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DEMOHOUSE

Design and Management Options for improving the energy performance of Housing

SPECIFIC TARGETED RESEARCH OR INNOVATION PROJECT

Thematic Priority 6

Deliverable 5: Securing of air tightness in building projects

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Executive Summary

The EU- Demohouse project is a specific targeted research and innovation project supported by the EU – 6th Framework programme. It started in October 2004 and is ongoing for 4 years until October 2008. Demohouse is here an acronym for Design and Management Options for Improving the Energy Performance of Housing. ECN from Holland is coordinator and there are realised demonstration projects in 5 countries – Denmark, Austria, Hungary, Spain and Greece, with main focus on housing renovation.

This report gives instructions regarding air tightness in different building constructions and shows examples of how the constructions can be made.

The constructions included in this report are external walls, roofs and windows. Furthermore connection between roof and external wall is dealt with here. For external walls also wind tightness on the outside is included in the report. Last but not least, problems regarding penetrations have also been enlightened.

In order to avoid leaks when dealing with installation work, i.e. electrical installations, pipes and ducts, a special instruction ought to be followed. An instructive air tightness measurement following the installations is a good idea here.

The tightness system of the external building components must take wind (coming from outside) and air (coming from inside) tightness into consideration. This demand comprises the external building components as well as connections and penetrations of the building components.

The exterior of the building must be wind-tight. This is implemented in connection with insulation and external covering. By this the cold outside air will be prevented from penetrating the building because of the difference in air pressure and consequently minimise the insulating ability, resulting in extra heat loss. The pressure difference is a result of wind pressure and thermal motive power.

The internal side of the building must be air-tight. This is implemented in connection with the constructions and the internal layer of covering. By this the humid indoor air should be prevented from penetrating the external construction because of the difference in vapour pressure *and the* vapour seal must therefore be placed on the warm side of the construction to avoid condensation on the colder exterior parts.

With a Blower Door test it is possible to measure the tightness of a building and at the same time find the leaks.

According to the Common Evaluation Protocol, described in Deliverable 22, a blower door test, which exists as an international standard, is proposed to be carried out as soon as the first phase of the building project is concluded. This allows to get indications of where the leaks are so possible problems can be rectified from the start. After improvements are made, air tightness should be checked with another Blower Door test.

Finally, Blower Door tests should be performed to check the finished building project.

Preface

This report deals with wind- and air tightness in both new built and retrofit projects. Most of the knowledge on this topic comes from countries as Germany, Austria and Denmark, which can be described as leading in the field. Therefore, the instructions in this document are partly worked out on basis of the German information booklet: *Luftdicht – Prima – Klima – Programm* from Synergie Haus /1/.

The material in German is very thorough and ought to be able to give inspiration to European building projects. A limitation as to implementation under general European conditions is however, that the starting point is German practice which perhaps differs from what is standard practice in other European countries. These differences are further discussed in chapter 8.

In addition to the German reference, the results are used from experiences from 81 engineering- and architectural companies and their construction investigations of 16.000 small houses, blocks of flats, office buildings and schools. The report, "Bygningskonstruktioners risiko for fugtskader" ("Risk for Moisture Damage of Building Constructions") can be found at the web site of Danish Building Research Institute: www.sbi.dk
In this report the above mentioned report is referred to as /4/.

Further we refer to the instruction manual from Bygge- og Boligstyrelsen from 1993, "Investigations of air tightness in building constructions" which was prepared by the Technological Institute in Tåstrup, in Denmark, in co-operation with numerous advisory groups e.g. consulting engineers. However, the principal aim of this instruction is primarily to secure air tightness to the ground /2/.

Further information from the SBI-instruction 184 concerning energy requirements of buildings is also used /5/.

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Introduction

In low-energy buildings, heat losses through unintentional air changes make up a substantial part of the total heat losses. Therefore, it becomes increasingly important to minimise these unintentional air changes by ensuring an air tight building envelope.

In addition, an air tight building envelope is important in order to:

- Avoid damage by damp (moisture)
- Avoid draft
- Improve the air tightness protection of the building components (external and internal building components).

Damage by damp is very often the biggest risk with leaking external constructions.

In order to obtain healthy indoor conditions, in particular good indoor air quality, a high air change is necessary. This can however not be obtained by accidental leaks of the building itself as this will mean rather large openings in the constructions. Furthermore it means that with the big difference in outside and indoor temperature, i.e. in winter, the air change will be so extensive that it will lead to draft.

As another consequence, the humid indoor air will reach the exterior building constructions and cause damage by damp. The requirement for heat will then rise uncontrollable. Afterwards it will usually be attempted to solve the problem by increasing the thermal insulation of the building. Of course, this does not help much if leak is the problem.

It is clear that air tightness of a building is necessary e.g. with a maximum of natural air exchange of 10 % an hour ($0,1 \text{ h}^{-1}$). Even more important is a good air tightness in case of a heat recovery ventilation system which will take care of the necessary air change in the dwelling. If the constructions are not air tight the effectiveness of the heat recovery will decrease and lead to increased energy consumption.

So the hygienic demands to high air change in buildings must not be satisfied by leaking constructions in the external building components.

A user controlled airing using the window openings is a very difficult practice to control – and with reference to energy savings and indoor air climate it is almost always inappropriate. The most efficient solution for buildings with a high heat insulation level is mechanical ventilation with heat recovery.

With thorough planning and implementation energy savings can be obtained, hereby minimising CO₂-emission, on the condition that the tenants co-operate, that is to say take a responsible part in the ventilation plan.

In this report we mention “wind tightness” (tightening from outside) and “air tightness” (tightening from inside) of a building.

The exterior of the building must be **wind-tight**. This is implemented by inserting a *wind-tight layer* in connection with insulation and external covering. By this the cold outside air will be prevented from penetrating the building because of difference in air pressure and consequently minimise the insulating ability, resulting in extra heat loss. The wind-tight layer is diffusion open and has low diffusion resistance (low Z-value, 1-2 GPa /kg/m²s).

The internal side of the building must be **air-tight**. This is implemented by inserting a *vapour barrier* in connection with the load-bearing constructions and the internal layer of covering. By

this the humid indoor air should be prevented from penetrating the external construction because of the difference in air pressure and the vapour seal must therefore be placed on the warm side of the construction to avoid condensation on the colder exterior parts. Joints between two pieces of vapour barrier should be made completely air-tight with 150 mm overlap. The air-tight layer is not diffusion open and must have a high diffusion resistance (high Z-value, min. 250 GPa/kg/m²s).

In chapter 1-5, recommendations are given to ensure an air tight building envelope for a number of building details, mostly for new build. In chapter 6, this is expanded with guidelines for renovation.

In chapter 7 the measurement of air tightness is discussed and finally, in chapter 8, the air tightness in the particular Demohouse projects is presented.

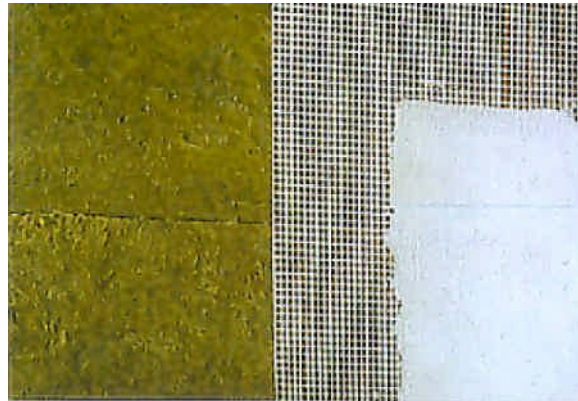
1. External walls

1.1 Measures for Wind Tightness

1.1.1 External walls with non ventilated coating

Insulated external wall

The heat insulation exists of a reinforcement, a base and a finishing coat. The finishing coat can e.g. consist of artificial resin or lime cast. These layers secure the wind tightness of the wall (see fig. 1.1.1.1.).



*Fig. 1.1.1.1.: Securing of wind-tightness
- Insulated external wall – here you see the order
of the layers.*

Brickwork with core insulation

The brickwork is in principle wind-tight. The heat insulation material has to be placed in a way so it is a tight fit to the brickwork. It is important that there is no air circulation around the heat insulation because of the danger for cold bridges with a possible condensation as a consequence.



*Fig. 1.1.1.2.: Securing of wind-tightness
- brickwork with core insulation – here you
see the layers from outside (front)to inside.*

1.1.2 External wall with ventilated coating

For an external ventilated coating a load bearing construction is required, which usually is a wooden construction. Depending on the dampness of the wooden construction in connection with the building of the project, shrinkage of the wood may result in a hollow space between the heat insulation material and the wooden profile. Therefore, in order to secure wind-tightness and letting out the humid inside air, it is recommended to implement a diffusion open wind tight barrier.



Fig. 1.1.2.1.: Securing of wind-tight - brickwork with insulation layer and ventilated coating on the back – here you see the order of the layers.

In order to avoid unnecessary heat losses because of airflow in the insulation, it will normally be necessary to cover the insulation with a wind-tight layer /2/. A diffusion open material as wind cover should be used, e.g. with a Z-value (diffusion resistance) of 1-2 GPa /kg/m²s. If a traditional wind-tight asphalt felt (Z-value of 20-30 GPa /kg/m²s) is used there will be a risk of moisture accumulation. Joints ought to be constructed in a way to obtain a two-stage sealing (sealing twice same place).

1.2 Measures for Air Tightness

1.2.1 Construction type 1 – External walls of brickwork

If the inside of external wall is built in the same way as the outside of wall it will be possible, through the special bricklaying techniques / joint techniques, to obtain a firm air tightness. As often as not it is the joints in the brickwork which are leaking. If it is possible to press a screwdriver into the joints it follows that the joints are not tight. If so they can be proofed with mortar.

The inside of wall without plaster is not airtight. The air tightness can be secured by help of a so-called "wet plaster" that is wet when it is plastered on the wall and then dries afterwards. For brickwork with a thin layer of mortar it is sufficient with a 5 mm layer of plaster or 3 mm plaster filler. In the areas where holes have been drilled for e.g. electrical outlets or similar it is possible to re-establish the air tightness using various measures e.g. by help of gypsum filler.

Usually airtightness cannot be obtained by the so-called "dry plaster", which is normally a fibre gypsum sheet. Without use of further measures it is almost always impossible to obtain an effective airtight connection on the building component.

Therefore, if using dry-set cast the brickwork has to be full-joint bricked up in order to secure air tightness. Small leakage can be repaired with a joint smother.

Also electrical outlets will penetrate the airtight layer as shown in photo 1.4, so extra caution is required around these in order to make the penetrations air tight. A solution can be to fill up part of the airspace in the installation pipes for the wiring , f.ex. mineral wool, or you can choose sealed armatures.



Fig. 1.2.1.1.: Dry-set cast, penetration point of the electrical outlet – in order to secure air tightness various measures are required.

1.2.2 Construction type 2 – External walls of reinforced concrete

For concrete walls cast on the construction site, usually there are no special measures to take into consideration in order to secure air tightness. However, it is important that the joint combining the components is tight. Cracks and holes can be mended with suitable joint filler.

1.2.3 Construction type 3 – External walls in timber frame construction

Walls of wood panels and plaster panels can be leaking along the joining of the panels, just as built in electrical installations might cause leakages. For external walls in timber frame constructed houses the air tightness, depending on the system, can be secured with similar measures, e.g. cracks and holes can be mended with filling or joint filler. Concerning the building-in of the electrical outlet the thickness of the hollow space for the installation should be in accordance with the electrical outlet i.e. a thickness of approximately 6 cm.



Fig. 1.2.3.1.: Mounting of electrical installation (e.g. for the electrical outlet) without reducing the air tightness using a thicker space for the wires.

After placing of electrical installation the hollow space can be filled up with a heat insulating material.

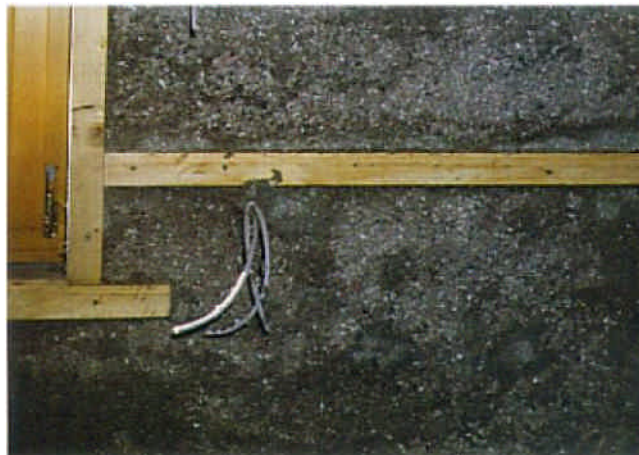


Fig. 1.2.3.2.: Additional layer of heat insulation in the hollow space of the installation.

When using these measures it is to be noted that it no longer will be possible to use the heat storage effect of a possible wooden plate to regulate the indoor climate in summer.

1.3 Risk of damage by damp

In the report from the Danish Building Research Institute /4/, where experiences from 81 engineering- and architectural companies and their construction investigations of 16.000 small houses, blocks of flats, office buildings and schools has been reported, the specific reasons for damage by damp for heavy/light external walls (i.e. heavy external and light internal) were divided evenly between leakage, lack of ventilation/airing and cold bridges. For the other two types of external walls the leakage was the most frequent cause (table 1.3.1.).

For internal walls there were an almost even distribution of the possibilities for specific

reasons, however, with added weight towards leakage (table 2).

Construction (external/internal)	Leakage	Ventilation/airing lacking	Cold bridges	Other
Heavy/heavy	56 %	34 %	5 %	5 %
Heavy/heavy	24 %	29 %	31 %	6 %
Light/light	43 %	39 %	15 %	3 %

Table 1.3.1.: Specific reasons for damage by damp in **external** walls. The figure in % state the number of tables in the report from the Danish Building Research Institute /4/ which have given blame to the reasons mentioned.

Construction	Leakage	Ventilation/airing lacking	Cold bridges	Other
Light	38 %	16 %	19 %	27 %
Heavy	29 %	25 %	22 %	24 %

Table 1.3.2.: Specific reasons for damage by damp in **internal** walls. The figure in % state the number of tables in the report from the Danish Building Research Institute /4/ which have given highest priority to the reasons mentioned.

Summarising the high portions of damage that can be attributed to leakage shows the importance of having an airtight construction.

2 Roofs

2.1 Measures for Air Tightness

2.1.1 Roofs with load-bearing construction of latticework construction (collar beams, roof truss and beams)

These roofs consist of several layer building materials and building components e.g. plates, lengths of heat insulating layers and internal boarding, e.g. wooden profiles. These elements result in a large number of joints which would be leaking without specific measures. Therefore, specific measures are required for the internal side.

In order to avoid cold bridges at least one layer of thermal insulation ought to be placed on the inside of the rafters.

FK: please improve lay-out below

To achieve air tightness necessary with a layer strong film (vapour vapour barrier should be polyethylene film, and However, it is not with staples. This is not

An overlap with a suitable. However, in not always free of dust may not stick Furthermore it is not exclusively with tape demands of efficient air

In addition, it should be noted that these adhesives can be under heavy strain because of wind power due to lack of external air tightness, and also from the power for difference in pressure. Therefore, these kinds of covering are also unsuitable.

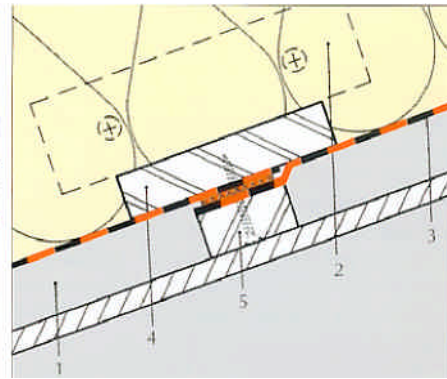
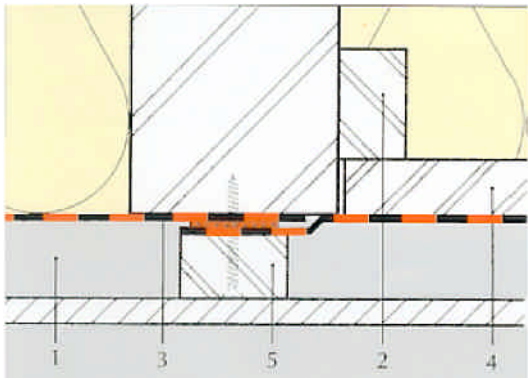
A technical correct design with efficient tightening for these kind of measures can only be obtained through a further mechanical security (a roof list or a bolted on board). Accordingly tightening length wise must always follow the beams. For tightening crosswise an adaptable board is built in between the beams (fig. 2.1.1.2. point 5 and fig. 2.1.1.3. point 4 & 5).



Fig. 2.1.1.1.: Sealing of the joining of the moisture barrier (length wise) on the rafter with overlap and fixed with clamps. Is not airtight.

for these roofs it is of airtight material e.g. barrier) or similar. The robust, e.g. 0,15 mm quite airtight. enough to affix the film sufficiently airtight.

durable tape is more practice the material is and grease so the tape sufficiently. certain that a covering can comply with the tightness.



- 1: Hollow space for electrical installation.
- 2: Wooden list by the rafter.
- 3: Airtight layer.
- 4: Built in board mounting element for 5.
- 5: Film list with inserted sealing strips mechanical protection with screwed on list.

Fig. 2.1.1.2.: Connection length wise – tightening excl. installation room, overlap and mechanical securing through screwed-on wooden profile.

Fig. 2.1.1.3.: Connection crosswise-tightening exc. installation room on adapted board, overlap and mechanical securing with screwed on wooden profile.

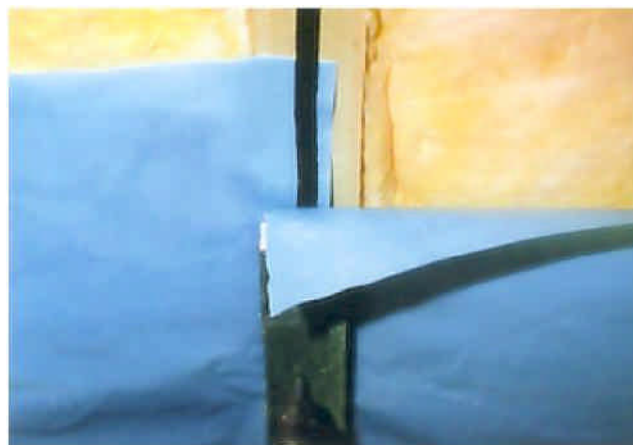
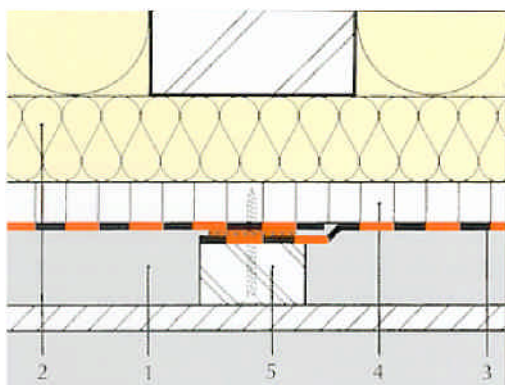


Fig. 2.1.1.4.: Tightening length wise the edge of the film with overlap and inserted sealing strip with mechanical securing (screwed on lath) on the rafter.

The best solution to secure standard air tightness is implementation with an overlap of film edges on the layer of installation (wooden board) with an inserted sealing strip between the film and a mechanical securing by a screwed on wooden profile (board or lath) in the layer of installation. Only this way these couplings will be sufficiently airtight (fig. 2.1.1.5. point 5 and fig. 2.1.1.6.).



1. Hollow space for electrical installation.
2. Heat insulation below the rafter / roof lath.
3. Airtight layer.
4. Wooden plate, instal. layer for 3.
5. Film connection with inserted sealing strap, mechanical securing with screwed on list.

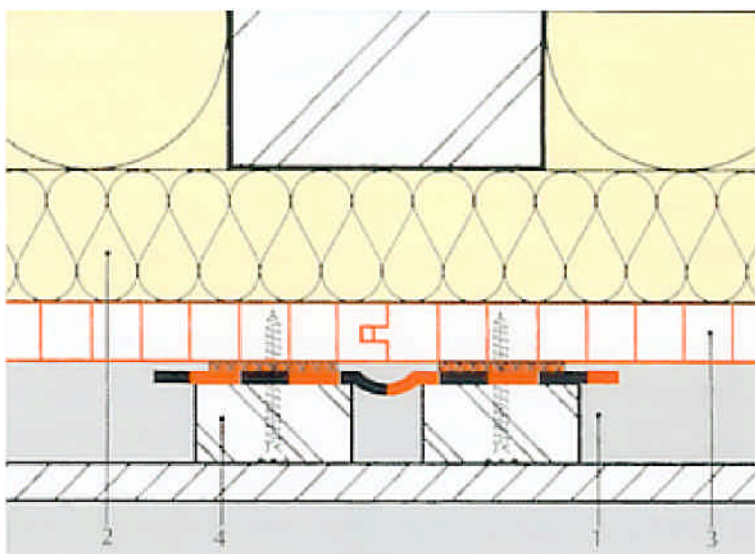
Fig.2.1.1.5.: Film edge, overlap, inserted sealing strip (5) and mechanical securing through screwed on wooden profile.



Fig. 2.1.1.6.: Installation of film assembling on a wooden plate. Overlap inserted sealing strip, mechanical securing (screwed on lists) hollow space for electrical installation and internal covering.

The installation space (point 1 in fig. 2.1.1.5.) is also very useful as regards protection of the building envelope and heat protection in summer (heat storage effect).

Alternative to fitting-in of a moisture barrier also wooden material can be used for air tightening. With this the sheet assembling must be attached effectively airtight with suitable materials. For this a sealing strip is recommended which is not glued to the back around the joint. Here a small arch is constructed (deformation reserve) securing that contraction of volume of the wooden plates do not cause various cracks.



1. Hollow space for electrical installation.
2. Layer of heat insulation under the rafter / roof list.
3. Airtight layer.
4. Connection of film with underlying sealing strips, mechanical.

Fig. 2.1.1.7.: Tightening exclusive of film. Here the wooden plate functions as an airtight plate. Tightening of the plate edge carried out by help of screwed on wooden profile.

Without a mechanical securing of the adhesive tapes the durability of these packing measures are uncertain.

In all wooden constructions a robust and durable moisture barrier is to be placed on the warm

side of the insulation with a Z-value exceeding 50 GPa/kg/m²s. It has to be airtight as regards e.g. installation of roof light, walls and duct penetrations. The air tightness of the ceiling construction is more important than a high diffusion resistance of the moisture barrier.

Risk of damage by damp

More than half in the report of SBI /4/ assessed that the specific reason for damage by damp of the roof was leakage. Especially attics, valleys and airing/ventilation were the main reason.

Construction	Leakage	Ventilation/airing lacking	Cold bridges	Other
Pitch of roof /Parallel	56 %	34 %	5 %	5 %
Flat area / Parallel	56 %	36 %	2 %	6 %
Other	58 %	26 %	8 %	8 %
Attics/valleys	79 %	13 %	2 %	6 %

Table 2.1.1.1.: Most frequent specific reason for damage by damp in the roof. The figure in % state the number of tables in the report from the Danish Building Research Institute /4/ which have given blame to the reasons mentioned.

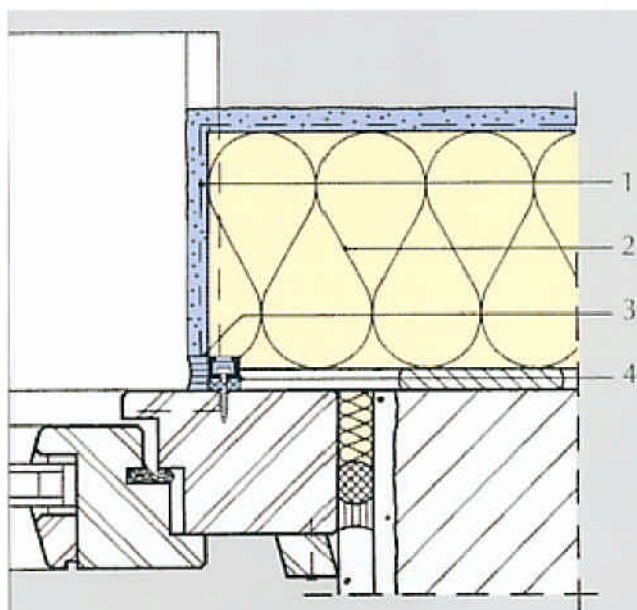
3 Installation of the window

3.1 Measures for Air Tightness

In the exterior wall air tightness is secured with the plaster on the heat insulation system.

3.1.1 Heat insulation system

The joint between the window frame and the heat insulation system can be sealed by help of a special profile with a sealing strip screwed on the frame (See fig. 3.1.1.1).



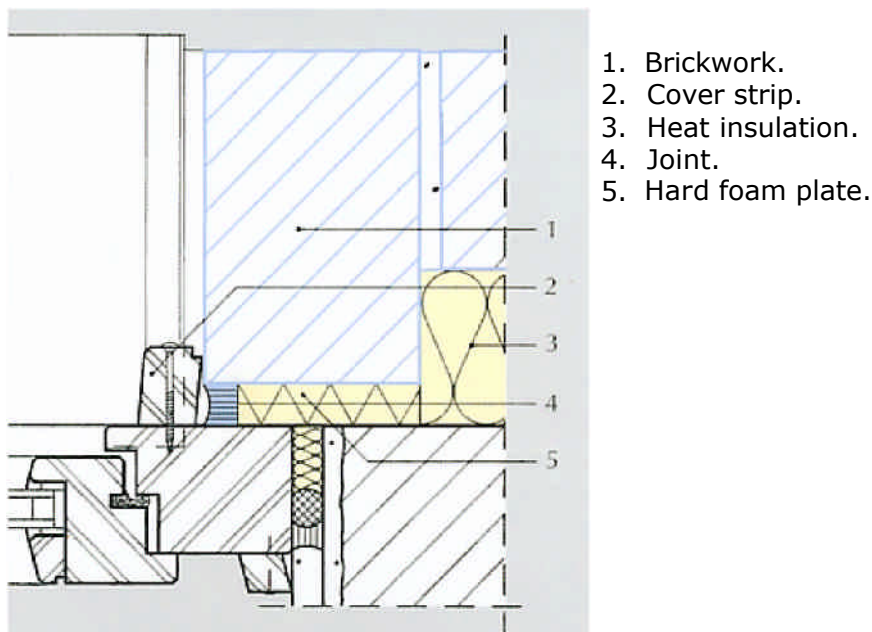
1. Layer of heat insulation system, e.g. plaster.
2. Heat insulation.
3. Joint.
4. Special profile with reinforcing connection tape and sealing strip.

Fig. 3.1.1.1.: Top view of window with airtight connection. Brickwork with heat insulation system. Inside is on the top.

3.1.2 Brickwork with core insulation

The air tightness in the flat area of the wall is secured with jointed brickwork. Sealing of the joint between the window frame and the brickwork is carried out using a sealing material (width approx. 2 cm) or additional width using a recompressed sealing strip (fig. 3.1.2.1., point 2).

Insufficient tightness in the joints surrounding the windows can lead to draft and heat losses. Window joints have a limited lifetime of up to 20 years depending also on maintenance and must be changed before the damage gets too extensive. The influence from sun and rain is most noticeable on joints facing south and west, accordingly they break down the fastest. Frequent inspections by maintenance personal f.ex. once every year can secure a good follow up on the quality of the joints.

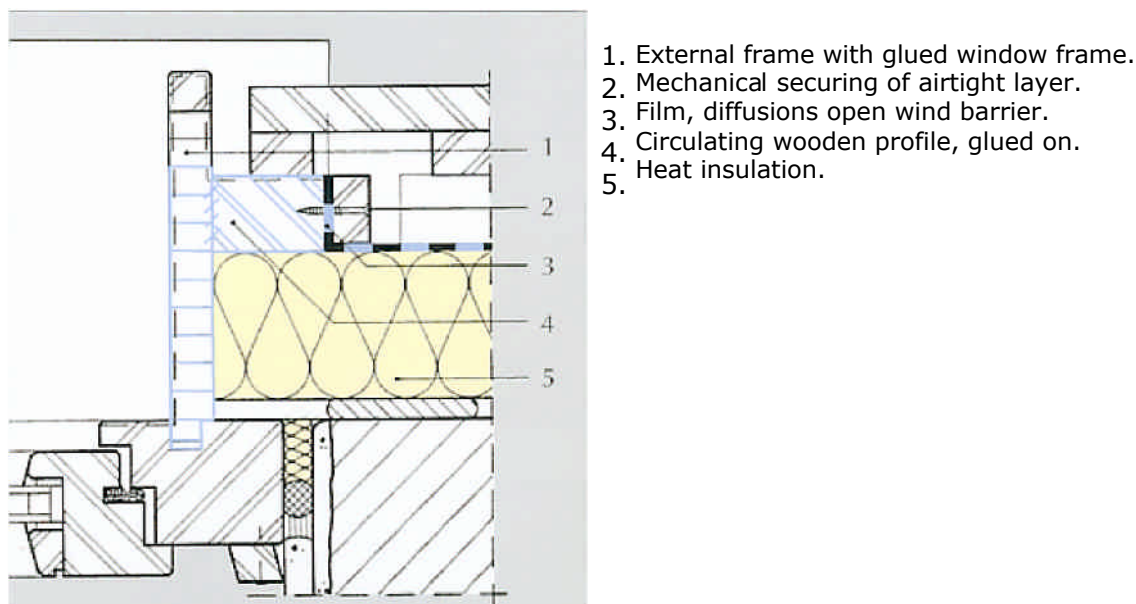


1. Brickwork.
2. Cover strip.
3. Heat insulation.
4. Joint.
5. Hard foam plate.

Fig. 3.1.2.1.: Window, airtight connection on brickwork with core insulation.

3.1.3 External wall with layer of heat insulation and ventilated covering

In the external wall area the air tightness is secured by help of diffusion open wind barriers (films). In order to secure air tightness in connection of insulation on the window sill, the window is designed with a solid glued frame (fig. 3.1.3.1., point 1). When mounting at location a list will be cut, planed and glued around the frame. The protection layer for heat insulation will be connected by help of a list and a foundation of an adhesive sealing strip on the planed list and further secured mechanical.



1. External frame with glued window frame.
2. Mechanical securing of airtight layer.
3. Film, diffusion open wind barrier.
4. Circulating wooden profile, glued on.
5. Heat insulation.

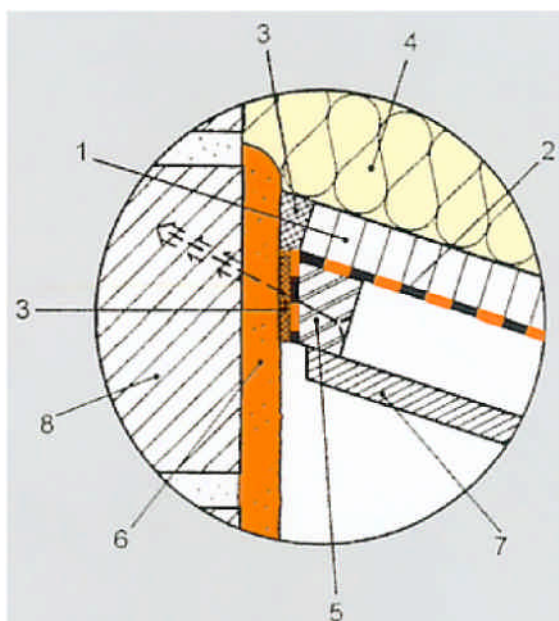
Fig. 3.1.3.1.: Window, airtight connection. Brickwork with heat insulation and external ventilated covering.

4 Connection on slanting roof – Penetration

4.1 Measures for wind- and Air Tightness

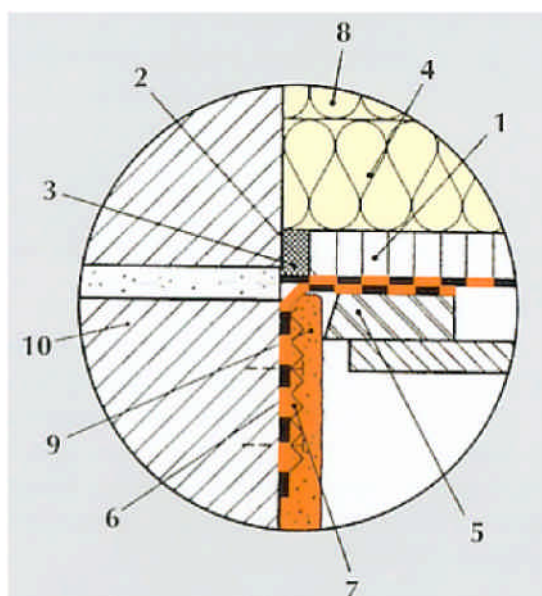
The sloping roof area could be penetrated by several different building components, e.g. the chimneys, ventilation pipes, fire barriers, aerals etc. If a wall penetrates the roof the airtight connection should be as shown in the fig. 4.1.1. and 4.1.2.

Photo 1 shows an external wall connected with a sloping roof. The air tight foil on the inside of the roof is connected to the inside of the wall by help of a screwed on board.



1. Chipboard, mounting layer for film.
2. Airtight foil, moisture barrier.
3. Sealing strip.
4. Heat insulation under the rafter.
5. Mechanical securing, screwed on roof board.
6. Internal cast.
7. Internal covering.
8. Brickwork

Fig. 4.1.1.: Airtight connection between sloping roof and wall. Here with mechanical securing through screwed on roof batten (board).

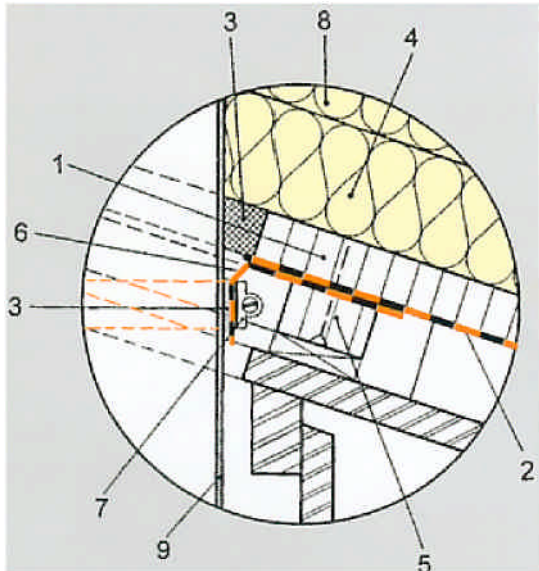


1. Chipboard, mounting layer for film.
2. Airtight foil, moisture barrier.
3. Sealing strip.
4. Heat insulation under the rafter.
5. Mechanical securing, board.
6. Foil strip, inserted.
7. Plaster base.
8. Heat insulation between the rafters.
9. Internal plaster.
10. Brick work.

Fig. 4.1.2.: Airtight connection between horizontal roof and wall. Here with inserted film strip.

In order to secure airtightness the connection of the wind barrier is carried out analog with the internal airtight connection (moisture barrier).

Pipe penetration in the roof could be carried out as shown on fig. 4.1.3.



1. Chipboard, mounting layer for 2. .
2. Durable film, airtight layer.
3. Sealing strip.
4. Heat insulation under the rafter.
5. Mechanical securing, wooden board.
6. board.
7. Film packing.
8. Manacle ring.
9. Heat insulation between the rafters. Roof penetration, here pipe penetration.

Fig. 4.1.3.: Pipe penetration; airtight connection by help of pre fabricated film packing, manacle ring and mechanical securing.

The connection of the pipe penetration has to be planned well ahead otherwise there will be several connections which it will be impossible for the workmen to carry out without faults (fig. 4.1.4. and 4.1.5.).



Fig. 4.1.4.: Ventilation pipe penetrates the function layer of the roof, massive leakage.



Fig. 4.1.5.: Pipe penetration – incorrect tightness concept in the planning phase. Because of the corner placing of the pipe a correct connection as regards workmanship

is not possible,

According to the report /4/ all penetrations of the roof (valleys, attics, overhead light and ventilation exhaust) are a potential risk for damage by damp. Further, on flat roofs ventilation components are often mounted and the cover is not designed to carry a load of the size of the components.

The turnkey contracts were mentioned as the reason why poor work on assembling solutions appeared, and the opinion of several people was that the pressed time of construction caused that the work was not carried out in a satisfactory way.

5. Penetration

Cracks often appear in concrete where the installations are carried through. Here the cracks are closed with a suitable joint filler (marked with red). At penetration in plate floors the cracks are closed by fitting a collar around the pipe, whereupon the cracks between the collar, the pipe and the plate are closed with a suitable joint filler, as shown in red in photo 5.1. Leakage around the installations in a casing pipe/manhole could be closed with joint filler or suitable expanding foam, /2/

It is here recommended to use foams, that will not dry out over time and to combine with use of a rubber gasket to ensure that airtightness is always secured.

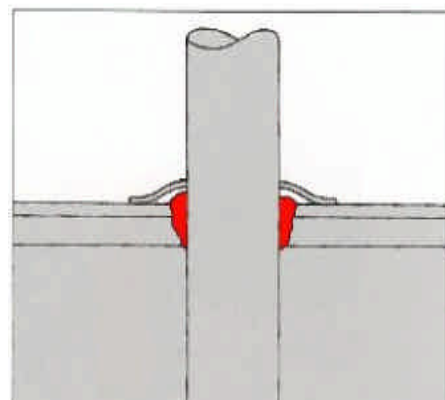


Fig. 5.1: Pipe penetration

Leakage around pipe penetrations in kitchens and bathrooms, joints around bathtubs and shower baths, and leakage in outlets for washing machines and automatic dishwasher machines are critical because moisture is supplied into constructions which are placed in warm spots. The consequence of this might result in mould fungus /4/. Constructions with bricked in bathtubs are especially exposed. It is therefore recommended to be extra careful with the mentioned constructions and assure tightness against water.

6. Ensuring air tightness in Building Renovation

This chapter concerns especially energy renovation of buildings. The air-tightness should be ensured on the inside of external constructions by help of a vapour barrier of e.g. aluminium foil or plastic film.

On the outside wind-tightness should be ensured to protect the building construction against bad weather conditions.

The first thing one should do when ensuring the air-tightness of a building is to check the joints between the different external constructions, e.g. the windows/doors and walls. By sealing up joints between the different external construction a good result can be achieved with low costs.

According to the German Passiv Haus Institut /8/ the most important rule for achieving good air-tightness is to seal the whole building with an air-tight layer (see fig. 6.1 below).

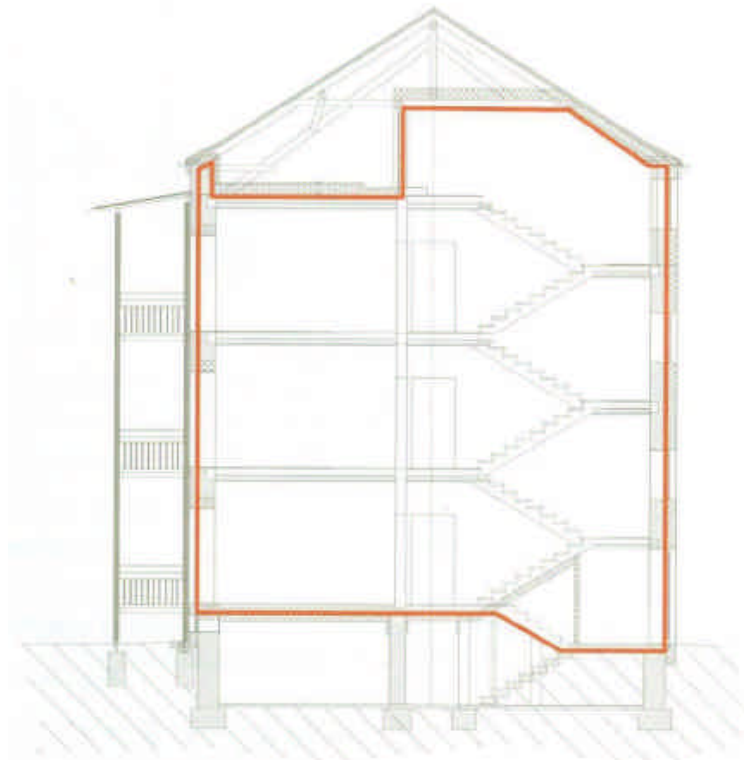


Fig. 6.1: Air tight layer (in red) wrapping the whole building.

This might however be not so easy for already built building, e.g. for renovation projects for old buildings.

Fig. 6.2 below shows examples of air tight layer placed on the inside of the building. Hereby the air can access from outside and basement through insufficient air tight joints between floor and external wall.

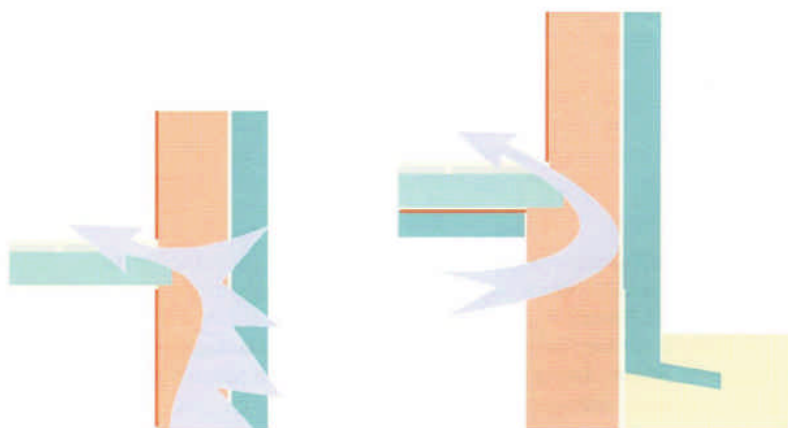


Fig. 6.2: Examples of insufficient air tightness of a building by inserting the airtight layer on the inside of the building.

The joints between e.g. floor and external wall must therefore be made air tight, so that air from outside or from basement cannot go inside the building.

Fig. 6.3 shows the air tight layer placed on the outside of the building. However air from e.g. basement can still access into the dwelling if no further initiatives are taken.

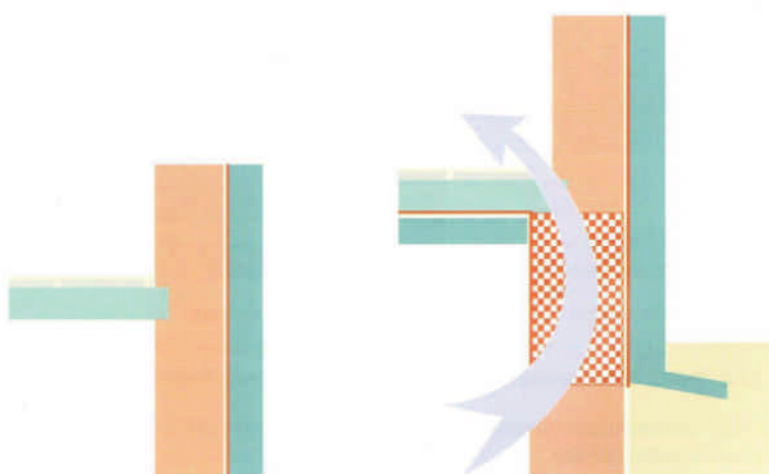


Fig. 6.3: Air tight layer placed on the outside.

The following subchapters show the placement of air-tight and wind-tight layers when renovating a building with extra insulation. The information is gathered from the web site of the Danish insulation material producer, Rockwool A/S, www.rockwool.dk/7/.

6.1 External walls

6.1.1 Renovation from outside

By brick walls the existing wall will be wind tight (see chapter 1.1.1). However, after mounting the extra insulation layer at the outside of the wall there must be a wind tight covering as

shown in fig. 6.1.1.1. for best possible insulation effect.

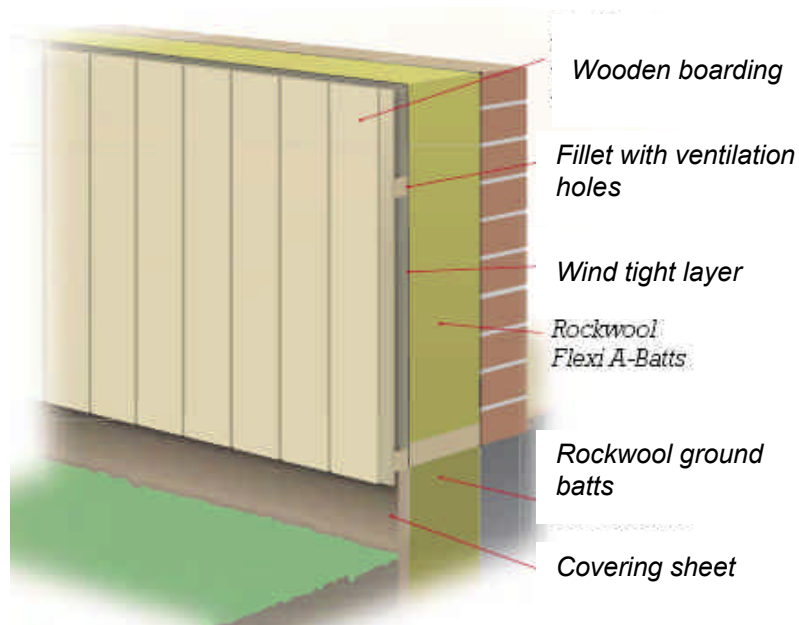


Fig. 6.1.1.1.: Wind tight layer at external wall for building renovation from out side.

6.1.2 Renovation from inside

After mounting the extra insulation layer on the inside of the external wall a vapour barrier must be mounted as well, e.g. 0,15 mm aluminium foil or plastic film with 150 mm overlap on the battens/planks to ensure efficient tightening.

Inside covering

Air tightness with vapour barrier

Extra insulation layer

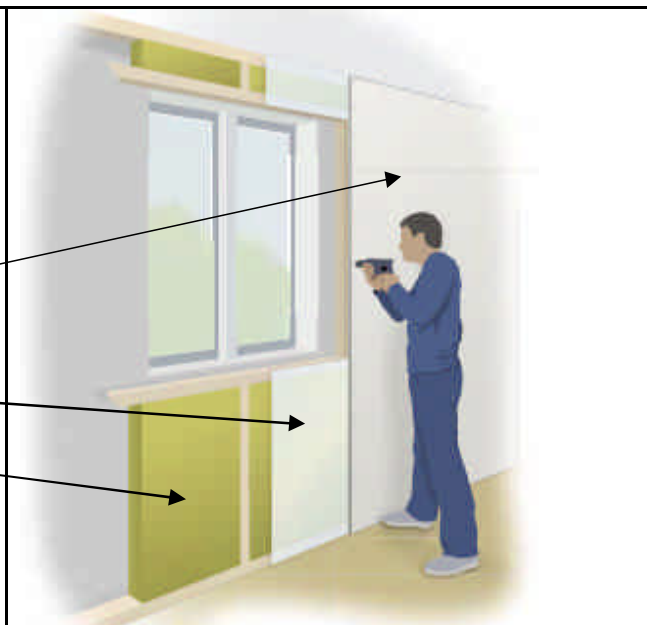


Fig. 6.1.2.1.: Air tight layer at external wall for building renovation from inside.

6.2 Roof/Loft

When mounting extra insulation layer **above the loft construction**, the vapour barrier should be checked. If the vapour barrier is defect a new one should be mounted in between the

rafters and stapled to the sides of the rafter feet, so that it goes up max. 20-30 mm on the sides of these (see fig. 6.2.1.). Here energy renovation is shown where the insulation layer is put above the loft construction.

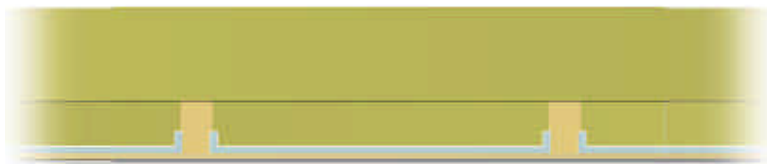


Fig. 6.2.1.: By loft construction without vapour barrier the new vapour barrier is mounted between the rafters and 20-30 mm up against these. If there at the same time is supposed to be a new ceiling covering a vapour barrier can be mounted instead, which covers the whole ceiling, also when this is of e.g. plaster, before a new ceiling covering is put up.

When mounting extra insulation layer **under** the **loft construction** with existing vapour barrier on the inside, the new insulation layer shall have a thickness of max 50 % of the existing insulation layer to avoid problem of condensation in the construction. If the thickness is larger the existing vapour barrier must be removed and a new shall be mounted.

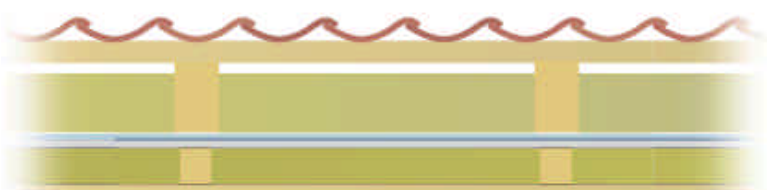


Fig. 6.2.2.: Loft construction with vapour barrier. New insulation thickness of max. 50 % of the existing insulation. If larger insulation thickness is wanted the existing vapour barrier must be removed and a new shall be mounted.

6.2.1 Afterinsulation of space under the roof slope

The floor separation shall be air tight so draft and increased heat loss can be avoided. This is done by help of a vapour barrier or a wind tight sheet across the floor separation.

The vapour barrier is mounted and after insulated with at least twice the thickness of existing insulation.

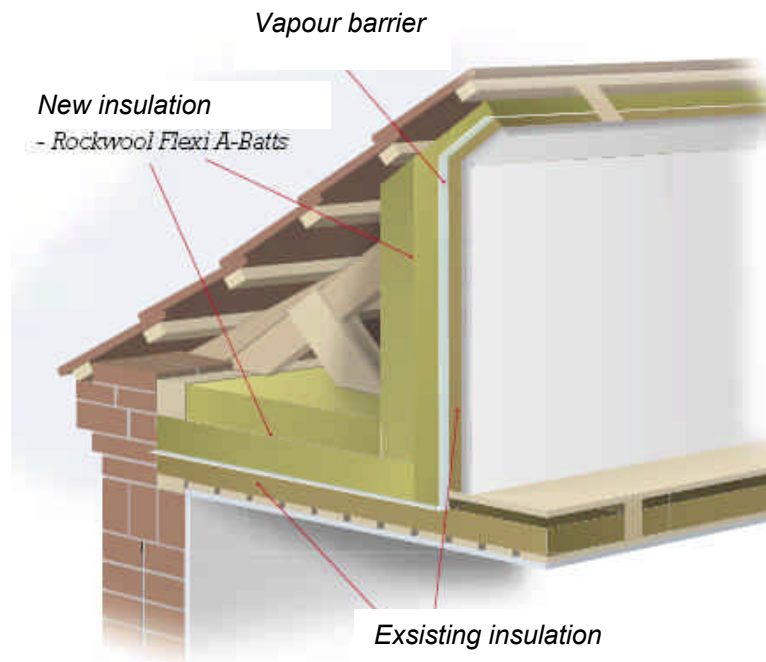


Fig. 6.2.1.1.: Energy renovation on inside of roof.

6.2.2 Sloping walls, internal

By internal after insulation of sloping walls the following should be taken care of, depending of the thickness of the insulation:

- If thickness of afterinsulation $<$ half of thickness of the existing insulation, battens and insulation are mounted without new vapour barrier and internal covering.
- If thickness of afterinsulation $>$ half of thickness of the existing insulation, existing vapour barrier and covering of the existing construction is removed. Hereafter the space between battens and planks is insulated to the desired and new vapour barrier and ceiling covering are mounted.

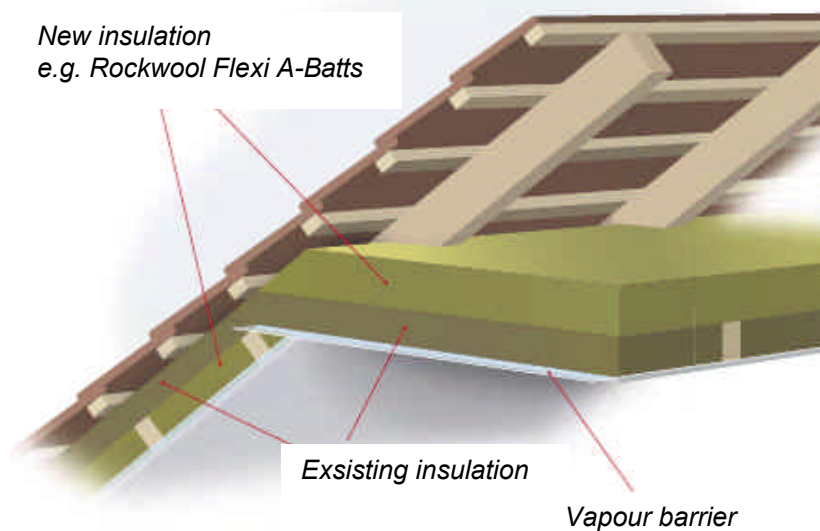


Fig. .6.2.2.1.: Energy renovation of sloping walls under the roof.

7. Measurement of air tightness: Blower Door Test

7.1 Description of method

A blower door test is carried out by blabla, as shown in figure 7.1.2.



Fig. 7.1.1.: Blower Door test in an apartment.



Fig. 7.1.2.: Example of registration of white smoke movement to trace cracks and crevices in combination with the blower door test.

With a difference in pressure of 50 Pa between the inside and the outside of a building the maximum air change should at least be less than two times per hour, according to *Home Energy Article*, reference /3/, and in several countries like Denmark and Austria it should be less than 1,5 arch. This has to be documented via a measuring of air tightness of the building according to the standards. For the so called "passive houses"¹ the air change should be at least less than 0,6 arch with pressure difference of 50 Pa between inside and outside. This is f.ex. also a general demand in Austria if mechanical ventilation with heat recovery is used. See also chapter 8 on this.

7.2 Maximum values for air change

According to *Home Energy Article* /3/ the following method of conversion could be used for conversion of change of air per hour at 50 Pa difference in pressure and the normal infiltration rate as:

$$n_{50} [\text{h}^{-1}] / 20,$$

n_{50} is the air change per hour at 50 Pa difference in pressure.

Thus an air change of 1,5 arch at 50 Pa is equal to an average air change by infiltration of 0,075 arch which is considered to be the maximum allowed air leakage if e.g. mechanical ventilation with heat recovery is used.

7.3 Follow up on Blower Door test

When carrying out the blower door test, the location of leaks can be found with 'artificial smoke pipes' blabla

Special places to carry out smoke control of leakage in connection to a blower door test are:

- connections between building components
- installation penetrations
- doorways and around windows

The first test has to be carried out just after the completion of e.g. a dwelling. The test should be carried out for each type of apartment and is carried out by the consultant for the owner. Just after the dwelling has become more air tight based on recommendations from the first test so it functions according to the demands, then the tests are carried out again, random checks should also be carried out.

A further follow-up on the energy quality can be made using the 'energy signature' method, which is a diagnostic tool for assessing the energy consumption of a dwelling. In this tool the energy demand in W/m² is monitored as a function of the outdoor temperature. Use of the tool is implemented in Deliverable 22: '*Common Evaluation Protocol*' and described in detail in Deliverable 4 (title).

8 Local Implementation of Airtightness Guidelines

¹ A passive house is a building in which a comfortable interior climate can be maintained without active heating and cooling systems (Adamson 1987 and Feist 1988). The house heats and cools itself, hence "passive". (Ref.: Passiv Haus Institut)

8.1 Danish Example I – Lineagården in Frederiksberg

8.1.1 Results from air leakage tests in the Danish Renovation project, Lineagården

As part of the project realisation in the Danish renovation project, Lineagården, which was also a part of the EU-Thermie project, SUNVENT, there was also made several attempts to ensure that the air leakage of the apartments should be as low as possible incl. extra tightening of the kitchen doors etc.

As part of the project evaluation it was decided to make an air leakage test of one of the apartments.

On 23rd of August 2002, a blower door test was carried out for one of the apartments on the third floor. Indoor temperature and ambient temperature were 24°C.

The result was an n_{50} of 8.4 /h, which gives an average infiltration rate of $8.4/20 = 0.42$ /h. This corresponds to an ELA (Equivalent Leakage Area) of 500 cm².

Even though there was an impression of a quite good air tightness, then the air leakage must be considered to be too high.

By using smoke detectors the main leakages were identified at the **entrance door, the panels between walls and floor** and **the drain system**. Based on this it is suggested to improve the air tightness here, e.g. to 50 % of this value.

It is difficult to say what the mentioned air leakage actually means, since the main part of the leakage is from apartment to apartment while some of the leakage is to the not heated hallway through letter boxes in the main door. But from the new windows there did not seem to be any air leakage.

The air leak from the apartment was approx. 4 times bigger than what was desired, but it was mainly between apartments as mentioned, e.g. through the soil pipe, which therefore does not have much influence on heat loss.

However there were found heat loss in the heat recovery (?) unit, which decreases temperature in the inlet air.

In general, it shows that in renovation projects, it is quite a challenge to achieve a satisfactory air tightness.

8.2 Danish Example II - Dalgasparken in Herning

In Herning in Jutland a low energy housing project with 72 housing units has been established. By November 2003 the first 38 apartments were ready. An evaluation, made by August 2004 for 32 of the 38 apartments, show that the bills for heating and DHW were reduced by 50 % compared to normal housing projects. Here the good results were mainly based on a very good follow-up on air tightness with several phases of blower door tests and use of innovative heat recovery ventilation systems which also had a very reduced electricity consumption for the fans.

Here also PV modules were used to match the electricity consumption for ventilation on a yearly basis.



Fig. 8.2.1.: Blower Door test in an apartment.



Fig. 8.2.2.: Example of registration of white smoke movement to trace cracks and crevices in combination with the blower door test.

A further follow-up has been made on the energy quality by help of a new system for energy signatures, "Programme for Evaluation of Energy Performance in Buildings and Diagnostics of Operation Malfunctions", where the effect demand in W/m^2 is monitored as a function of the outdoor temperature (see also Deliverable 4 and 22 where this is elaborated).

A reporting on monitoring results for the 32 apartments in Dalgasparken, Herning was made in August 2004 by the Energy Group Jutland based on 57 % of the yearly energy consumption for heating and DHW. A 50 % saving of the costs for the tenants was the result.

8.3 Danish demonstration project Gyldenrisparken

In the Danish Demohouse demonstration project it is aimed to reach an airtightness of 1,5 arch at 50 Pa pressure difference. To obtain that special design and implementation workshops are foreseen. Besides blowerdoortests of a test apartment with new windows have been made, and documented that it should be possible to reach the aimed at quality. A Danish version of this report has also been given to the design and implementation team.

8.3 Spanish Project

Ventilation is not a key point for energy efficiency of buildings located in Spain, and most of them use natural ventilation for air exchange. However, uncontrolled air leakages can be a relevant cause of heat losses. They are mainly associated to windows sealing. Although the majority of the commercial windows have solved this problem nowadays, it is not so common in the market for roller (exterior) blind boxes, which are typically separately placed above the window constructions. This is currently one of the main weak points of heat losses in Spanish buildings.

At this time there is no specific Spanish normative with numerical threshold for air infiltration

maximum values; and only recommended figures can be found from public energy boards. These values address equilibrium conditions for both minimum air renovation for internal healthy conditions (CO₂ concentration) and maximum air renovation to avoid excessive heat losses, ranging 0.4 to 0.6 air changes per hour (EVE-CADEM).

Spanish demonstration building aims at reaching these recommended values, with special care on air leakage through roller blind boxes. These problems have been overcome using monoblock system blind boxes, where the window and the box are in one piece, and hence especially designed to avoid undesired heat losses through better sealing than standard joints.

8.4 Austrian Project Laudongasse/Starhemberggasse Graz

8.4.1 Regulations concerning air tightness in Austria

ÖNORM 8110-5 (Austrian standard)

There are no benchmarks in the Styrian building law, air tightness is regulated by ÖNORM, an Austrian norm.

Measured air change rates by a reference pressure difference of 50 Pa must not exceed the following values:

- Low energy buildings without mechanical ventilation $n_{50} < 3,0 \text{ h}^{-1}$
- Low energy buildings with mechanical ventilation without heat recovery $n_{50} < 1,5 \text{ h}^{-1}$
- Lowest energy buildings with mechanical ventilation with heat recovery $n_{50} < 0,6 \text{ h}^{-1}$

Air passage coefficient for well sealed windows and doors should be less than $0,2 \text{ m}^3/\text{m.h.Pa}^{2/3}$.

8.4.2 Styrian subsidy system

The Styrian housing subsidy for new built multi-storey buildings requires the same values for air change rates as ÖNORM 8110-5. Measurements have to be done by a Blower Door test according to ÖNORM EN 13829. For new buildings up to 10 living units every third flat, from 10 living units on every fifth flat has to be measured. Blower Door measurements have to be done by an independent contractor (not by the building constructor!).

Experiences in Austria have shown that from $n_{50} = 3,0 \text{ h}^{-1}$ to $n_{50} = 1,5 \text{ h}^{-1}$ the decrease of energy consumption is $5,5 \text{ kWh/m}^2/\text{a}$ and from $n_{50} = 1,5 \text{ h}^{-1}$ to $n_{50} = 0,6 \text{ h}^{-1}$ decrease is $3,2 \text{ kWh/m}^2/\text{a}$.

8.4.3 Measures concerning air tightness in the Austrian demonstration building

The Austrian pilot project is two blocks of flats in the city of Graz: Laudongasse 14-16 as well as Starhemberggasse 13-15. Both buildings were constructed in 1976 and they consist of 127 flats (between 75 and 110 square meters each). Building components with influence on air tightness are:

- Windows, doors to the outside
- Entrance doors of the flats to the staircase
- Outer walls, ceilings
- Ventilation ducts in bathrooms and WCs

Air tightness related measures in the Austrian demonstration building are

1. Replacement of the windows
2. Insulation of the thermal building shell

8.4.4 Replacement of the windows

Existing windows (wooden windows with compound double glazing with an U-value of 2,30 W/m²K) have been replaced through new energetic optimised windows (low-E glazing with U-value 1,1 W/m²K, U-value frames 1,5 W/m²K). Assembly of the new windows follows ÖNORM B 5320 (Austrian norm dealing with joints of windows and doors in the thermal building shell). To minimise heat loss and to improve air tightness the reveal is insulated with 3 cm of insulation.

In figure 8.4.4.1. is shown recommendation for mounting of plastic windows according to ÖNORM B5320.

Seite 10
VORNORM ÖNORM B 5320 Beiblatt 1

3.3 Kunststoff-Fenster

Kurzbeschreibung

Rahmenwerkstoff:	Kunststoff
Blindstock:	keiner
Baukörper:	Betonmauerwerk mit Wärmedämm-Verbundsystem
Lage:	Fensterelement mit Rohbau-Außenkante bündig

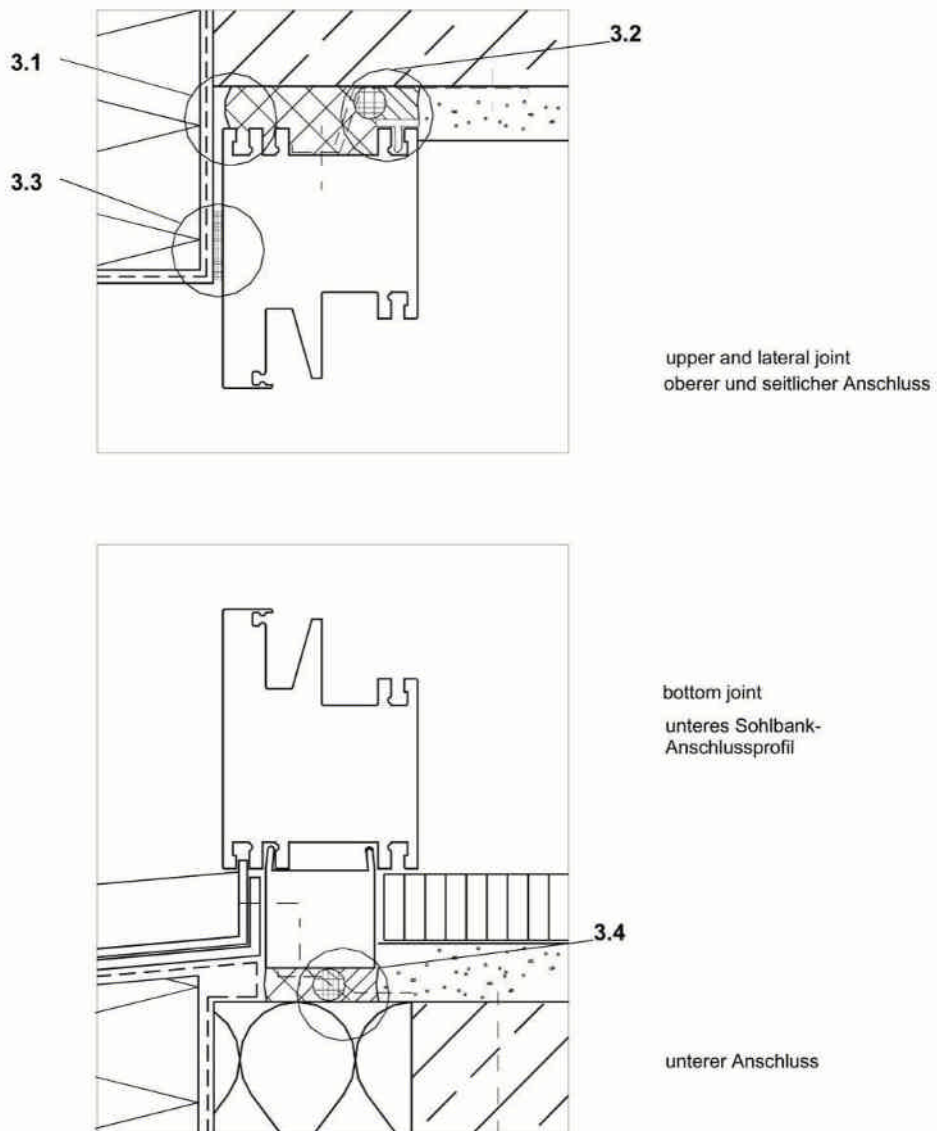


Bild 11: Kunststoff-Fenster, Schnitte
(Details siehe Bild 12)

Joints for plastic windows - Sections

Fig. 8.4.4.1. Illustration of upper and lower points for plastic windows mounted in wall constructions (ÖNORM B 5320)

Mounting of windows - demonstration building

Anschluss Fensterbank

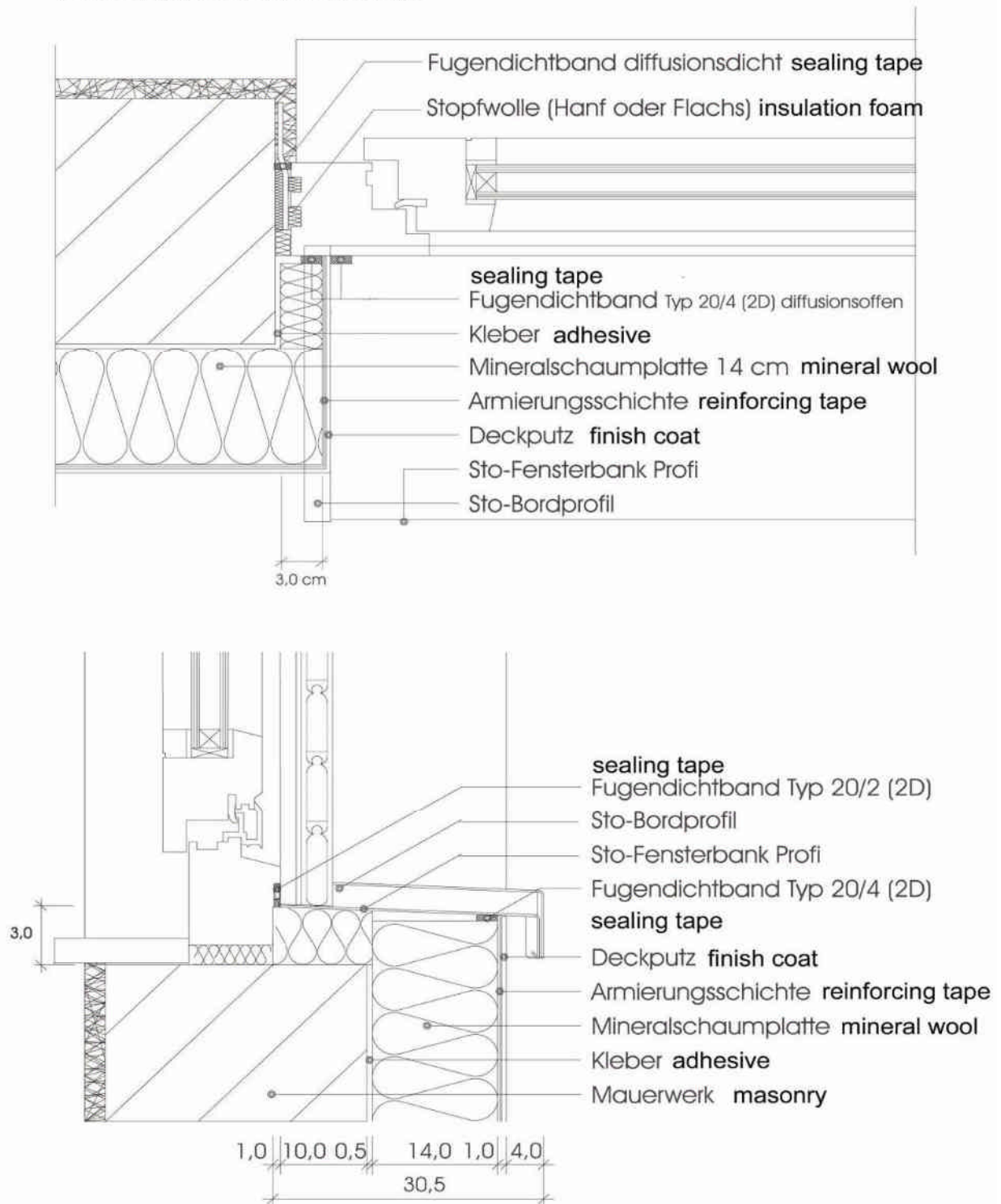


Fig. 8.4.4.2. Illustration of how windows is mounted in the Austrian demonstration building. This is equal to the recommendations shown in fig 3.1.1.1.

8.4.5 Insulation of the thermal building shell

The existing outer walls of the Austrian demonstration building are wood-fibre coated concrete and isolating plaster with a total thickness of 330 mm and an U-value of 1,42 W/m²K. As there is no renovation measure concerning the interior plaster of the building, the air tightness (wind tightness) only can be improved by the thermal insulation composite system and the airtight mounting of new windows. The thermal insulation composite system consists of mineral wool, reinforcement, a base and a finishing coat of artificial resin. Accurate handling especially concerning joints and edges provides wind tight construction and should be state of the art. This is however not always the case, so it is recommended to have special meetings on this, in both the design phase as well as during implementation. Besides the information in this, Demohouse guidelines report has been provided to the involved stakeholders,

8.4.6 Quality control – Blower Door test

According to Deliverable 22: '*Common Evaluation Protocol*', the buildings' air tightness will be assessed using the blower door test after the completion of the construction works. This methodology can measure the tightness of a building and at the same time finding any leaks, as described in chapter 7.3. Three flats will be tested, following the schema below:

To measure the air tightness of the windows all ventilation ducts in bathrooms and WCs are sealed air tight and the ventilator for Blower Door testing is placed in the entrance door of the dwelling. In a second step Blower Door testing is done without sealing ducts of bathrooms and WCs. In a third step the ventilator for Blower Door testing is placed in a window, ducts of bathrooms and WCs are air tight sealed. This constellation will show the influence of the entrance door (although there was no change of entrance doors in the demonstration building) on the air tightness of the dwelling. Above mentioned approach gives chance to identify the air tightness of different building components and their influence on the total performance of the air tightness.

Measurements will be done by an independent, accredited contractor, relevant construction firms (windows, thermal insulation composite system) are invited to attend the Blower Door procedure, discussing malfunctions (if detected) of their work. Blower Door testing must be repeated until the appropriate standard is achieved. First test is on charge of the building owner, further tests if necessary, are on charge of the relevant building constructor. This strategy should be kept in mind when tendering the construction work, not to charge the building owner with a lot of Blower Door tests.

In fig. 8.4.6.1. is shown the basis of the blowerdoor test for the Austrian demonstration project.

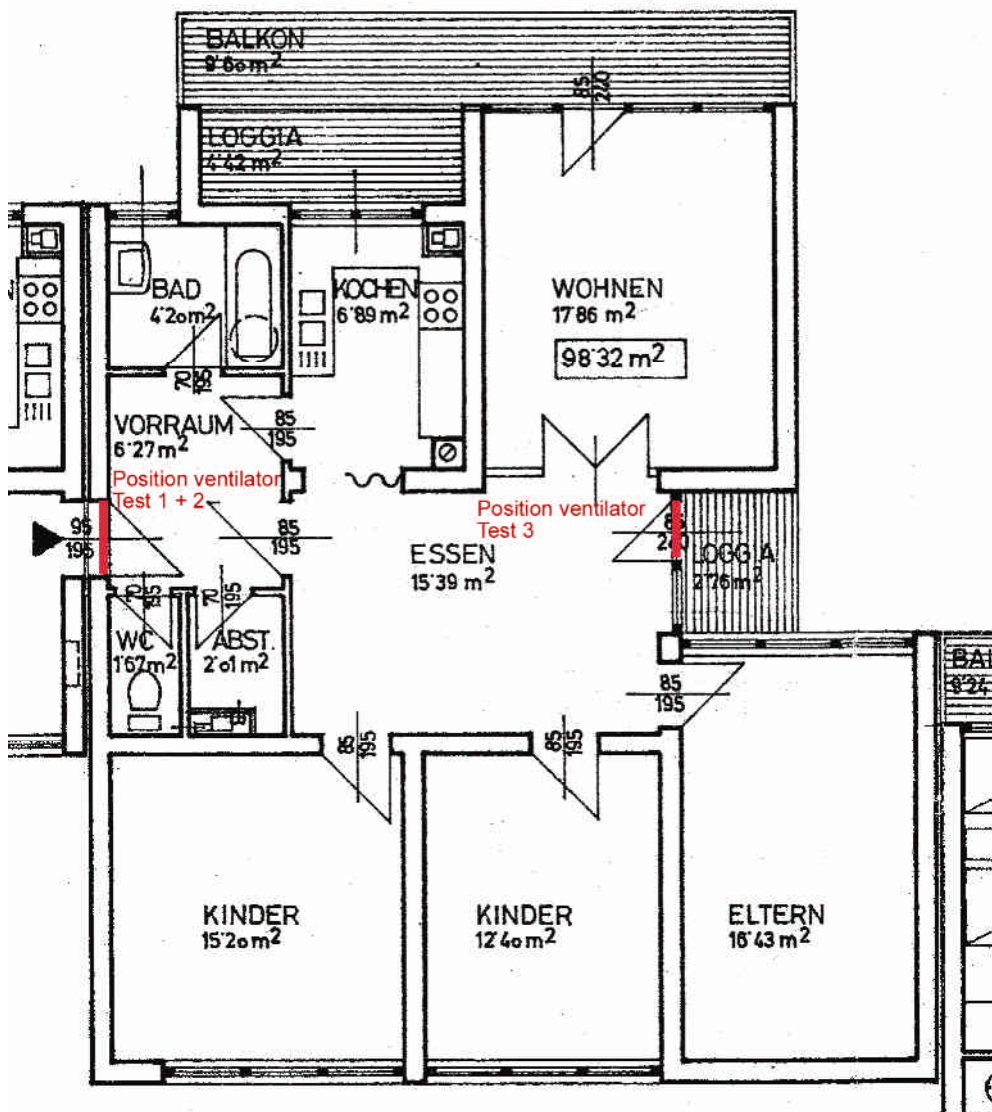


Fig. 8.4.6.1.: Schema of Blower Door testing in the Demohouse dwellings

8.5 Greek project

After the completion of the construction works, the air-tightness of the 'DEMOHOUSE' dwellings will be tested using the fan pressurization method (blower door test).

The fan pressurization method is intended to characterize the air-permeability of the building envelope. This method does not measure the air infiltration rate of the building. The results of the fan pressurization test can be used to estimate the air infiltration using the formula in chapter 7.2. However, for greater accuracy, it is better to use the fan pressurization method for diagnostic purposes and measure the actual infiltration rate with tracer gas methods.

Ideal conditions for the test are small temperature differences and low wind speeds. Standard **EN 13829** is intended for the measurement of the air leakage of building envelopes of single-zone buildings. For the purpose of this standard, many multi-zone buildings can be treated as single-zone buildings by opening interior doors.

The test is carried out by taking measurements of air flow rate and indoor - outdoor pressure difference over a range of applied pressure differences, from 10 Pa to 100Pa for best accuracy.

And the actual air change can be found as explained in chapter 6 in this report and can be compared to tracer gas movements.

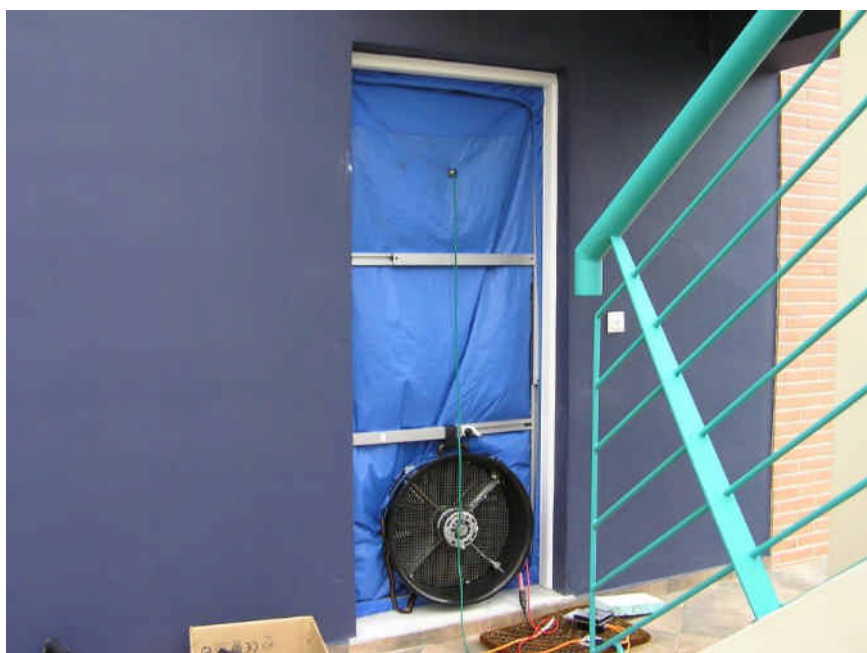


Figure 8.5.1.: blower door test in Greek demonstration project

8.6 Hungarian example – Solanova in Dunaújváros

The **EU funded** SOLANOVA demo-house project in Dunaújváros, is an example for a complex ultra efficient renovation project of a building with industrialised technology. The renovation process ended in October 2005; the monitoring and scientific research in 2006.

The goal was to significantly decrease the heat consumption of the building regarding both heating and DHW production and to improve the thermal comfort based on an eco-efficient optimisation, social research, supported by a detailed long-term monitoring. The first results show a heating energy saving of approximately 85% and a significant improvement of both winter and summer thermal comfort. In the project, the building envelope was insulated and new energy efficient windows were installed, a green terrace roof was constructed, a flatwise balanced ventilation system with heat recovery was installed and the heating system was changed for a double pipe system with roomwise control. Water saving equipment was installed and 72 m² solar collectors support the DHW production.

The air-tightness of four flats on the 5th and 7th floor was measured with a Blower Door test before the retrofit. The test proved a rather poor air-tightness: air change rates $n_{50} = 7,1 - 12 \text{ h}^{-1}$ were measured. According to EN 832, this corresponds to a low air-tightness level. The Blower Door test has not been carried out yet after the retrofit, but due to the installation of air tight layers and new windows a significant improvement is expected. DIN 4108-7:2001 requires $n_{50} = 1,5 \text{ h}^{-1}$ in case of mechanical ventilation, the Passive House Standard requires $n_{50} = 0,6 \text{ h}^{-1}$ for passive houses, as mentioned in chapter 6.



Fig. 8.6.1. Illustration of Blowerdoor test in Solanova demonstration project in Hungary.

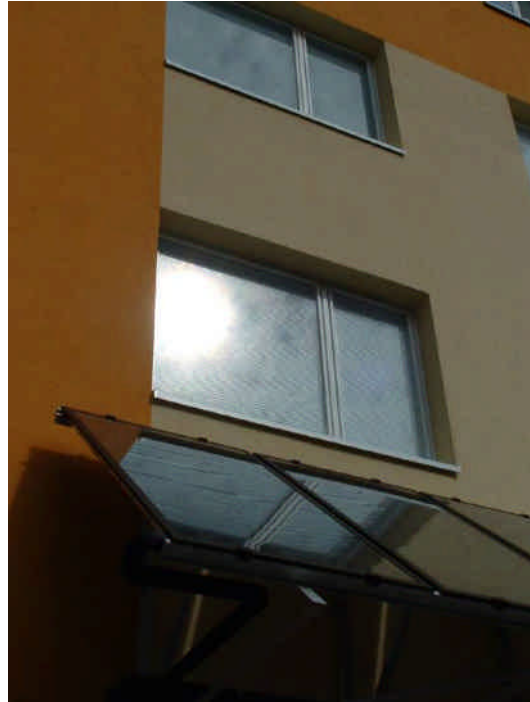


Fig. 8.6.2.: The retrofitted building in the Solanova project, with the solar collector canopy.

For the Hungarian Demohouse demonstration project it is foreseen to use Blowerdoor tests to document an airtightness of 1,5 arch at 50 Pa pressure difference.

To ensure this will be met, special design and implementation meetings on this aspect will take place, and a test of the quality will be made at the moment the first apartment is finished.

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