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Installation of vapour barriers in existing buildings – obstacles and solutions

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ABSTRACT

With new demands for energy consumption in refurbished houses, some houses now need a vapour barrier although they could function without when the insulation was less. This is typically in ceilings; the traditional plaster ceiling was maybe airtight but open to vapour. Now the vapour must be stopped as well as the air. To install a vapour barrier in ceilings from the attic side can be very difficult, the obstacles are listed in the paper. This means traditional solutions are not robust to minor faults in the execution. Prefab fittings that can reduce the risk are on the marked, but they should be made more flexible to be useful for refurbishment, as the tolerances are bigger in existing than in new buildings. Furthermore, apprentices and skilled craftsmen should be trained by hands-on exercises where air leaks can be made visible. Guidelines should not only focus on new buildings but also give instructions for refurbishment. Finally the paper addresses the question whether all buildings must compile with the new energy requirements, or it is safer to allow some energy loss to prevent moisture problems.

1. Introduction

The two main strategies for reducing energy consumption in buildings are:

- Thermal insulation of the building envelope. This will reduce energy loss by conductivity
- Tightening the building. This will reduce energy loss by convection, as uncontrolled air change means that heated air will leave the building.

From a strictly theoretical and energy oriented view, this means that all new houses should be airtight and have very low U-values and only small thermal bridges. For existing buildings the strategy should be the same, e.g. if refurbishment is needed to prevent further degradation of the building, the building should at the same time be insulated and tightened.

From a moisture point of view low U-values mean higher moisture content in the winter in the outer parts of the building envelope. Airtightness prevents moisture transport through uncontrolled openings. Otherwise warm moist air penetrating through leaks can result in condensation or high moisture content in the outer part of the building envelope. The risk is increased when the U-value is reduced, as the temperature in outer parts of the envelope will decrease. With the same absolute moisture content the relative humidity will thus increase. However, airtight buildings must have controlled ventilation to avoid high moisture content in indoor air.

Theoretically the two strategies are correct for new as well as existing buildings. For new buildings the strategies are described in building regulations. However, for practical reasons it can be difficult to follow the strategies in existing buildings to the same level as for new buildings. The paper describes different obstacles for obtaining sufficient airtightness in existing buildings.

2. Airtightness

Airtightness in buildings has always been important as it influences comfort and heat loss. Over the years the demands have been tightened as focus has shifted. In Denmark the development can be described as follows:

- Before 1950. Vapour barriers are used in timber framed walls. In other constructions focus is only on airtightness to avoid draft. No specific demands.
- In the 1950'ies vapour barrier in roof constructions are recommended to avoid diffusion. The barrier is typically a part of the insulation batts, no attention to joints (Becker & Korsgaard 1957)
- In the 1960'ies vapour barriers as membranes in roofs become common practice to avoid diffusion.
- In the 1970'ies airtightness of the vapour barrier is in focus to avoid moisture problems caused by convection (Andersen et al. 1974)
- To minimise heat loos caused by convection the Danish Building Regulations prescribes in 2006 a maximum air change in new buildings when tested at a pressure difference of 50 Pa (Danish Enterprise and Construction Authority 2006).

The Danish Building Regulations now prescribe that the U-value for refurbished constructions should comply with demands for new constructions if this is feasible and moisture safe (Danish Enterprise and Construction Authority 2010). However, there is no requirement for the airtightness of existing buildings.

2.1 New buildings

Today the main effort on reducing energy consumption in buildings is on new buildings. The Danish building regulation prescribes maximum air change values for new buildings and for two classes of low energy buildings (Danish Enterprise and Construction Authority 2010).

2.1.1 Current demands on airtightness

The maximum air change rate in new buildings must not exceed 1.5 l/s per m^2 heated floor area at a pressure difference of 50 Pa. The value must be determined as an average of measurements with depressurisation and pressurisation. Air changes must be determined on the basis of EN 13829, (CEN, 2000), a standard equivalent to ASTM

E779 - 03 (ASTM, 2003). In practice a blower door assembly is often used for the test.

When the demand was given, many houses failed the test, and it was considered difficult to meet the required airtightness. However, after a while contractors have learned to build more airtight (Møller et al 2010). This indicates that there is a learning curve for building airtight. If the requirements are tightened further it might be realistic to achieve even better airtightness. For low energy buildings the requirements are already tighter.

The Danish building regulations include two classes of low energy buildings. These classes are equivalent to the future energy requirements for ordinary buildings in 2015 and 2020, respectively. These are listed in Table 1

Table 1. Maximum air leakage now and in the future (Danish Enterprise and Construction Authority 2010).

Year of implementation	Air leakage (l/s per m^2 heated floor area
2006	1.5
2015	1.0
2020	0.5
Passive house *	0.4

*For comparison, not part of the building regulations

2.1.2 Practical solutions in new buildings

In Denmark airtightness is typically achieved by using the vapour barrier as air barrier as well. Therefore, when finding practical solutions, focus is on how to tighten the vapour barrier. In this paper it is taken for granted, that the material for the vapour barrier is sufficient tight against diffusion, a tight vapour barrier therefore means air and vapour tight, and focus will be on the airtightness.

In many ways airtightness is simply achieved by placing a vapour barrier at the inside of the building envelope. Tape or sealing strips ensures airtightness at joints, penetrations etc.

However, taping the vapour barrier can be difficult and time consuming. Different fittings have been developed, to make airtightness at penetrations etc. easier and more reliable. Fig. 1 shows different ways to ensure airtightness around a cable. A pre-fab collar with an elastic hole is fast and easy to install. Taping around the cable requires great care of the craftsman and a good tape. There are similar fittings available for in and outgoing corners and where the vapour barrier is penetrated by beam ends and pipes.

A SBi guideline was published to explain the necessity of an airtight barrier and to give general directions on how to establish this and how to test the airtightness (Rasmussen & Nicolajsen 2007). The guideline helps planners and craftsmen to establish an airtight barrier. The guideline gives examples of joints in airtight barriers where building components meet or the vapour barrier is penetrated.

The guideline is made for new houses and the air barrier is therefore described as yet another building material that is built in during the building process. However, installing an air barrier in an existing building can be very difficult; e.g. it can be difficult to build a continuous membrane into a construction with many rafters, which should not be covered by the membrane, as the membrane also serves as a vapour barrier.

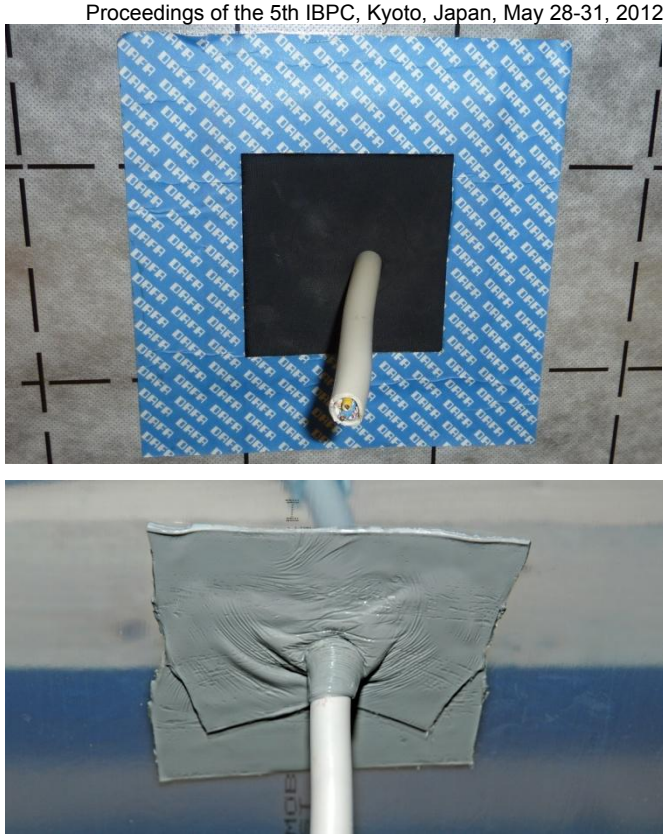

Fig. 1. Two different ways to ensure airtightness when a cable perforates the vapour barrier. Top photo: Pre-fab collar with elastic hole. Bottom photo: Elastic tape around the cable.

2.2 Existing buildings

When buildings are refurbished possible energy savings must always be investigated. For the parts of the building envelope that is being refurbished, the Danish building regulations requires that economically viable extra insulation up till approximately the level of new building components, must be installed, if it can be done without jeopardizing the safety as regards moisture problems.

There is no requirement for airtightness, e.g. existing buildings can be as leaky as ever, although most inhabitants expect the building to be less drafty after refurbishment.

A possible reason for not requiring airtightness when the building is renovated is that the test method (blower door) does not give any information on where the leaks are. Additionally it is not likely that a minor refurbishment e.g. changing windows in a façade should be followed by requirements to the entire building.

It is possible and in Denmark quite normal to combine measurement of the airtightness with measurements of air flow. However, it is not possible to determine if one part of the building envelope is as tight as it would have to be if it was in a new building. E.g. if only one façade of a building is refurbished, but the others are unchanged and therefore leaky. After the refurbishment it may still not be possible to build a pressure difference of 50 Pa between indoor and outdoor with normal fans, as the leaks in the remaining facades may still be too big. Experience shows (see Fig. 2), that it is difficult to obtain airtightness similar to the demands in new buildings, even if refurbishment has focus on airtightness.

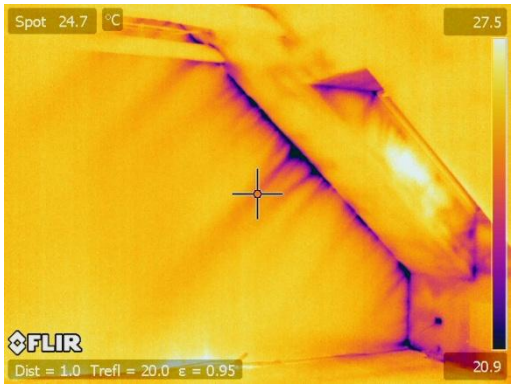

Fig. 2. IR-picture of air leaks in gable in refurbished building. The building is more than six times leakier than the requirements for new buildings.

However, tight vapour barriers are important to avoid moisture problems. The importance increases with insulation thickness (Hagentoft et al 2008). As a consequence, the energy requirements to refurbished building envelopes indirectly result in demands for airtight vapour barriers although these cannot always be tested the same way as in new houses. This implies that the tightness of the vapour barrier often only will be tested by real life, and that the result relies on the care of the craftsmen. Furthermore, flaws will probably not be discovered before the consequences are visible as growth of mould or other fungi, and it will therefore be expensive to rectify any errors.

It is therefore important to identify the difficulties in tightening the vapour barrier and to give craftsmen guidelines on how to overcome these difficulties.

3. Mapping of obstacles

The obstacles that make it difficult to achieve an airtight vapour barrier are many; from simple difficulties to fix the barrier at the right place to lack of knowledge of the importance of a tight barrier.

3.1 Irregularities

Establishing a tight vapour barrier on an even surface is relatively easy. E.g. if the underlay is gypsum board at the inner side of an outer wall or at the underside of a ceiling. The challenge here is to ensure airtightness at the intersections between wall and ceiling and wall and floor respectively.

If the ceiling is to be insulated and the room below is not to be touched, the work must be done from the attic side. This means the vapour barrier must be placed between the bottom chords. See Fig. 3.

In newer buildings where rafters are fairly even and with nail plates, the principle sketched in Fig. 3 can be used; it is difficult but possible. In older houses, where rafters are made of sawn timber with wane edges or the connections are made with fished joints (see Fig. 4), it becomes even more difficult to place a vapour barrier as sketched in Fig. 3.

3.2 Materials

It is only possible to achieve a tight vapour barrier if the materials and the tools are effective. There are a few simple rules that must be followed:

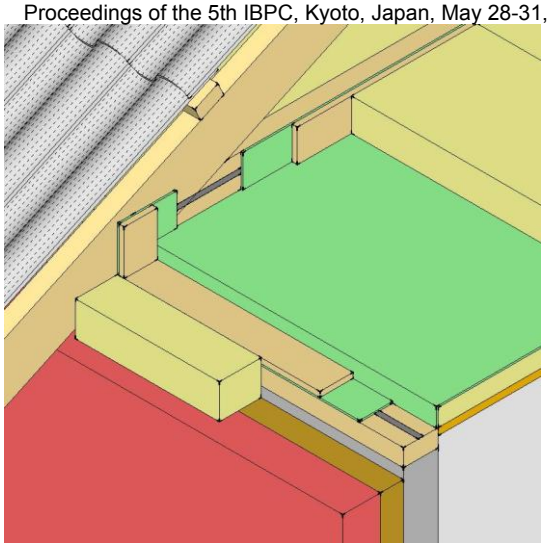

Fig. 3. Post insulation of ceiling from the attic side. Vapour barrier (green) placed between bottom chords. To ensure the airtightness the vapour barrier is stuck with an adhesive strip of butyl and clamped to the bottom chords.

Fig. 4. Rafters with fished joints make it more difficult to install a vapour barrier. In this case the vapour barrier is under the insulation; the mould growth on the roofing underlay indicates that the vapour barrier was not effective.

- Vapour barrier joints should always be made with an adhesive e.g. taped with a suitable tape with documented long service life
- There must be a firm underlay for joints in order to press the two parts firmly together
- Joints must have an overlap of at least 50 mm
- Vapour barrier, adhesive, sealants collars etc. should preferably be part of a system; ensuring that the materials will work together and that adhesive stick to the vapour barrier

Unfortunately, too many craftsmen are unaware of the importance of choosing the right materials; the cheapest materials from the nearest DIY marked is often used especially when it comes to tape. The vapour barrier is often specified by the planner e.g. as 0.2 mm PE-foil whereas the tape is rarely specified.

3.2.1 Adhesives

To achieve airtightness all joints must be connected by means of an adhesive. The adhesion must be intact in the entire lifetime of the vapour barrier. It is very difficult to ensure this, but there are some tapes on the market with 20-25 years guaranties for the adhesion. Long-time experience

with these tapes is difficult to achieve as it is unlikely that the chemical composition of the adhesive has been unchanged by the manufacturer over a period of e.g. 20 years. However, some manufacturers have test results from artificial ageing.

Previously it was considered safe to hold joints together by clamping a board over the joint (Andersen et al 1993). But as wood changes dimension with moisture content, it may bend or warp and the joint will then no longer be airtight. A combination of an adhesive strip of butyl and a board may be a good solution where possible. Vapour barrier and adhesive must chemically be compatible; otherwise one part may dissolve the other part. This is prevented by choosing a system where vapour barrier and adhesive are tested together.

3.2.2 Membranes as vapour barrier

In lightweight constructions the vapour barrier is often a membrane, e.g. PE-foil (most popular product in Denmark). Membranes are relatively easy to work with as they can be shaped around irregularities and are easy to cut and adjust. At the same time this can be a problem, as membranes can be penetrated during the installation. In Denmark the recommended thickness is 0.2 mm for a PE-foil as vapour barrier (Brandt 2009). This is a compromise between the risk of penetration and how difficult the foil is to work with. The vapour resistance of even very thin PE-foils is sufficient to stop the vapour, and is therefore not an issue.

Fig. 3 shows how the membrane is placed between and following the bottom chords and not as a continuous membrane over the entire surface. This is because vapour barriers should be placed at the warm side of the insulation. As a result the vapour barrier consists of narrow lengths and the bottom chords. Timber is considered to be tight enough to act as vapour barrier in this way. The many joints make the installation of the vapour barrier very difficult and time consuming and increase the risk of leakages.

If the vapour barrier instead is installed as a membrane from the ceiling side (underneath the bottom chords), it can be placed as a continuous membrane. Only the width of the roll determines the number of joints. However, taped joints must have a firm underlay; otherwise small leakages will appear as it is not possible to press the materials firmly together e.g. with a small roll to close the leakages where the materials wrinkle. The leaks are typical at the size of a pencil. Fig. 5 shows an example of this.

Fig. 5. Taped joint without firm underlay in a new building. The joint cannot be pressed firmly together; as a result small leaks appear where the materials wrinkle. Here illustrated by applying a small overpressure to the construction and adding theatrical fog.

Finally, some vapour barriers are easier to tape together than others, as a general rule the more smooth the surface of the membrane the easier it is to remove the tape, hence the risk of the tape relinquishing from the foil increases with the smoothness of the foil. Once again buildability and risk of leaks go in opposite directions.

3.2.3 Boards and plaster as vapour barrier

Boards of different materials can be used instead of membranes to ensure airtightness; they are more robust and may in some cases be easier to work with than membranes although the adjustment often is more complicated. The sealing of joints is just as important for boards as for membranes.

However, although boards might give the impression of being airtight, this is not always the case, and if the board should act as a vapour barrier it is important also to look at the vapour resistance of the material. OSB boards (Oriented Strand Boards) have become increasingly popular in the Danish building industry. The quality of the OSB boards varies and some of the boards are too open to be used as air or vapour barrier, see section 3.2.4.

Airtightness alone is not enough if the board shall act as air and vapour barrier. E.g. gypsum boards are airtight but open for diffusion, and can therefore not be used as a combined air and vapour barrier. Another example is plaster ceilings (timber framework, reed mesh and mortar), which were the traditional ceilings of houses until approximately 1950. Uncracked plaster ceiling is considered airtight, but like gypsum it is open to diffusion. With a relatively low thermal insulation level, the airtightness may be sufficient to avoid moisture problems in ventilated attics. However, with modern insulation levels avoiding convection is not enough; diffusion must also be stopped as the temperature and moisture conditions in the attic are changed. With decreased temperature even the small amount of moisture penetrating by diffusion might lead to condensation in the attic. This is the main reason why focus now is on installation of vapour barriers to improve the resistance against diffusion. The membrane may be placed from either side of the ceiling.

3.2.4 Airtightness of different vapour barriers

To test how different vapour barriers perform under realistic conditions, small buildings see Fig. 6, have been tested with the blower door method (50 Pa pressure difference). The vapour barriers were placed with great care, but not all joints had firm underlays. Therefore, the main reason for air leakage is probably due to openings in the joints, see Fig. 5.

Fig. 6. Small test buildings where the airtightness of the vapour barrier was tested by the blower door method with a pressure difference of 50 Pa.

The small buildings resemble new houses. To compare this with difficulties in refurbished houses, similar tests were made on a mock-up of an existing attic, see Fig. 7.

Fig. 7. Mock-up to resemble refurbished attics. Blower door tests were performed to test the airtightness of different vapour barriers.

The results of the measurements are shown in Table 2.

Table 2. Airtightness of different vapour barriers installed in new and refurbished buildings.

Vapour barrier	Air leakage (l/s per m^2 vapour barrier)	
	New buildings	Refurbished buildings
OSB boards	0.023	Not tested
PE-foil	0.130	3.52
Moisture adaptive vapour barrier*	0.067	0.68

* Vapour resistance depends on moisture level

Tests with different OSB boards show that the airtightness depends on the quality of the board. The tightest boards has an air leakage of 0.023 l/s per m^2, and the most open ones more than 100 times more (2.5 l/s per m^2), see Fig. 8.

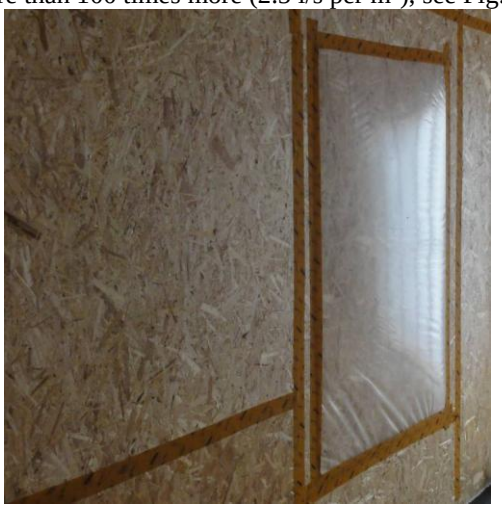

Fig. 8. Airtightness of an open OSB boards, measured by blower door test. A PE-foil is placed on the board to illustrate the openness of the boards.

An example illustrates the importance of choosing the right material:

A typical one-family house of 150 m^2, has 280 m^2 building envelope (exclusive floor area). Based on the results in Table 2 for new buildings, this means that an air leakage of 36 l/s must be expected if a PE- foil is used and installed with great care. This is 60 % of what is allowed in a passive house. This leaves little room for mistakes; or in other words the solution is not robust when requirements become stricter.

Only copper plates soldered together were so tight that leaks only could be detected with tracer gas.

3.3 Working environment

Ensuring airtightness of vapour barriers can be time consuming and requires great care, especially during refurbishment. Unfortunately, some of the most difficult joints to seal are placed in areas where it is difficult to work e.g. in attics or eaves voids. Not only can it be difficult to find a good working posture but it can also be difficult to see the joint either because it is difficult to light the area or because hands and head cannot be in the same area at the same time. Often the craftsman will have to lie in uncomfortable positions in small dusty spaces with temperatures that are too high or too low. In other words the buildability is not good.

If the vapour barrier shall be placed in a roof from the outer side (roof cladding removed), as shown in Fig. 9 the working environment might still be a problem. Even if the roof is covered by a temporary canopy, the working posture is not optimal and cold can be a problem because fingers and materials get stiffer with lower temperatures.

Fig. 9. Continuing education of craftsmen in establishing an airtight vapour barrier in a mock up of an existing roof. Unlike real conditions the roof is placed indoors resulting in far better conditions concerning temperature and lighting.

3.4 Knowledge

Establishing an airtight vapour barrier is difficult and can only be achieved if planners and craftsmen are aware of the necessity of having an airtight vapour barrier. It is therefore essential that planners and craftsmen are made aware of the effect of an airtight barrier and the risks for moisture problems in case of leaks. It is a challenge to change old habits; post insulation of ceilings from the attic side without establishing a new vapour barrier has been routine work since the 1970'ties. But with modern insulation thicknesses the tightness has become more important. In Denmark plaster ceilings are since 2007 no longer considered sufficient vapour tight to avoid moisture problems when the ceiling is post insulated (Hansen et al. 2007). Guidelines (e.g. Brandt 2009) have since then had focus on how defects in existing vapour barriers can be a problem when the post insulation is thick.

As a consequence, methods of energy refurbishment, used for decades with success, are no longer acceptable and planners and craftsmen must be convinced to use more expensive and demanding methods.

4. Possible solutions

To overcome the obstacles it is necessary to find new ways that are cheaper, faster and less prone to leaks than the existing methods. There is probably not one simple solution but it will have to be a combination of several initiatives.

4.1 Prefab solutions

Some of the solutions used in new houses may be applicable to refurbishment as well. Prefab collars and corners can also be used in existing buildings. However, as tolerances often are larger and materials less standardised in older houses than in new buildings, the prefab solutions will have to be more flexible or consist of smaller parts that can be combined on site e.g. flexible vapour barrier corners. There are prefab vapour barrier corners on the marked, but these are expensive and made for 90 ° corners. In refurbishment some corners are slightly different from 90 °. If the existing prefab corners are used, the corners or the attached foil will wrinkle or be stretched. Only if the stretched material has the same expected lifetime and airtightness as the original material and the wrinkles do not introduce leaks like in Fig. 5, the existing corners can be used. One way to reduce the risk of leaks where the material wrinkle is to have a firm underlay as stated in the guidelines. However, at the moment the instructions from the manufacturer of prefab corners do not include firm underlays.

4.2 New vapour barriers

To reduce the number of joints in the vapour barrier in roof constructions new materials could be helpful. “Smart” (or moisture adaptive) vapour barriers whose vapour resistance vary with the relative humidity, can be placed on the cold side of the rafters (where normally a vapour barrier should be avoided) as well as on the warm side between the rafters. Fig. 10 shows the difference. Traditional vapour barriers must be placed only on the warm side of the building envelope, and must therefore be assembled at the rafters. “Smart” vapour barriers are vapour open in moist environment and can therefore be laid out as a continuous membrane following the rafters.

Joints are always time consuming to make and increase the risk of leaks. The joint at the rafter bottom with butyl strip and clamped with a board is a more safe solution than taping the vapour barrier to the rafter but it is time consuming, because the insulation has to be adjusted to the board. If the conditions for using a smart vapour barrier are fulfilled, the solution shown at the bottom of Fig. 10 must be preferred as it has fever joints and therefore fever potential leaks than the traditional vapour barrier. This is probably one of the main reasons for the big differences between PE-foil and smart vapour barrier in Table 2.

4.3 Adaptive ventilation

The need for a barrier that is not only airtight but also vapour tight is a result of high thermal insulation. If the barrier in a ceiling is not vapour tight it will result in moisture problems in the attic. Previously when attics were moist the ventilation in the attic was increased. It often solved the problem, as the outdoor air could absorb the moisture that diffused through the plaster ceiling and remove it by ventilation. Outdoor air has often high relative moisture content and the system only worked because the attic was heated by the heat loss through the relatively low insulation in the ceiling. The outdoor air became therefore heated when entering the attic.

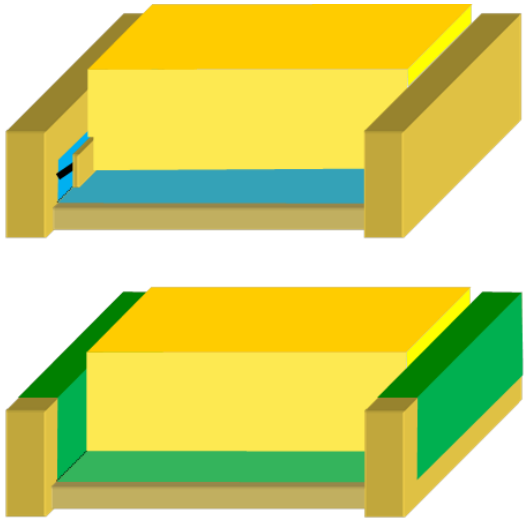

Fig. 10. Top: Traditional vapour barrier placed between the rafters where it is made airtight with an adhesive strip of butyl and clamped with a board. Bottom: Smart vapour barrier can be laid out as a continuous foil following the rafters.

With large insulation thicknesses the attic becomes cold, and increased ventilation will not reduce the problem; it might even increase the risk of moisture problems as the outdoor air sometimes is cooled when entering the attic e.g. in clear summer nights where night sky radiation can result in undercooling of the roof. Hagentoft et al. (2008) have proposed adaptive ventilation to avoid ventilation with moist air. The idea is to seal the attic (no natural ventilation) but comprised with mechanical fans and dampers, controlled by sensors and therefore only active when the outdoor air has a potential to dry out the attic. The airtightness of the ceiling becomes less important as there is an under pressure in the living space which means that the air movement is downwards. The system has been tested in field studies which has supported the simulations (Hagentoft & Sasic Kalagasidis 2010).

The system requires electricity, i.e. energy, to work. The energy consumption must be compared to the extra costs of ensuring an air and vapour tight barrier. Maybe the risk of moisture problems are smaller in the ventilated case, this will depend on how difficult it is to install an airtight vapour barrier in the ceiling. It will have to be evaluated from case to case.

4.4 Continuing education

The building industry is very conservative in its methods; although part of the education is conducted at schools, most of the training takes place at the building site, where skilled craftsmen teach the apprentices how to do the work. If the old ways are no longer applicable, it is important not only to tell the new generation of craftsmen in the schools how things must be done in the future, and hope they will teach the old generation. The old generation must also be educated. As a part of their continuing education they should come back to school and learn about the effects of airtight vapour barriers and the risks if the vapour barrier is leaky. It is essential to explain why the old ways must be changed.

Finally, the craftsmen should be taught how to ensure airtight vapour barrier by hand-on experience and training. Fig. 9 shows skilled craftsmen working on establishing an airtight vapour barrier in a mock-up of an old attic. When the craftsmen are finished, the airtightness is tested visually by releasing theatrical fog in the attic. A method also proposed for a new ASTM standard (ASTM 2011) and very effective in illustrating leaks. In this way leaks are easily discovered, and it is clear where the difficulties are. The combination of theoretical knowledge and practical illustration of the problem will hopefully make the craftsmen aware of the problem and they will teach the apprentices the same thing the schools teach.

4.5 Guidelines and inspections

The Danish building regulations have become more and more function based instead of giving concrete solutions. As a consequence it describes what is demanded in a building e.g. airtightness of 1.5 l/s at 50 Pa pressure difference but not how this can be achieved. Different guidelines give examples and recommendations on how the requirements of the building regulations can be fulfilled. Different organisations produce these guidelines e.g. the Danish Building Research Institute (SBi), the Foundation for Building Technological Experience (BYG-ERFA) and different trade associations. The guidelines are generally acknowledged as they are the result of discussions among specialists from different companies and organisations and therefore do not promote specific companies. The guidelines are in general coordinated; if there are conflicting methods it is usually because experience has shown that the older methods must be changed. Therefore newer guidelines go before older.

The guidelines are part of the required common technical knowledge, this means that planners and contractors are not obligated to build the way the guidelines describe. However, if they follow the guidelines and there later is a building technological problem, they cannot be held legally responsible. On the other hand, if they do not follow the guidelines and something goes wrong, they have to prove, that their method was at least as good as the method described in the relevant guideline. Otherwise they will be held responsible.

Therefore, guidelines de facto describe the way houses should be build. Ways to ensure airtightness are described in several guidelines e.g. (Rasmussen & Nicolajsen 2007), (Brandt et al 2008), (Hansen et al. 2007) and (Brandt 2009). Focus is often on new buildings and the intentions must be translated by the user to what is possible when a building is being refurbished. However, refurbishment becomes more and more regulated; energy requirements are given for refurbished buildings and since July 2011 publicly funded refurbishments must be insured by the Danish Building Defects Fund (BSF). The latter implies, that one year and five years after completion of the refurbishment, the building will be inspected. It is expected that this will reduce the number of faults in refurbishments.

That inspections do have an influence shows the success of the Danish Building Defects Fund, who since 1986 has carried out building inspections in new publicly funded housing projects as part of the Danish Quality-Assurance and Liability Reform. This has greatly reduced defects and damages; from building defects in 36 % of the projects built from 1987 to 1992 to 4 % in the projects built from 1999 to 2009 (The Danish Building Defects Fund, 2010).

It must be expected that there is a bigger interest in guidelines for refurbishment when the control with the projects is increased.

5. Discussion

Most specialists agree on that buildings should be made as airtight as possible and have well defined openings for controlled ventilation. But some people are afraid of having too tight buildings, as they think this will introduce moisture problems. The commonly used term is that houses should be able to “breath” and that nobody wants to live in a plastic bag. The reason is, that in some cases tightening buildings has not been followed by controlled ventilation, and mould growth and damp buildings have been the result. Unfortunately, the image of airtight buildings being like plastic bags is easy to understand and frightening. Therefore, some people, even some craftsmen, tend to disregard the advice of the specialists as being too theoretical. They prefer building without a vapour barrier or they are not careful about making airtight joints. The argument is “air circulation is good” which is true, but should be accomplished by controlling the ventilation.

Apparently education is not enough to overcome this scepticism against airtightness, and the next logical step is control. In new building this is a reality but it cannot as easily be made a requirement for refurbished buildings.

In new buildings five years’ experience with blower door tests show, that it seems to have become easier to fulfil the airtightness requirements, probably because craftsmen now have learned, where the problems are and how to solve them. This learning is a result of education and on the control. Hopefully, the learning from new buildings will be used also when buildings are refurbished. But it is important that we do not require unrealistic airtightness as unrealistic demands are disregarded. On the other hand, we know from new buildings that what might have been unrealistic five years ago might be standard today. Therefore, requirements should be ambitious but not impossible to fulfil.

Most of the solutions that are at hand today (section 4) or a combination hereof should be used in the future possibly in improved versions.

5.1 Realistic demands

It is without a doubt possible to reduce air leakages from existing buildings, the question is what is an acceptable air leakage? Is it realistic to demand the same airtightness in a refurbished building as in a new building? Do we need airtightness in refurbished buildings? If we want the same insulation standard as in new buildings the answer to the last question is yes. It also means that in some houses the actual airtightness is not enough; vapour barriers must be installed. But it is difficult to install a vapour barrier in an existing building. Therefore, it may not be realistic to reach the level of new houses. But will lower demands be sufficient to prevent moisture problems caused by warm moist air leaking through the building envelope? It is impossible to give an exact answer, as it depends on the distribution of the air leakage; whether the leak is one big hole or a number of minor leaks distributed over the whole building envelope.

If the existing practice of making joints without firm underlay was accepted, leaks like those shown in Fig. 5 are practically unavoidable. And experiments show that with PE-foil this means it will be difficult to achieve better airtightness than required in passive houses today (0.4 l/s per m^2 heated floor area). But maybe the level of new buildings today (1.5 l/s) is sufficient and the expensive and time consuming firm underlay is not always necessary.

5.2 Should all houses become airtight?

Not all refurbished buildings must comply with the new energy requirements; listed buildings or buildings worthy of preservation are exempt from the requirements. If airtightness at refurbishment should become a requirement these houses are likely to be exempt from this as well.

Maybe airtightness should only be a requirement in some houses where it is fairly easy to install a vapour barrier. The rest of the houses do not have to be insulated to the new levels, but more heat loss is accepted as this makes it possible for the houses to function without a new vapour barrier. This will make it more difficult to reduce the energy consumption of the existing building stock. Therefore the number of houses where this can be done must be kept low.

On the other hand, if new insulation thicknesses result in a requirement for a new vapour barrier, which is difficult to install, insulation of the house may no longer be feasible. In that case it would be better than to do nothing at all to leave out the vapour barrier and still post insulate the house, although it would be to a lower level than today's standard.. The Danish building regulations are open to this option of less insulation.

6. Conclusion

When existing buildings are refurbished they should be post insulated to reduce the energy loss. Modern insulation standard in e.g. attics mean that traditional plaster ceilings are no longer sufficient to prevent moisture transport to the ventilated attic. An airtight vapour barrier must be installed. This can be difficult, the main obstacles are:

- The sealing of the vapour barrier around the many penetrations and in the many joints. A job that becomes even more difficult at eaves where there is little work space, dusty and uncomfortable temperatures.
- Lack of knowledge among planners and craftsmen about the importance of a vapour barrier at places where plaster ceiling used to be sufficient when the insulation was less.

There are different ways to overcome these obstacles:

- Use of prefab corners and flanges in flexible materials
- Hands-on training of apprentices and skilled craftsmen
- Guidelines for refurbishments

Requirements of airtightness in refurbished buildings are unrealistic, as it either requires refurbishment of the whole building envelope or new methods to test parts of the building envelope.

Instead of making unrealistic demands for air and vapour tightness resulting in moisture problems where it went wrong, it might be a better idea to identify where it is unrealistic to install an airtight vapour barrier and in those cases use less insulation and accept higher energy consumption but avoid moisture problems.

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