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Well insulated airtight buildings

Design and construction

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Swedish Council for Building Research

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Background

In Sweden, specifications concerning thermal insulation and
airtightness of buildings are contained in the Swedish Building
Code. In previous codes specifications pertaining to thermal
insulation were mainly based on hygienic and comfort requirements
to provide acceptable indoor climate. However, both in terms of
economic as well as the energy conservation policy the insulation
provided exceeded the minimum requirements of the building code.

In 1975, an energy policy decision was taken in Sweden in an
attempt to reduce energy consumption. To realize this, among
other things, the energy used for the heating of buildings
was to be reduced on the average by 0,9 % annually up to 1985.
As a result of this energy policy decision, new specifications
concerning the energy management in buildings were drawn up.
They come into force on January 1st 1977, containing considerably
more stringent requirements concerning the thermal insulation
of buildings as well as entirely new requirements pertaining to
the airtightness of buildings.

In the Swedish Building Code, SBN 75, the highest permitted
values for thermal transmittance (U-values) are specified for
different components of a building. These vary depending on
the geographical location of the building as well as on the
temperature to which the premises are to be heated. Table 1
gives examples of the highest permissible U-values for building
components enclosing premises which are to be heated to 18 ^{O}C or
more. Temperature zone I + II includes northerns Sweden,
entailing somewhat more stringent requirements than those for
zone III + IV covering southerns Sweden. Space which is to be
heated to temperatures above 18 ^{O}C is considered to include

dwellings, offices, schools and shops. The Code also contains rules limiting the permissible window area.

Table 1. Maximum permitted thermal transmittance coefficients (U-values), W/m^2 $^\circ$C for building components for rooms intended to be heated to temperatures higher than +18 $^\circ$C

Building Component	Requirement in temperature zone	
Description	I + II	III + IV
Walls directly against the open air or throug earth to the open air	0,25	0,30
Roofs or attic floors and roof above facing the open air	0,17	0,20
Floor construction above crawle space	0,30	0,30
Floor structure on ground	0,30	0,30
Non-glazed portions of doors (including frame)	1,00	1,00
Windows	2,00	2,00

For premises which are to be heated to temperatures not exceeding 18 $^\circ$C, the U-values specified in the table may be exceeded. The U-values may also be exceeded, within certain specified limits, for individual components of a building provided it can be shown that the total energy consumption of the building is thereby not increased. In other words, if the thermal insulation of one part of a building is reduced, this must be compensated by a corresponding increase of the insulation in another part.

A large proportion of the energy consumed in buildings is used for the heating of the ventilation air. In an attempt to reduce the total number of air changes, SBN 75, established requirements for airtightness. These are specified for different building components in terms of the maximum permissible infiltration at various over and under pressures.

Table 2. Maximum permitted air-leakage m^3/m^2 h

Building components	Pressure difference Pa	Building: number of storeys		
		1-2	3-8	8
External walls	50	0,4	0,2	0,2
External windows and doors (relates to absence of leakage in the gap between frame and window lintel or door)	50	1,7	1,7	1,7
	300	5,6	5,6	5,6
	500	–	–	7,9
Roof and floor in contact with the open air or floor in contact with ventilated room	50	0,2	0,1	0,1

The requirements in this table relate only to infiltration through the actual building components including joints which are a part thereof. But the joints between the components are not included.

The airtightness of the completed building is to be determined by means of a special pressure test in which the total number of air changes is determined at a pressure difference of 50 Pa. According to the recommendations given in SBN 75, the number of air changes should not exceed the values specified in Table 3. After a transitional period which ends on 1st July 1978, the highest permitted number of air changes is reduced.

Table 3. 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

As already mentioned, the requirements concerning air infiltration are new. The values for the transition period up to 30 Juni 1978 have been specified keeping in mind the standards which could be achieved to date in a well constructed building employing techniques which do no require special provisions for airtightness or special design procedures.

Investigations have shown that only a small proportion of housing production conforms to the more stringent requirements regarding airtightness. Both design as well as workmanship must therefore be changed if the more stringent requirements are to be satisfied. The main reasons for increasing the airtightness of buildings are set out below. Examples are also given of construction methods which meet stringent requirements concerning airtightness and good thermal insulation. Finally, climatic conditions - mainly ventilation - and energy consumption in well insulated airtight buildings will be analysed.

The Reasons for the Construction of Airtight Buildings

In well insulated buildings about 30 - 40 % of the energy consumed is used to heat the ventilation air. From the point of view of energy conservation, it is of interest to study ways whereby the energy consumed by ventilation can be reduced. This can be achieved in two ways: the number of air changes can be reduced and/or a heat recovery unit can be built into the ventilating system. Many buildings have natural ventilation and depend on a certain amount of air leakage. In such cases ventilation is thus primarily governed by the external climate and not by the need for fresh air, being greatest in the winter when it is cold. A natural ventilation system is thus uncontrolled with ventilation largely left to chance. In order to better control ventilation, mechanical exhaust ventilation has been introduced. However, for such systems to work in a satisfactory manner, it is essential that uncontrolled or unintentional air leakage into the building be small. It must thus be possible to control the inflow of air.

Unintentional and uncontrolled ventilation of a building results
in an increase of the energy needed for heating. The reasons are
as follows:

a) the outside air must be heated to room temperature,

b) air leakage may lead to draughts. To compensate for the
    resulting discomfort room temperature must be raised, which
    in turn results in higher energy losses,

c) uncontrolled infiltration may cool down the inside surfaces
    of the building envelope, calling for higher room temperature
    to compensate for the lack of comfort due to the cold surfaces
    and

d) airflow through the thermal insulation will deminish its
    effectiveness.

In airtight buildings the control of ventilation is largely
independent   of the external climate. This means that the
desired air quality can be set and maintained regardless of the
external climate. For systems with heat recovery from the
ventilation air, it is essential that the building be airtight
if the system is to function in a satisfactory manner and its
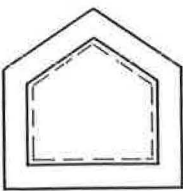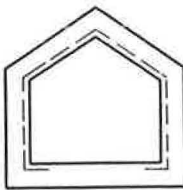full economic potential be realized.

Design for Airtightness

Careful detailing during the design process is essential if
buildings are to be airtight. Moreover, this will also greatly
simplify the contruction process. It is essential that suitable
details be developed for junctions between external and internal
walls, at the sill, between external walls and the attic floor,
between external walls and the attic ceiling as well as joints
around windows and, last but not least, for points where services
for electricity, water, space heating and ventilation penetrate
the building envelope.

Some of the most common causes for the lack of airtightness can
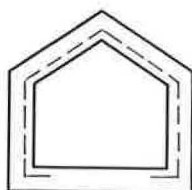be attributed to faulty or inappropriate design, incomplete

drawings (the way in which junctions are to be made airtight is
not specified), wrong working sequences on the site, substandard
sealants and poor workmanship, and far too many and incorrectly
insulated penetrations for services.

Depending on materials and construction details, there are a
number of ways in which a building can be made airtight. Table 4
outlines conceiveable ways whereby airtightness can be achieved.
The approach chosen should be applied as consistently as possible
over the entire building envelope. This means that not only
the walls and roofs must conform to this principle, but that it
must also be carried out consistently at all joints and
connections.

Table 4. The main principles for the design and placement of
         airtight layers in stuctures

Construction principle	Advantages	Drawbacks
Internal airtight cladding, e.g. plasterboard	makes use of the properties of ordinary board material can be checked and repaired relatively easily	the layer is unprotected risk of puncturing joints must be carefylly sealed sensitive to movement and consequent cracking
Internal airtight layer (polyethylene sheet)	the vapour barrier can naturally also be used as airtight layer sheets of large size can be used	certain construction details are difficult to deal with needs accuracy in lapping penetrations for services lead to problems

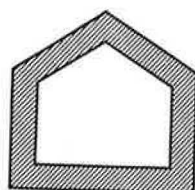|		
Recessed airtight layer (felt, polyethelene sheet)	the airtight layer is protected from mechanical damage	unknown risk of damage at high RH and low outside temperatures
	electrical installations possible without damage to airtight layer	effect of joinery and furniture on moisture conditions at airtight layer, especially at outside corners, is unknown
	good chance of achieving high degree of airtightness	requires a double stud wall
External airtight layer (windproofing)	easy to apply	great risk that airtightness is so great that there will be condensation
	the airtight properties of the windproof layer can be utilised	layer affected by outside climate
		risk of damage during construction
		material must have high degree of weather resistance
		places high demands on internal vapour barrier
Combination of internal and external airtight layer	double safety	a double airtight layer is uneconomical
		an aritight windproof layer may cause moisture damage
Homogeneous constructions, e.g. cellular concrete	simple	limited choice of materials
		junction details must be designed separately
		all parts of the building should be constructed according to the same system, and this restricts the choice of method and material
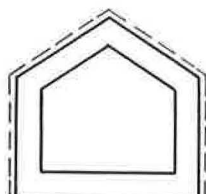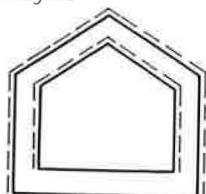
Examples of Design Solutions for Detached Houses

To illustrate ways and means whereby airtightness can be achieved
the design, construction and evaluation of single family dwellings
in a Stockholm suburb will be considered. The 1 1/2 storey
dwellings were built to comply with SBN 75.

The principle adopted during design was that the internal vapour
barrier consisting of polyethylene sheet be applied consistently
to provide an impermeable envelope. The goal was to achieve a
level of airtightness exceeding that specified by SBN 75.

General Description of the Buildings

The study comprised seven bungalows with attic storeys, each
having a floor area of 138 m^2. The foundations consist of concrete
slabs on ground while the wood-frames are loadbearing. Wood
panels are used for cladding and the roofs are covered with
corrugated metal decking. The seven bungalows are erected by the
Byggnads AB Folkhem.

The concrete slab is laid on a fill of blasted rock covered with
a capillary breaking layer of crushed rock. The frame is made up
of a double stud system, with the vertical studs on the inside
and the horizontal ones on the outside. All framing lumber was
pre-cut to a high tolerance. The wall frame sections were
assembled on the concrete slab and one by one tilted into position.
The roof trusses were assembled on the site in a template and
lifted into place. The horizontal studs as well as the doors and
windows were then attached. The stud systems were carefully
designed to maintain a 60 cm stud spacing throughout. This made it,
to a very large extent, possible to use standard sizes of insula-
tion materials and boards without the need for cutting, thereby
facilitating the achievement of good workmanship.

Mineral wool for thermal insulation was provided in the thick-
nesses of: 12 + 5 cm for the exterior walls, 19,5 cm for the
sloping parts of the attic roof, 19,5 + 5 cm for the attic
ceiling and 10 cm on the floor slab. Roof insulation was applied
from the inside, making it possible to provide weather protection

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to the building and especially the insulationsmaterial at an
early state of construction. The roof itself consisted of fibre
board covered with nailing strips and corrugated metal decking.

Insulation between the horizontal studs in the external walls
was applied from the outside and covered with a windproof layer of
sheathing felt. The sloping roof was insulated from the inside,
while the attic ceiling was insulated from the top after the
polyethylene sheet vapour barrier and strapping had been applied.

The vapour barrier was applied first to the gable walls of the
upper floor, then to the ceilings of the upper floor, and finally
to the walls on the ground floor.

Chipboard on the gable walls, and plasterboard in the remaining
locations was used for internal wall covering. The chipboard also
serves as wind bracing.

The floor on the slab on grade consists of chipboard sheets or
laminated oak boards laid on wooden sleepers with intermediate
mineral wool insulation. A polyethylene sheet was first laid
down to cover the concrete slab.

Construction Details

Some details which require a great del of attention during design
to ensure that the building is sufficiently airtight are shown
in FIG 1.

External Wall - Ground Floor

Complaints about draughts at the floor and cold floors are common.
This is often due to faulty construction of the junction between
the wall and the floor. In order to avoid this, the sill must be
made airtight, and the inner and outer airtight layers must be
applied properly.

In this example, a sealing strip of EPDM rubber was laid on the
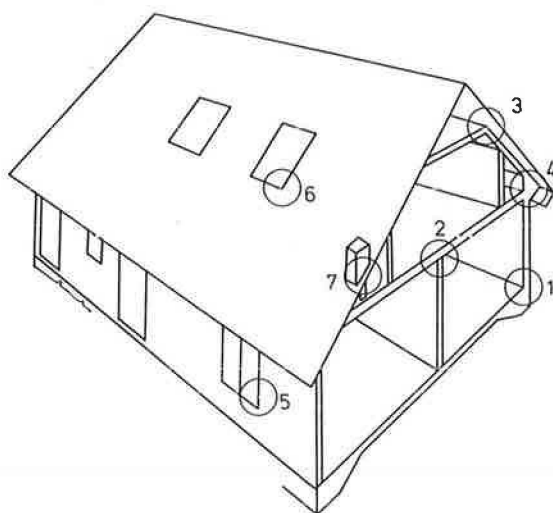steel floated concrete surface. The sill was then placed in the

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

correct position and fixed to the concrete with expansion bolts.
The wall frame was then tilted into position.

From the point of view of airtightness, this detail is well
thought out. Three components are used to achieve aritightness:

1   a continuous windproof layer of sheathing felt is carried
     over the sill and down onto the edge of the floor slab,

2   a sealing strip of EPDM rubber is clamped underneath the
     sill and

3   an inner airtight layer of polyethylene sheet is applied.
     The polyethylene sheets on the wall and floor being over-
     lapped and taped.

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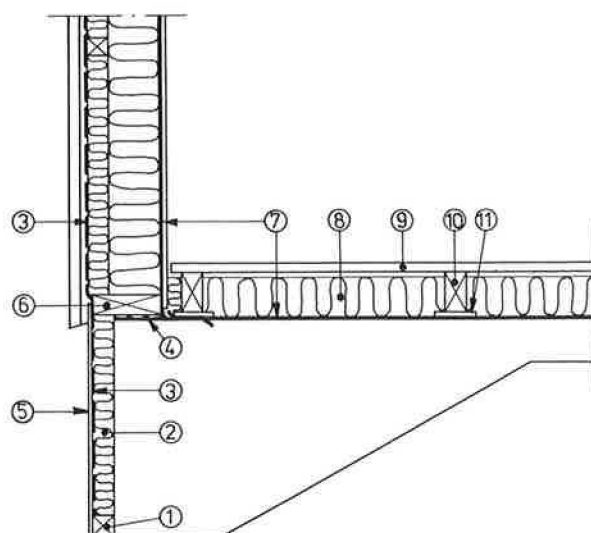of

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FIG 2. Junction between the external wall and the ground floor

1   50 x 50 mm pressure impregnated batten
2   50 mm mineral wool
3   sheathing felt
4   sealing strip of EPDM rubber under the sill
5   5 mm "Steni interior" glassfibre reinforced concrete
6   48 x 160 mm sill
7   0,20 mm transparent polyethylene sheet
8   100 mm mineral wool
9   22 mm floor grade chipboard or 22 mm laminated oak boards
10 45 x 95 mm sleepers
11 100 mm wide strip of 12,7 mm asphalt-impregnated wood
    fibre board

This detail is relatively easy to complete while the risk of
failure i minimized.

In order that this solution function as intended it is essential
that the concret be placed with reasonable care, steel trowel
finishing being usually required. It has been found that it
is possible to achieve the required degree of accuracy with
this detail.

Loadbearing Partition, Attic Floor - Gable Wall

Preparations are made during erection of the frame for application
of the vapour barrier by placing strips of polyethylene sheet
underneath the loadbearing partition wall, between the load
bearing partition wall and the gable wall, and between the gable
wall and the attic floor (see FIG 3). These strips make it
possible to provide for continuity of the inner airtight layer.
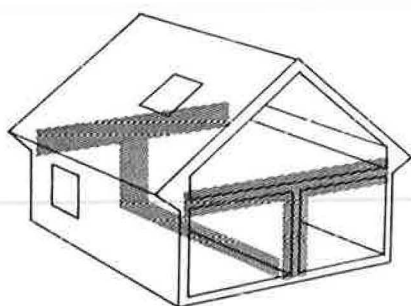These strips should be about 60 cm wide to provide sufficient
overlap.

FIG 3. During erection of the frame strips of polyethylene
       sheet vapour barrier are placed underneath the load-
       bearing partition wall, between the loadbearing partition
       wall and the gable wall as well as between the gable wall
       and the attic floor.

Figurs 4 and 5 show details of the junctions between the load-
bearing partition wall and gable wall, and between the gable
wall and the attic floor. The strips of polyethylene sheet are
applied during the erection of the frame.

Erection of the frame and application of the polyethylene sheet
to walls and ceilings take place at different stages. As the
frame is erected at a fast pace, it is easy to forget to install
the above mentioned polyethylene strips. In order to prevent this,
the strips should be clearly marked on the framing drawings, and
the stage at which they are to be applied should be specified
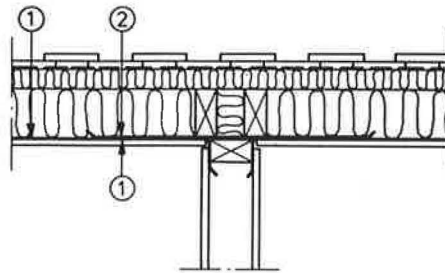in the working instructions.

FIG 4. Horizontal section, gable wall - loadbearing
partition wall

    1 0,20 mm transparent polyethylene sheet
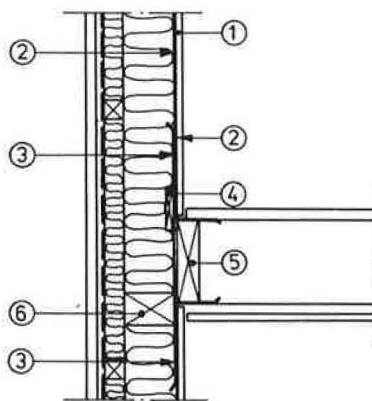   2 60 cm wide strip of polyethylene sheet

FIG 5. Vertical section through the junction between the
gable wall and the attic floor

    1 13 mm plasterboard
    2 0,20 mm transparent polyethylene sheet
    3 60 cm wide strip of polyethylene sheet
    4 25 x 100 mm blocking
    5 48 x 195 lower chord member of roof truss
    6 73 x 120 mm top plate

Attic Ceiling - Gable Wall

If the airtight layer is not applied properly at the junction between the wall and the ceiling, cold air can spread out in the joist spaces between the floor and the ceiling, thereby "short circuiting" the insulation. Warm moist air can also flow outwards into the thickness of the building enclosure where damage due to moisture can result. It is therefore essential that both the outer and inner airtight layers be properly installed.

Airtightness is ensured by overlapping the polyethylene sheet at all joints and carefylly taping it. In the attic ceiling the vapour barrier sheet is laid above the strapping to ensure good contact between the mineral wool och the vapour barrier. This will reduce the risk of loss of effectiveness of the insulation due to convection.
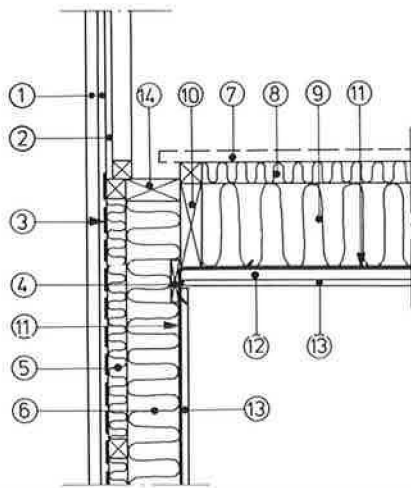
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FIG 6. Vertical section through junction of the attic ceiling and the gable wall

1 Chipboard panel
2 12,7 mm asphalt-impreg-nated wood fibre board
3 Sheathing felt
4 25 x 100 mm blocking
5 45 mm mineral wool
6 120 mm mineral wool
7 25 x 125 mm walkway plank

8 50 mm mineral woll slab with felt
9 195 mm mineral wool
10 50 x 195 mm tie beam
11 0,20 mm transparent polyethylene sheet
12 23 x 95 mm strapping
13 13 mm plasterboard
14 48 x 120 mm top plate

FIG

Eaves

The most difficult detail from the point of view of airtightness in 1 1/2-storey houses is the point where the polyethylene sheet passes through the floor at the eaves. Owing to the large number of penetrations for services and the rectangular floor joists, application of the polyethylene sheet becomes both difficult and time consuming. In view of this, the design of this detail merits careful attention.

In principle there are two methods of applying insulation and the vapour barrier at the junction of the attic floor. These are illustrated in FIG 7.
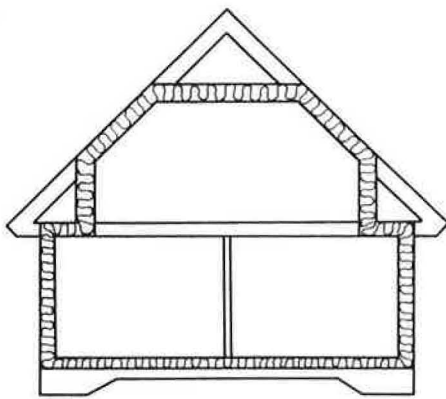

FIG 7 a. Roof truss with in-
        sulated walls along
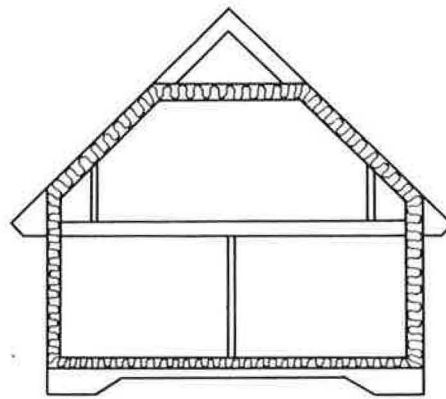   the truss supports.

FIG 7 b. Roof truss with the
        supports in line with
        the external walls and
        with lightweight stud
        walls.

The conventional roof truss of a 1 1/2-storey house has the insulated wall set back some 1 to 2 m from the exterior wall (see FIG 7 a). The application of insulation and vapour barriers is both difficult and time consuming, often leading to the leakage of cold air into the joist space. However, by moving the vertical support members of the trusses together with the vapour barrier and insulation into the plane of the exterior wall two right angle corners with associated vapour barrier and insulation application problems were eliminated (see FIG 7 b).

The space left behind the lightweight stud wall but inside the insulation and vapour barrier can now be used to advantage to house various electrical and mechanical installations. In this way, there is no need to utilise any of the dwelling space for pipes and ducts nor to make difficult to seal penetrations through the vapour barrier.

In order to ensure a good seal at the point where the attic floor joins the external wall polyethylene sheet was clamped onto the joists. It was clamped between the plasterboard and pieces of blocking (marked 9 and 10 on FIG 8) which were nailed to the joists and the top wall plate after erection of the frame. Jointing compound was used as a supplement to the clamping of the joints.

Joints Around Doors and Windows

Around doors and windows there is naturally a joint between the vapour barrier and the frame. The overall lenght of this joint in the houses studied is about 80 m, while the total joint length where the airtightness function of the polyethylene sheet is taken over by some other building material amounts to about 100 m (including junctions at floors and around ventilation ducts). This means that about 80 % of the total joint length is at doors and windows. It is therefore essential that simple yet reliable details be developed for such joints.

Here the outside dimension of the window frames were made to suit studs spaced at 60 cm centres which reduced the number of studs in walls and facilitated the installation of insulation.
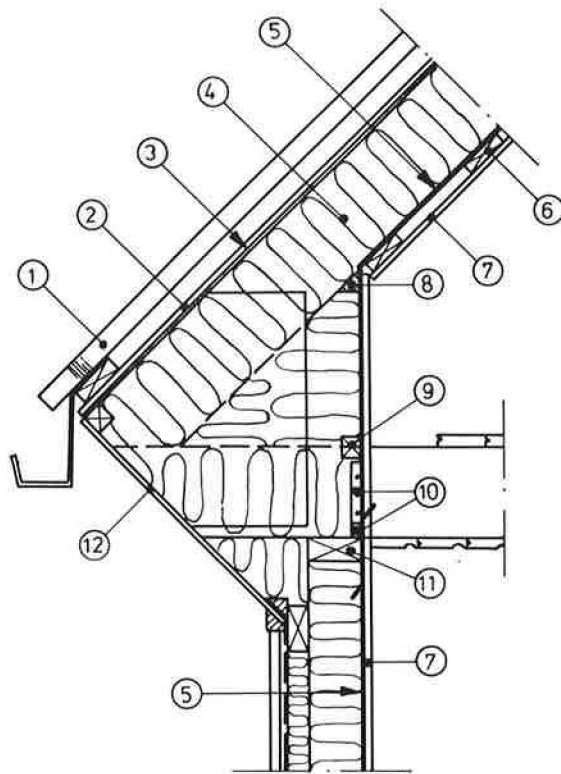
FIG 8. Vertical section through the eaves

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 1   Corrugated metal decking
 2   13 x 50 mm battens
 3   6,3 mm wood fibre board
 4   195 mm mineral wool
 5   0,20 mm transparent polyethylene sheet
 6   23 x 95 mm strapping
 7   13 mm plasterboard
 8   45 mm triangular batten
 9   45 x 45 mm blocking
10   25 x 25 mm blocking
11   48 x 120 top plate
12   9 mm wood fibre board
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Door and window frames were also provided with a rebate to
facilitate the clamping of the plastics foil against the frame.
This was accomplished by nailing a strip of chipboard (No 1
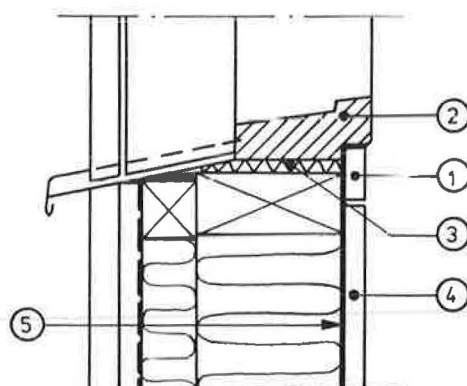in FIG 9) to the frame and the studs.

FIG 9. Detail at window sill
    1   12 mm chipboard
    2   Window sill
    3   Mineral wool caulking or expanded polyurethane
    4   13 mm plasterboard
    5   0,20 mm transparent polyethelene sheet

Chipboard was used as it is stiffer and stronger than plaster-
board, and can thus be expected to proved better clamping
action.

Mineral wool caulking or one - component expanded polyurethane
foam was used to seal the space between the frame and the
surrounding studs.

Penetrations for Services

To satisfy the new code requirements it is essential that
the effect of various penetrations of the building envelope on
airtightness be taken into consideration at the design stage.

The most obvious measure is to cut the number of such
penetrations to the bare minimum. For instance, electric cables
can be located in interior walls in special baseboard conduits.
Unavoidable penetrations should be made so that they can be
easily sealed. For instance, ventilation ducts can be fitted
with soldered-on sheetmetal collars or have butyl rubber collars
stretched onto them.

In the buildings studied, most of the electric cables were
located in interior walls, the attic floor and between the
strapping of the attic ceiling. Consequently, only four
penetrations of the building enclosure were necessary (for
outside lighting, the bell circuit, external kWh meter and
the antenna cable). These penetrations as well as those for
the ventilation pipe were sealed with tape. At the ventilation
outlet (FIG 10). the polyethylene sheet was clamped between
the flashing at the bottom of the outlet and the strapping
of the attic ceiling.

Here the cover sheet was screwed to the strapping after which
the 2 holes for the ventilation pipes through the cover sheet
were sealed with a sealing compound. If the sheetmetal cover
had been located underneath the slats (see FIG 10), the
airtightness around the holes would have been further improved.

Installation of the Polyethylene Sheet

Polyethylene sheet, 0,20 mm thick and of two sizes was used.
A sheet of width 2,70 m, i.e. exceeding the height of a wall,
was placed on the walls, while in the roof a sheet 1,35 m wide
was used which covered the space between two roof trusses
(at 1 200 mm centres).

Top Floor

The polyethylene sheet was first of all attached to the gable
walls (FIG 11). It was rolled out on the floor along the wall
and cut to be about 80 cm too long. The sheet was then attached
to the underside of the attic ceiling, after which it was
folded down and stapled to the rest of the wall. After completing
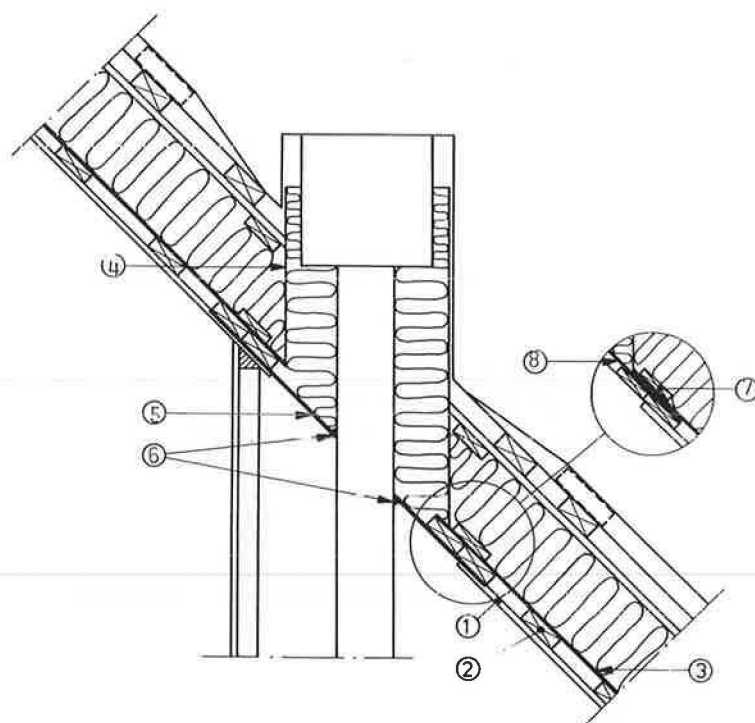
FIG 10. Roof Ventdetail:

1	13 mm plasterboard	
2	23 x 95 mm strapping	
3	0,20 mm transparent	
4	Bottom flashing	
5	Cover sheet	
6	Sealed with compound	

Proposed modification:
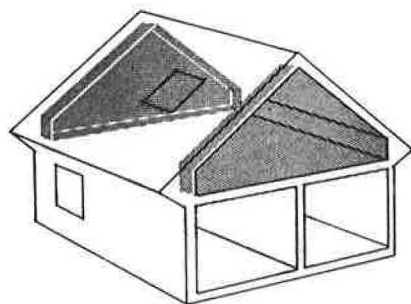7   23 x 95 mm blocking
8   Cover sheet moved

FIG 11. Line the gables on the top floor with
        polyethylene sheet

the gable wall the sheet could be applied to the ceiling
(FIG 12). Here it was first fixed at one of the eaves, after
which the sheet was secured along the sloping roof and then
down to the eaves on the opposit side. At each eaves the sheet
was cut about 40 cm too long, so that it could pass through
the attic floor and be overlapped with the vapour barrier for
the lower wall. The sheet had to, however, be cut where it
passes each joist in the attic floor. Each portion of the
sheet was then folded down through the floor and attached to
the joists, the blocking pieces and the top plate.
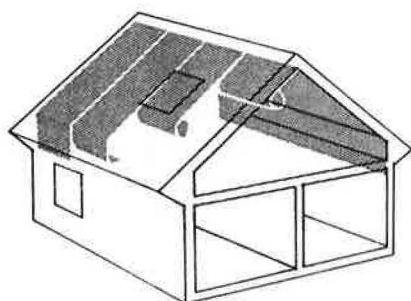

FIG 12. Line the ceiling with polyethylens sheet parallel
        to the roof trusses. Pass the rolls through an opening
        at the edge of the attic floor. The joints are to be
        laid over the supports with a good overlap and
        clamped with strips of plywood, or taped.

The sheet for the ground floor walls was placed last (FIG 13).
Use was made of the fact that the width of the sheet exceeded
somewhat the height of the wall, whereby it could be applied
horizontally, thus reducing the number of vertical joint -
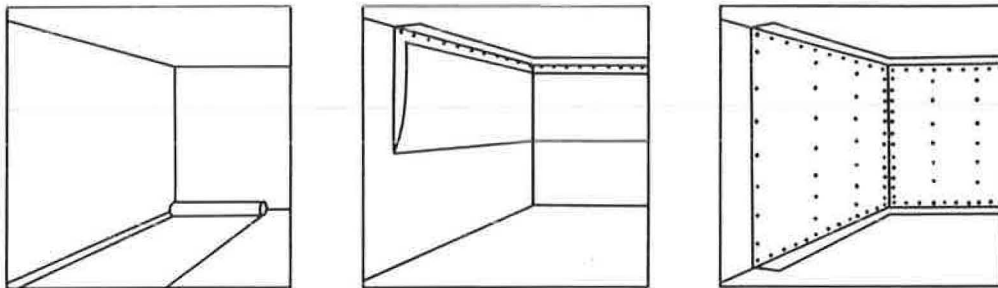preferable to one.

FIG 13.   Principle of operation in placing the 2,70 m wide
          polyethylene sheet
          a   roll it out around the external wall

          b   lift it up, fold the narrow piece up against the
              ceiling and attach to the wall underneath the ceiling

          c   fold down the rest of the sheet and attach it to
              the wall.

Checking the Airtightness

When construction of the buildings was finished, the airtightness
was checked by the pressure test method. The results from
these tests are presented in   FIG 14 in terms of the
number of air changes per hour for an overpressure of 50 Pa.
The number of air changes per hour were found to vary between
0,67 and 0,86 for the 7 buildings. These values are very low
for this type of building, and are well below the code
requirements, as shown in FIG 14.

The investigation shows thus that it is feasible to construct
this type of building so that it is very airtight. The good
results can be first of all attributed to the following:
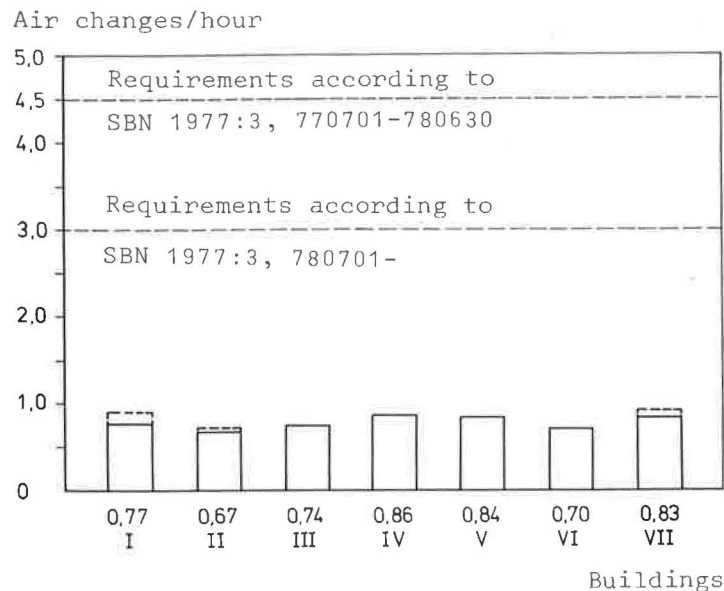
Air changes/hour

FIG 14. The results of pressure tests.

careful and systematic design,

careful workmanship and

the availability of materials for the airtight layer which
were fit for the purpose.

Some of the significant factors which contributed to the
results were that detailed drawings had been prepared for
practically every construction detail, that the sizes of the
wallboard were made to fit the frame spacing, and that the number
of penetrations for services was cut to a minimum - for instance,
all the electricity cables were laid in the interior wall and
joist spaces, and that a high grade polyethylene sheet was used.

Study of Climatic Conditions and Energy Consumption
Ventilation

As mentioned above, the buildings are ventilated mechanically
by an exhaust air system. The fan capacity can be varied between
three positions - basic rpm, 50 % fan capacity and 100 % fan
capacity. Intake air is obtained through slot vents at the
top of the 11 windows. The   slot openings can be regulated
but cannot be closed completely.

Air changes measured at different intake vent settings and
fan capacities are presented in Table 5. It is evident from
the results that it is the fan setting which has the decisive
influence on ventilation.

Table 5.

Fan setting,	Air changes m^3/h when slot vents are		
% of capacity	closed	40 % open	fully open
basic rpm	78	81	82
50 %	168	172	160
100 %	276	285	304

This means that ventilation is governed almost entirely by the
exhaust fan. Supplementary pressure difference measurements
also show that the outside climate has only a modest effect on
the difference in pressure between outside and inside. Nor could
changes in air flow, attributable to changes in the outside
climate be detected.

In 1977 Nylund calculated with the aid of a theoretical model
the effect of the airtightness of the building, the capacity
of the ventilation system itself as well as outside weather
on ventilation. FIG 15 gives an example of expected results for
a detached house. Here it was assumed that ventilation is by
an exhaust fan adjusted to provide 0,5 air changes per hour
when there is no wind. In practice, ventilation will thus
depend on the airtightness of the house, expressed in terms
of the number o air changes at an overpressure of 50 Pa (n_{50} in
the figure) and thereby primarly on wind velocity. It can be
seen from the figure that the ventilation in airtight houses
(n_{50}= 1 change/hour or less) is independent of wind when its
velocity is below 6 - 8 m/s. It is only at higher wind velocities
that ventilation is increased. This result agrees well with
measurements for the test houses. In permeable houses, on the
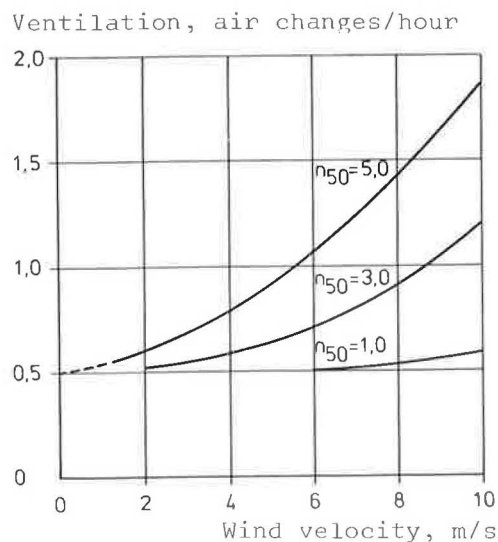other hand (n_{50}= 5 changes/hour), ventilation increases rapidly

Ventilation, air changes/hour

FIG 15. Relationship between ventilation and wind velocity for
different degrees of airtightness (n_{50}) of the building.
It is assumed that ventilation is by an air exhaust
system which is set to provide 0,5 air change/hour when
there is no wind and no temperature difference between
inside and outside air.

as wind velocity rises. Already at a wind velocity of 6 m/s,
ventilation is doubled.

Nylund's calculated values for average annual ventilation for
detached houses of varying airtightness are presented in FIG 16.
It is assumed that the average wind velocity is 4 m/s, that
the mean outside air temperature during the heating season
is +2 °C, and that the house has an exhaust air system set to
0,5 air change per hour when there is no wind and the temperature
inside and outside is the same. Energy losses due to ventilation
can also be determined from this figure. The results show that
in very airtight houses with an exhaust system, ventilation is
entirely dependent on the setting of the exhaust fan and that
there is no increase in energy consumption when wind velocities
are high.

Air velocities in the houses have been low. There is however
some risk of inconvenience due to draughts in the vicinity of
the slot vents. At a distance of 1 m from these, air velocities
were however never above 0,2 m/s. It should however be possible
to enhance comfort somewhat by improving the way whereby supply
air is provided.

To sum up, the results of the ventilation and air velocity
measurements show that in airtight houses the flow of ventilation
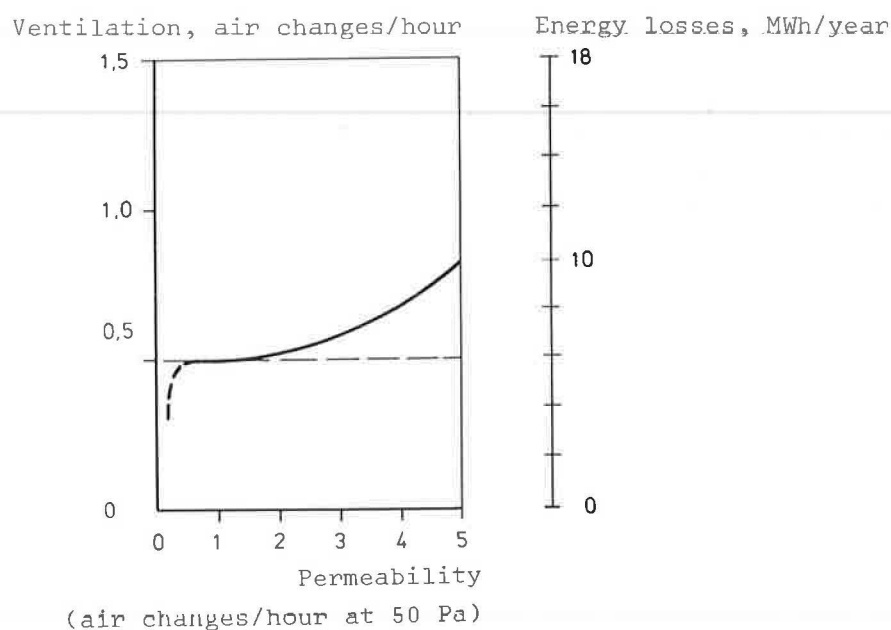air can be accurately controlled by means of the exhaust fan.

Ventilation, air changes/hour   Energy losses, MWh/year

FIG 16. Calculated annual average ventilation in a building
eqipped eith an exhaust system,as a function of the
permeability af the building (number of air changes per
hour at 50 Pa). The scale to the right shows the energy
losses owing to ventilation at a climate equivalent to
110 000 $^{\circ}$C h (Stockholm climate).

Energy consumption

Energy consumption was measured over short periods during the winter of 77 - 78. During these periods the exhaust fan was operated at about 50 % of its capacity, and all slot vents were about 40 % open. Air was exhausted of a rate of about 170 m^3 per hour, corresponding to about 0,5 air change per hour. Energy consumption was measured on cloudy days when the variations in the outside temperature were small. During the course of measurements the house was uninhabited, and the inside temperature was kept constant at +20,5 ^oC. On the average, 0,177 kWh/^oC h was supplied during the measuring period. Of this 0,058 kWh/^oC was attributed to ventilation losses, and 0,119 kWh/^oC to transmission losses. It is of course difficult to reliably predict the annual energy consumption on the basis of measurements taken over short periods. (It is intended to continue to measure energy consumption over a period of at least 1 year).

The number of degree hours based on an inside temperature of 20 ^oC is about 110 000 in Stockholm. The energy consumption due to ventilation losses for one year is then about 6 400 kWh, and that due to transmission losses about 13 100 kWh. Based on information by Munter 1974, an annual energy balance can then be drawn up as follows.

It is considered probable that the exhaust fan setting will be kept at the minimum level consistent with acceptable air quality in order to conserve energy.

Energy losses kWh/year	No of air changes per hour	
	0,5	0,25
transmission losses	+13 100	+13 100
ventilation losses	+ 6 400	+ 3 200
domestic hot water	+ 5 000	+ 5 000
domestic electricity	+ 3 500	+ 3 500
waste heat from domestic hot water	- 1 500	- 1 500
waste heat from domestic electricity	- 2 500	- 2 500
heat generated by occupants	- 1 500	- 1 500
solar radiation	- 3 200	- 3 200
forced ventilation	+ 300	+ 300
total annual energy requirement kWh	19 600	16 400

It may be assumed that the number of air changes will be 0,5 per hour for half the heating season, and 0,25 per hour for the remainder. This means that the annual energy consumption will be about 18 000 kWh.

Munther, 1974, and also Adamsson & Källblad, 1975, show that houses in the Stockholm climate of comparable size constructed at the beginning of the seventies have an annual energy consumption of around 26 - 28 000 kWh. These values relate to houses constructed before the "energy crisis" and before the new Swedish Building Regulations came into force. The results thus indicate that the improvement of thermal insulation and airtightness in these houses should result in an annual energy saving of about 8 - 10 000 kWh under normal operating conditions. This is a considerable saving which has been achieved only by construction measures, which can therefore be expected to have a very long life and which do not give rise to any additional maintenance expenditures.

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