the reasons for this satisfactory drying out is probably the fact that there is always a certain amount of negative pressure in the house which means that warm moist air cannot escape through the external structure.

The result from pressure tests gives a clear indication that air-tightness remains constant for a long period after drying out.

Indoor climate

During an investigation of the indoor climate it was shown that two type B houses, as well as type A houses, had an air leakage, when completed, of 3.0 changes/h at 50 Pa negative and gauge pressure respectively. (Compare with type A houses $<$ 1.0 changes/h).

These houses are factory built as two volume elements and eight roof elements. They also have accessible foundations. These houses are also designed as dormer houses (see figure 3).Compare with type A houses.

The exhaust air ventilation system is fan-controlled. Supply air is supplied through special air supply devices (slot air valves) in the window frame heads. The slot air valves can be adjusted but cannot be closed completely.

Air change rate

Tracer gas measurements have been carried out to monitor air change rates in individual rooms occupied by people over long periods (e.g. bedrooms).

In houses ventilated with an exhaust air system there are usually no exhaust air devices in bedrooms, workrooms, etc., whereas such devices are fitted to wet rooms (bathrooms, toilets, etc.) and kitchens. "Tainted air" is extracted via exhaust air devices in these areas wherein outdoor air is drawn into the house through supply air devices (slot air valves) usually positioned above windows in the rooms where exhaust air devices are not fitted. A certain amount of air also comes through leakage sources in the house.

The exhaust air flow is often regulated with a centrally-positioned control device on the cooker hood. The exhaust air fan is normally positioned in a ventilation flue above the roof.

The fan is set so that its basic flow corresponds to the air change rate (1/s) given in the Swedish Building Code for each individual wet room and kitchen. The minimum air change rate for the whole house must however not be less than 0.35 $l/s\ m^2$. This value corresponds to approximately 0.5 changes/h for the whole house. There is no indication of a minimum change rate for individual rooms in the Swedish Code, it merely states that "hygienic discomfort must not arise".

From a hygienic point of view an air change rate of 4 m^3/person and hour, at 18^{o}C and a relative moisture content of 60%, is the minimum change rate to ensure that the air shall not contain more than 0.5% CO_2. (the maximum value allowed at a place of work by the National Swedish Board of Occupational Safety and Health). There is no corresponding value for dwellings. Bearing in mind comfort requirements such as smell, a relative humidity value in the room which is not too high, and consideration of material-conditioned evaporation including radon, an air change rate of 10 m^3/person an hour is a more suitable limiting value, (see Ubisch 1977). This means that in the master bedroom a ventilation rate of approx (10+10+5)=25 m^3/hour is necessary if two adults and one child sleep in the room.

In all the houses which were investigated it was very easy for the individual householder to adjust the fan - and therefore the total air change rate in the house. In type A houses, the fan's basic setting - or basic speed - (lowest fan setting) has been adjusted so that the total air change rate in the house was approximately 0.5 changes/h including natural ventilation. The average air change rate at the basic speed in type B houses was 0.23-0.26 changes/h for the whole house including natural ventilation. The reason for having a "basic speed" which gave approximately 0.25 changes/h in type B houses was said to be that, during the daytime or during a longer absence from the house, it should be possible to reduce the ventilation and thus the energy consumption. There is no position which indicates when the houses have an air change rate of approximately 0.5 changes/h in type B houses.

It has been shown that most householders nearly always had the fan set to its lowest value in order to save energy.

The greatest risk of being subjected to an unacceptable indoor climate occurs in bedrooms since these are occupied for longer periods and since these rooms do not have exhaust air devices. The measurement results shown in Table 2 indicate the air change rate in type A and B houses with the fan set at basic speed and in accordance with the Swedish Building Code's recommendation (approx 0.5 changes/h). Measurements were carried out with the slot air valve both open and closed. The measurements shown relate to a master bedroom of approximately 13 m^2. The doors to the respective bedrooms were kept closed.

Table 10 Air change rates for different fan settings in master bedrooms with open and closed slot air valves respectively. Bedroom doors were closed.

Fan Setting	House A	House B1	House B2	Recommended Value
Basic speed approx 0.25 changes/h in the whole house (slot air valve closed)	-	4.7	5	25
Basic speed approx 0.5 changes/h in the whole house (slot air valve open)	-	9.7	12.2	25
As per Swedish Building Code approx 0.5 changes/h in the whole house (slot air valve closed)	21.6	9.4	8.4	25
As per Swedish Building Code approx 0.5 changes/h in the whole house (slot air valve open)	29.5	18.5	19.6	25

The table shows that only type A houses have an air change rate which corresponds to the recommended value of 25 m^3/hour. In type B houses, with the fan set at basic speed, the value was as low as approximately 5.0 m^3/h with the slot air valve closed. The value is totally unacceptable from a hygienic point of view and causes an increase in relative humidity and CO_2 content.

The results also show that the slot air valves have a decisive effect on the air change rate in the rooms. For this reason it should not be possible to close the slot air valve completely.

Even when the fan was set to correspond to the values quoted in the Swedish Building Code, very low values (9.4-14.1 changes/h) were obtained in type B houses (with the slot air valve closed). This value is approximately the same as at basic speed with the slot air valve open.

Determination of CO_2 content

In type B houses, very low air change rates were measured in bedrooms. The lowest value measured is 5 m^3/h. 5 m^3/h in type B houses corresponds to an air change rate of 0.15 changes/h and this agrees favourably with the measured amount of natural ventilation in the house.

In order to illustrate the increase of the CO_2 content an example below shows the increase of the CO_2 content in house B2. The CO_2 content is calculated using the following equation.

$$c = \frac{q}{nv} (1-e^{nt})+c_o e^{-nt}$$

where c = CO_2 concentration at time t

n = air change rate (changes/h)

t = time (h)

q = exhaled CO_2 content in m^3/h

v = room volume (m^3)

c_o = background concentration of CO_2 in the room

The calculations assume that the room is occupied by two adults and one child, that the door is closed and that a person at rest exhales 20 l CO_2/h at rest. The corresponding figure for a child at rest is 10 l CO_2/h.

Figure 4-5 CO_2 content variation with time in type A and B2 houses for different air change rates in the master bedroom with closed door occupied by two sleeping adults and one child

Table 11 Air change rate for different fan settings in masters bedroom

House	Fan Setting	Air change rate measured in bedroom	
		m^3/h	changes/h
A	Fan setting according to Swedish Building Code (0.35 l/s m^2) approx 0.5 changes/h in the whole house, slot air valve open	29.5	1.0
	Fan setting according to Swedish Building Code (0.35 l/s m^2) approx 0.5 changes/h in the whole house, slot air valve closed	21.6	0.73
	Note. The slot air valve in type A cannot be closed completely whereas it can in house B		
B2	Fan set at base speed approx 0.25 changes/h in the whole house, slot air valve closed	5	0.15
	Fan set according to Swedish Building Code (0.35 l/s m^2) approx 0.5 changes/h in the whole house, slot air valve closed	8.4	0.26
	Fan set at base speed approx 0.25 changes/h in the whole house, slot air valve open	12.2	0.37
	Fan set according to Swedish Building Code (0.35 l/s m^2) approx 0.5 changes/h in the whole house, slot air valve open	19.6	0.66

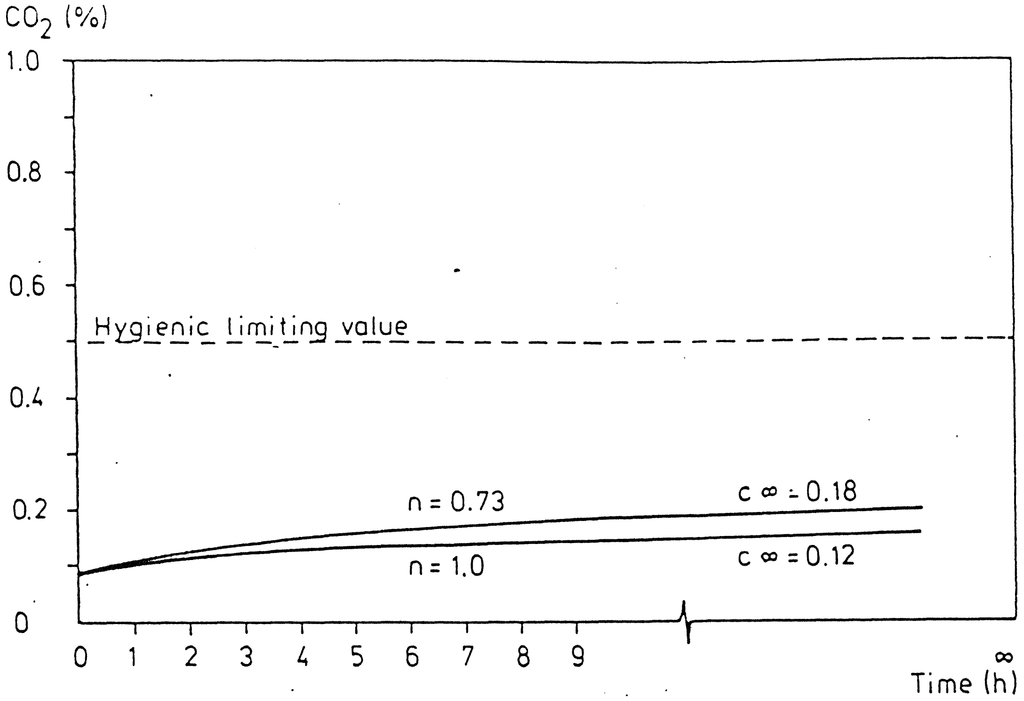


Figure 4 Type A houses

From the figure it can be seen that the hygienic limiting value is not exceeded in type A houses

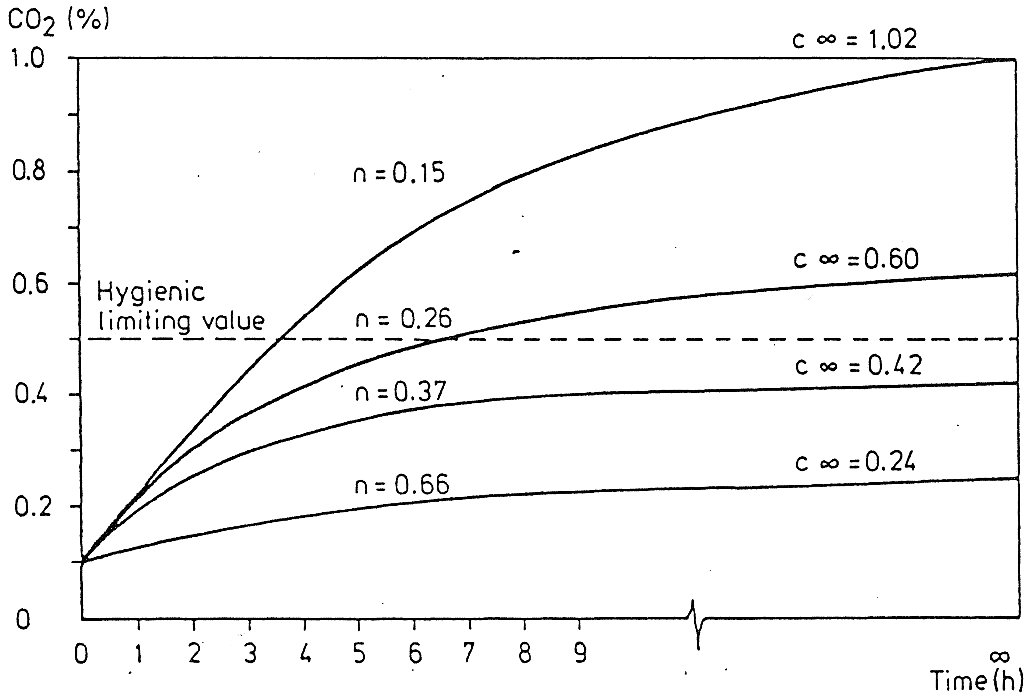


Figure 5 Type B house

From the figure it can be seen that if the slot air valve is closed in the bedroom the hygienic limiting value is exceeded in house B2 at both basic speed and at air change rate values which correspond to the requirements in the Swedish Building Code. With an air change rate of 0,15 the CO_2 content becomes as high as 1,02%. From a hygienic point of view this value is totally unacceptable. An initial value of 0,18% CO_2 is assumed in house B2 during the day.

Determination of moisture content increase in the air

A person gives off approximately 40 g of water vapour per hour at rest. If we assume that two adults and a child sleep in the master bedroom, the vapour gain will be approximately 100 g/h (40+40+20). There may be other moisture sources which can increase moisture emission even further. These will be considered in the text that follows since they are considered to be minor.

The increase in the moisture content in the room is dependent on how well the room is ventilated. Figure 6-7show how the moisture content increases according to time for type A and B2 houses where the outdoor temperature is 0°C and where the outdoor humidity is 80%. The calculations have been made using the same method as for calculating the CO_2 content above.

The values indicate the upper limit for moisture content in the bedroom. The presence of absorbant material in the room reduces the calculated value somewhat. All the calculations are based on the values shown in table 11. The initial values in figures 6-7 indicate the moisture content at steady state conditions with an average moisture gain in the whole house of 3.0 g/m^3 with an air change rate of 0.5 changes/h.

Figures 6-7 indicate that the moisture content of the air in the master bedroom in house B2 becomes unacceptably high with the slot air valve closed. When the slot air is open the values become acceptable however in the master bedrooms of both type A and B houses.

Since most of the slot air valves available on the market today fitted to single family dwellings can be closed completely, it is quite probable that many people close the valves during the winter period in the hope of saving energy or to cut down "draughts". However by closing the valves the indoor climate deteriorates. Raising the moisture content over long periods can give rise to rust damage on windows and mould growth behind cupboards up against external walls etc.

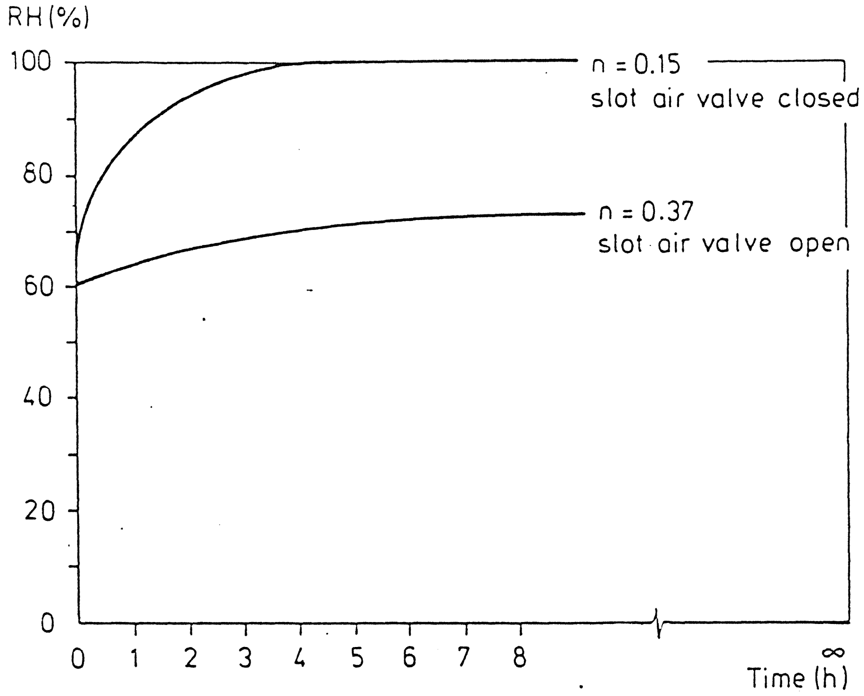


Figure 6

Increase in moisture content in master bedroom (house B2) with slot air valves closed and open respectively. Fan set at approx 0,25 changes/h (basic speed). Indoor temperature 19 °C and outdoor temperature 0 °C (RH 80%)

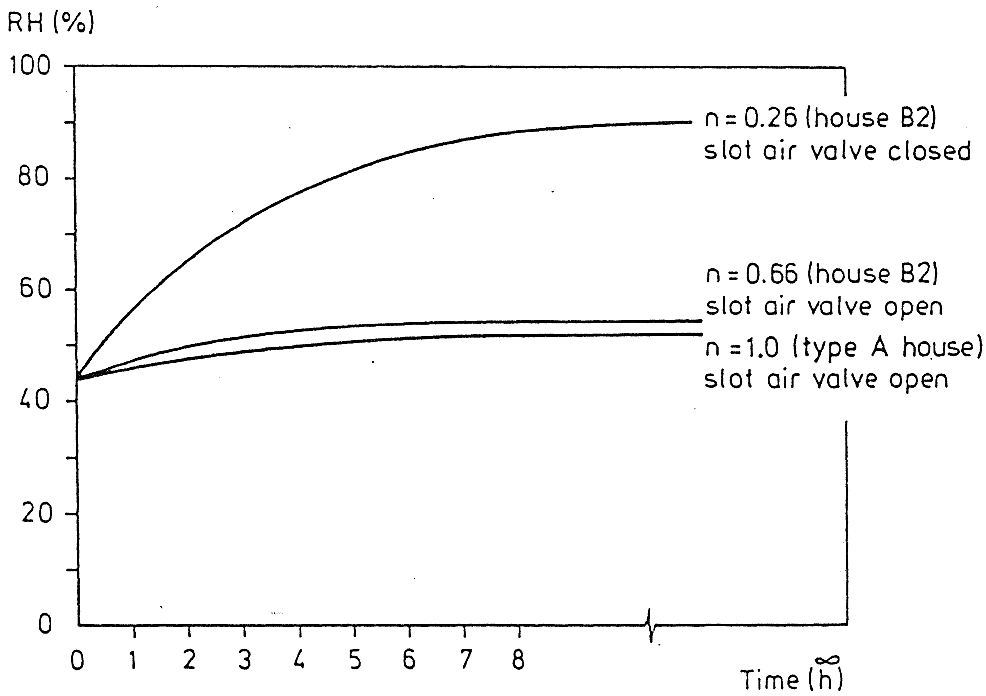
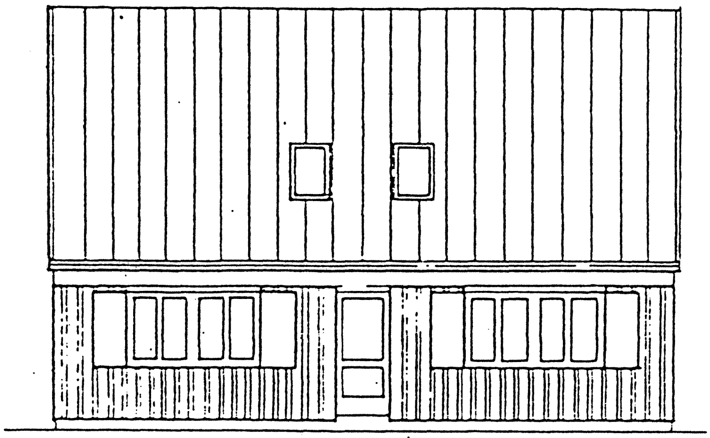
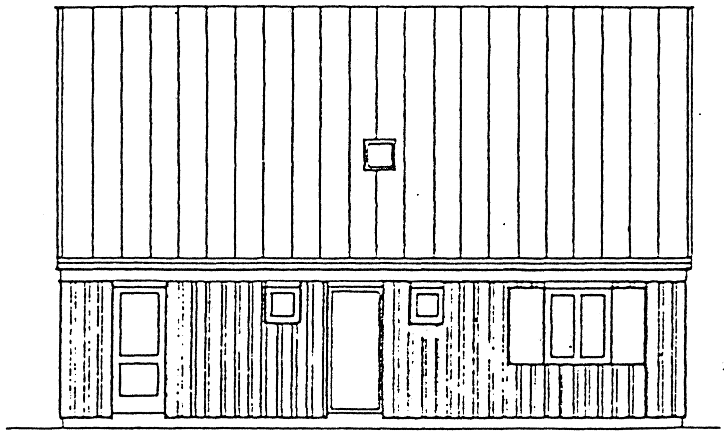


Figure 7

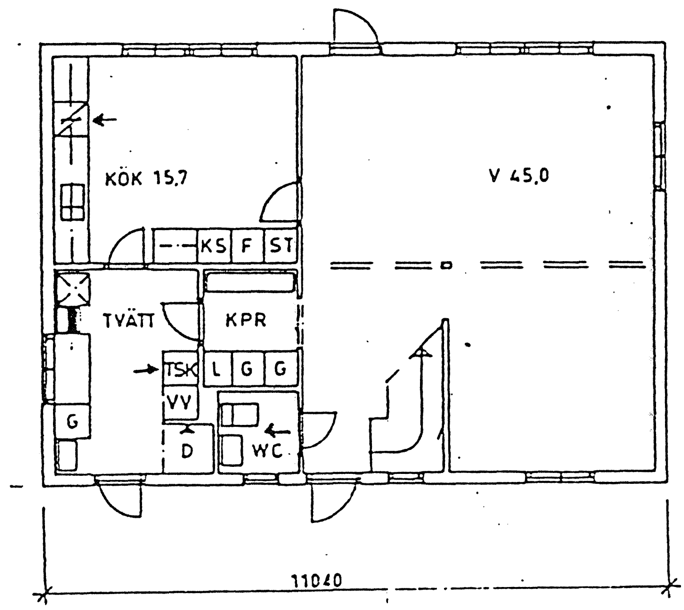
Moisture increase rate in master bedroom (type B2 and A houses) with slot air valve closed and open respectively. Fan setting approx 0,5 changes/h (0,35 l/s m²). Indoor temperature 19 °C and outdoor temperature 0 °C (RH 80%)



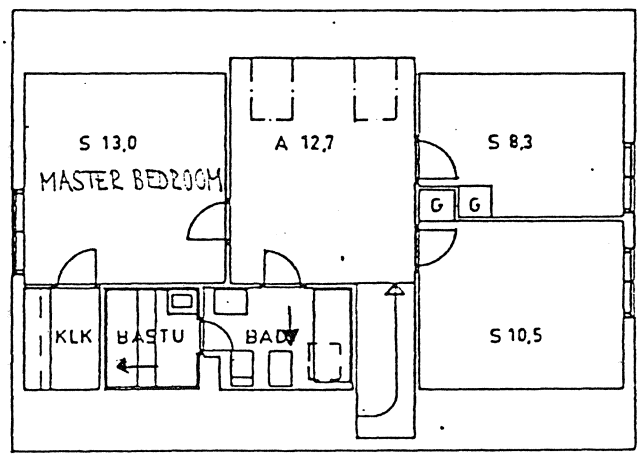
ENTRANCE ELEVATION



GARDEN ELEVATION

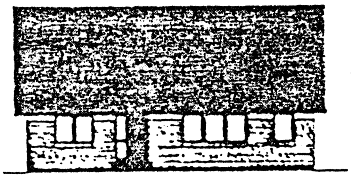


ENTRANCE FLOOR



FIRST FLOOR

FIGURE 2. HOUSETYPE A



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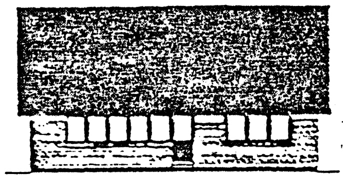

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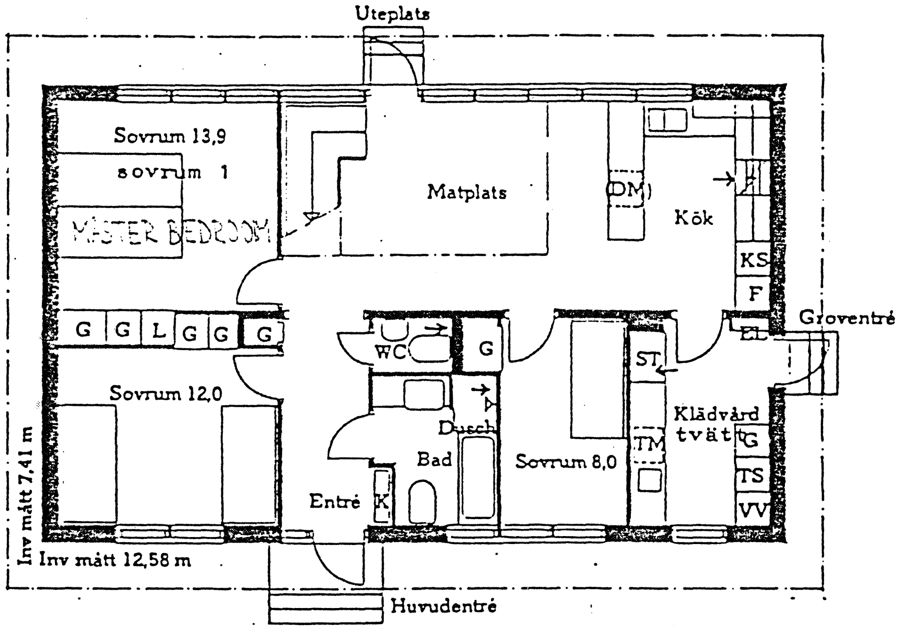

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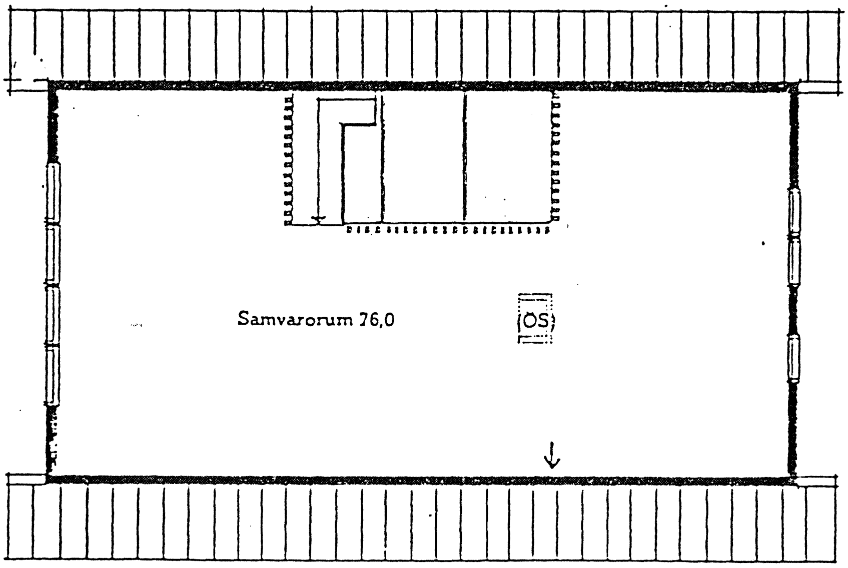

FIRST FLOOR

FIGURE 3. HOUSETYPE B

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