RENOVATION STUDY

Airtightness solutions for the energy-efficient renovation of roof structures

Optimal positioning of airtightness and vapour control layers in constructions

IRELAND AND THE UK

Sub-and-top: Comparison of the potential freedom from structural damage due to moisture penetration when using vapour checks with various vapour resistivity's

Computer-based simulation of the combined heat and moisture transport resulting from various methods of roof renovation, taking the natural environmental conditions and moisture transport mechanisms within building materials into consideration

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Renovation solutions that p

Airtightness of existing roof structures – how can it be improved?

Introduction:

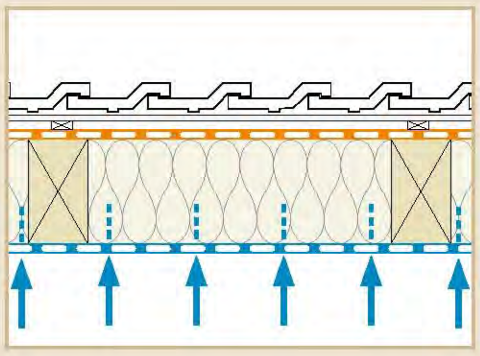
It is widely known that airtightness is essential for a thermal insulation layer to function properly. Airtight structures result in a comfortable indoor environment and help to offset the risk off structural damage due to moisture penetration as a result of interstitial condensation. Moist convection currents (i.e. air leakage), can result in large amounts of moisture penetrating the thermal insulation layer within a short period of time, thus jeopardising both the supporting structure as well as putting the thermal insulation's effectiveness at risk. This frequently results in the growth of mould and impairs the integrity of the structure.
The question that arises for existing roof structures is, by what means can we improve an initially poor airtightness layer when performing energy-saving renovations, while at the same time, increase the thickness of the insulation layer without introducing interstitial condensation risk.

Firstly, it is necessary to investigate the various options for where to install the insulation.
Point 5, "Planning and implementation" of DIN 4108-7 [1] states that the airtightness layer "should, as a general rule [...] be installed between the insulating layer and the inner wall surface". This recommendation in the standard assumes that the building is in an ideal condition, as is typical of a new building. This can only be achieved with considerable effort and at major inconvenience to the occupants of the building on which the roof is being repaired or renovated. It is thus possible to airproof buildings in accordance with the standard by installing an airtightness layer at any level of the building element. When deciding where to install the airtightness layer, it is necessary to consider condensation within the structure in accordance with the requirements of DIN 4108-3 [2]. If the diffusion resistance (moisture/vapour) of the internal airtightness layer is too low, this may allow too much moisture to penetrate the structure and, depending on the subsequent layers of the building element, may form interstitial condensation. If – on the other hand – there is an airtightness layer on the outside that is too impermeable, this may also result in moisture accumulating within the structure if the vapour diffusion resistance is too low.
The aim of this study is to investigate the various options, evaluate them and make recommendations for long-term protection of the structure with the highest possible level of freedom from structural damage. Robust and reliable refurbishment is especially important when constructing on existing buildings.

A. Optimal positioning of airtightness and vapour control layers within constructions

It is possible to accurately calculate vapour diffusion currents in constructions

Fig. 1
Exposure of insulation to moisture in the winter



With a vapour check and airtightness layer with an vapour resistance value of 15 MNs/g, only 5 g of water per square metre penetrate the structure per day.

The golden rule 1/3 to 2/3

The DIN 4108-3 [2] standard refers to the so-called 20% rule. This states that without mathematical proof, 20% of the total thermal resistance (with the same thermal conduction groups within the structure it is 1/5 of the total thermal insulation thickness) is allowed to be below the diffusion resistant layer (i.e. the vapour control layer) of the building element. If this value is exceeded, mathematical proof must be provided.

This is due to the fact that, if the standard environmental conditions are taken into account with insulation of the same thermal resistance on either side of the vapour control layer, the temperature falls below the dew point (9.2 °C) after approx. 1/3 of the total thickness of the insulation. If the airtightness layer and vapour control layer is above the dew point, an unknown amount of condensation is liable to form. Critical moisture contents can already be reached at a rel. humidity of over 80%. >From this moisture level the growing conditions are ideal for almost all types of mould between 0 °C and 50 °C [3].

In addition to this, the formation of condensation on an external diffusion open airtightness membrane located in the frost zone towards the outside of the construction can lead to the formation of a layer of ice. This prevents any kind of moisture transport through the airtightness layer (e.g. diffusion or gas exchange through pores), as ice is practically impermeable. This may hence lead to further moisture accumulating and leads to inevitable inevitable structural damage.

Sources of moisture transport

We differentiate between two basic causes of entry of moisture into thermal insulation:

- Entry of moisture by diffusion
- Entry of moisture by convection (i.e. air leakage)

Moisture transport caused by diffusion processes can be calculated using general stationary environmental data (e.g. in accordance with DIN 4108-3 [2]) or using a realistic non-stationary calculation of the moisture transport using real environmental data and building material data in accordance with DIN EN 15026 [4].

Moisture transport caused by convection cannot be calculated and often results in several hundred times as much moisture collecting within the structure as could accumulate due to diffusion.

Calculation models for diffusion processes

There are various calculation models that can be used to calculate the moisture transport due to diffusion within the structure with varying levels of accuracy.
In DIN 4108-3 [2] the quantity of condensation or evaporation that can penetrate or escape from the building element in question by diffusion is calculated using standardised environmental conditions. There are 2 block climates that can be used for the calculation (winter or summer climate).
DIN 4108-3 also provides the option of using the Jenisch method. This gives more differentiated results due to the fact that it uses regionally adjusted environmental conditions.
Neither of the approaches referred to in DIN 4108-3 permits detailed consideration of the heat and moisture currents and it is impossible to determine the precise moisture content of one of the materials used. The Glaser method has been used for decades in the building trade to give a rough estimate of the amount of condensation or evaporation.
The non-stationary calculation model in accordance with DIN EN 15026 [4], such as those used by WUFI pro [5] or WUFI 2D [6], or by Delphin [7], simulate the moisture and heat currents within structures. By far the most accurate results are achieved if the calculation is performed using environmental data recorded on an hourly basis. All of the calculation models described here assume that the layers within the building element are airtight.

Calculation according to DIN 4108-3 [2]
a) The Glaser method

The moisture currents are calculated for a generalised environment of 60 winter days (-10 °C outdoors/ 80% rel. humidity and 20 °C indoors/ 50% rel. humidity) and 90 summer

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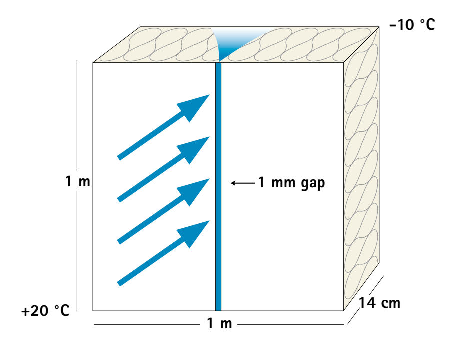
Entry of moisture into the structure due to leaks in the vapour check

Fig. 3
1 mm gap = 800 g/24h per metre



Moisture transport
through the vapour check: 0.5 g/m² x 24 h
Through a 1 mm gap: 800 g/m x 24 h
Increased by a factor of: 1,600

Conditions:
Vapour check vapour resistance value = 150 MNs/g
Indoor temperature = +20 °C
Outdoor temperature= -10 °C
Pressure difference = 20 Pa
Corresponding to wind force 2-3

Measurement carried out by: Institute for Building Physics, Stuttgart [11]

Convection and simulation

It is only possible to estimate the convection currents due to leaks. If the interior lining is ignored when performing the calculation, moisture only enters the structure by diffusion.
The actual amount of moisture that enters due to convection is higher.
High µ values increase the risk of the formation of condensation.

To convert to Irish and British standards:

s_d (m) x 5.1 = G value (MNs/g)

s_d = water vapour diffusion equivalent air layer thickness

G = vapour resistance

Calculation models for moisture transport by convection

It is not yet possible to simulate the entry of moisture into structures due to convection (currents of moist, warm air) using commercial software solutions. The driving force behind the convection is the pressure difference between the interior of a building and the air outside. This pressure difference is a result of the wind impinging on the building from the outside and the rising of heated air inside the occupied building. As an approximation, it is possible to estimate the moisture transport due to leaks in a structure by ignoring the diffusion-inhibiting internal layers of the building element (e.g. layers of vapour check or interior lining). Since we are only looking at diffusion currents here, and there is no driving force due to pressure differences, the actual moisture load due to convection is significantly higher. Air currents due to leaks result in moisture concentrated in a small area, meaning that it is actually much higher in the affected area than indicated by the results of the calculation. Air convection through a gap 1 mm wide and 1 m long (= 1/1000 m²) can result in 800 g/m² of moisture entering the thermal insulation by convection per day.
Even the most diffusion-open roofing underlay is incapable of allowing so much moisture to dry out, especially given the fact that the diffusion current of a thin building element at a lower (or no) pressure difference is actually much lower in practice than the vapour resistance value would suggest (see the section on the vapour resistance value and µ value).

Increase in the quantity of moisture due to internal convection

Convection currents can also occur within structures. Due to the heating of the structure from outside as a result of direct sunlight, moisture is able to migrate from within the building element and may accumulate in places where further convection is blocked, for instance by purlins or timber noggings between rafters.

Layers of ice are vapour barriers

If condensation occurs on layers of material that are in the frost zone (e.g. on an airtightness diffusion open membrane on the outside of the structure) a layer of ice may form there if the temperature drops below zero. Since this prevents the structure from drying out to the outside any more, this can result in a lot more condensation accumulating, which can in turn freeze too, reducing the effectiveness of the insulation and increasing the risk of damage to the materials in the structure.

The vapour resistance and the µ value

The most decisive factor affecting the formation of condensation is the µ value (the water vapour diffusion factor [-]). This is a measure of the material's relative reluctance to let water vapour pass through. The s_d value (equivalent air layer thickness [m]) also takes the thickness of a building material into account. The s_d value is defined as the multiple of the vapour diffusion resistance coefficient (µ value) - as material constant - and the thickness of the component in metres:
s_d = µ x s (m)
s_d x 5.1 = G value (MNs/g)
As the thickness of a building material increases, the time taken by a water molecule to pass through the material increases.
A roofing underlay may be diffusion-open and have a low vapour resistance value. Due to the low layer thickness, however, the µ value is comparatively high.
In real terms, a roof lining membrane with a microporous functional film has a µ value of 40 at an vapour resistance value of 0.1 MNs/g and is 0.50 mm thick. In comparison to a fibrous insulation material (µ value = 1) the membrane is 40 times more diffusion-tight. This means that condensation may also form on a diffusion-open roofing underlay.

A diffusion-open roofing underlay/external airtightness membrane may also allow the structure to dry out far less than the µ value and vapour resistance value would suggest due to the low (or complete lack of) pressure difference of a thin building element in the situation resulting from those environmental conditions.

The reason for this is that the driving force behind diffusion currents is always a pressure difference. If the same environment exists on both sides (e.g. 10 °C and 80% rel. humidity), no moisture transport takes place. Only if the temperature or the rel. humidity is different on each side of the building elements. Then the molecules tend to migrate from one side to the other by diffusion.
If roofing underlay/external airtightness membrane is used there is no temperature difference because the material is so thin, meaning that it is necessary to concentrate on the difference in the relative humidity. This is pretty low in the winter when there is a risk of condensation on the roofing underlay/external airtightness membrane if the humidity on the inside of the membrane is 80% or higher and the amount of water in the air on the outside is similar.

In such situations, added protection is provided by a roofing underlay with a monolithic functional film. In the event that condensation forms on the inside of the membrane within the structure, moisture is actively transported out of the building element by diffusion along the molecular chains. If exposed to moisture, the diffusion resistance of pro clima SOLITEX UD and PLUS drops – reducing the risk of ice forming. The permeability of microporous membrane, on the other hand, is reduced by the formation of condensation on the membrane, meaning that moisture can only escape through the membrane passively when in its gaseous form, increasing the risk of ice forming relative to monolithic membrane.

Measurement uncertainties when dealing with highly diffusion-open materials

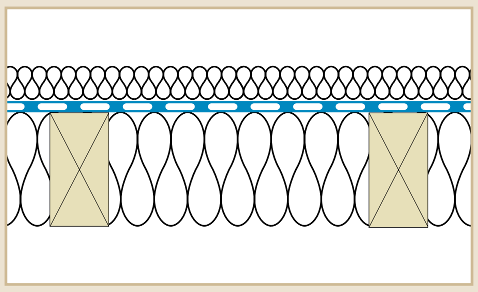
Section 9 of the standard that is decisive for determining the diffusion resistance, DIN EN ISO 12572 [8], Measurement accuracy" contains a list of potential sources of error. In addition to the quality of the test specimens and the accuracy of the measuring equipment, this also lists the environmental

Comparison of four structures

Case 1:
35 mm of natural wood fibre softboard used as external insulation

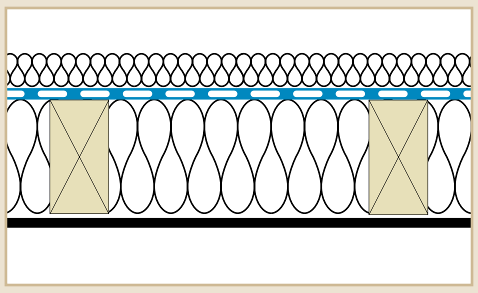
Structure with external airtightness layer.

Fig. 5
1a: Without an airtight layer on the inside



- Natural wood fibre 35 mm
- Diffusion-open airtightness layer (vapour resistance = 0.1 MNs/g)
- Fibrous, non-absorbent insulation material 120 mm
- Without interior lining

Fig. 6
1b: With an airtight layer on the inside



- Natural wood fibre 35 mm
- Diffusion-open airtightness layer (vapour resistance = 0.1 MNs/g)
- Fibrous, non-absorbent insulation material 120 mm
- With plasterboard 10 mm

temperature required for germination. The temperature is subject to fluctuation between day and night, which can result in the conditions only being suitable for mould to grow at certain times of day. [3] states that, according to Zöld, there is a risk of mould growth at temperatures of under 20 °C if the rel. humidity in the structure is over 75% for more than 12 hours over a 5 day period.
The criterion for a structure at risk of mould growth can be defined as follows:

1. Daily mean temperature over 0 °C

2. Daily mean rel. humidity permanently over 90%

3. The temperature and rel. humidity need to be within this range for a prolonged period of time.

Structures studied

In the first part of this study, we will investigate the following structures on the basis of the criteria formulated above to assess the likelihood of mould growth. This is performed using WUFI pro [5] developed by the Fraunhofer Institute using the climatic data for Holzkirchen to compare the following structures:

1. 40° pitched roof facing north, grey clay roof tiles

2. Height of existing rafters: 12 cm with full rafter insulation made of fibrous insulation material
   – Absorbent insulation material (e.g. natural wood fibre or cellulose fibre)
   – Non-absorbent insulation material (e.g. mineral wool) (gross density = 60 kg/m³)

Absorbent insulation materials provide added protection as they can act as a buffer for moisture peaks at the boundary layers of the building element. This is achieved, for example in natural wood fibre or cellulose fibre, by the moisture being taken up by the cells of the wood on the material.

The indoor climate is defined as having a normal moisture load in keeping with the assumptions made in the WTA information leaflet 6-2-01/D [9] (included in WUFI), as is typical of rooms in residential buildings (bedrooms and living rooms, bathrooms and kitchens).
The structures specified are calculated with plasterboard (10 mm thick), in order to estimate the effect of the airtightness of the interior lining (e.g. gypsum plasterboard), covering the entire surface, and without plasterboard, so as to take the effect of a timber lined interior lining of interior lining that is not very airtight into account.

Cases 1, 2 and 4 below are considered with non-absorbent insulation material (mineral fibre). In case 3, absorbent insulation material was used (cellulose fibre).

Case 1:
35 mm of natural wood fibre softboard (Fig. 5 + 6)

Insulation over the rafters using 35 mm of natural wood fibre insulation, with a diffusion-open airtightness membrane under it on the outside (vapour resistance = 0.1 MNs/g).
Insulation between the rafters is a non-absorbent insulation material.

(Contrary to the recommendations given in DIN EN ISO 12572 or DIN 4108-3, the calculation is performed using an vapour resistance value of 0.1 MNs/g (rather than 0.1 MNs/g, as specified in the standard).

Case 2:
50-50 solution (Fig. 7)

The airtightness layer is between two layers of insulation of equal thickness: 50% of the thermal insulation before the airtightness layer – 50% of the thermal insulation on the rafters, with both layers having the same coefficient of thermal conductivity λ.
Insulation over the rafters using 120 mm of natural wood fibre insulation, with diffusion-open airtightness membrane under it in the middle (vapour resistance = 0.1 MNs/g).
Insulation between the rafters using non-absorbent insulation material.

(Contrary to the recommendations given in DIN EN ISO 12572 or DIN 4108-3, the calculation is performed using an vapour resistance value of 0.1 MNs/g).

Case 3:
30-70 solution (Fig. 8)

Insulation over the rafters using 60 mm of natural wood fibre insulation, with diffusion-open airtightness membrane under it (vapour resistance = 0.1 MNs/g). Insulation between the rafters using absorbent insulation material (e.g. natural wood fibre or cellulose fibre) 120 mm thick.

Case 4:
Sub-and-top solution (Fig. 9)

The airtightness layer is laid in loops (sub-and-top) over the interior lining and over the supporting structure.
Insulation over the rafters using 35 mm of natural wood fibre insulation, with

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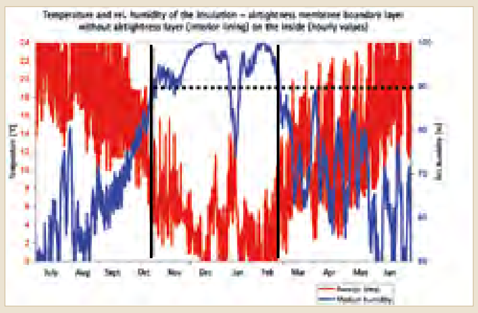
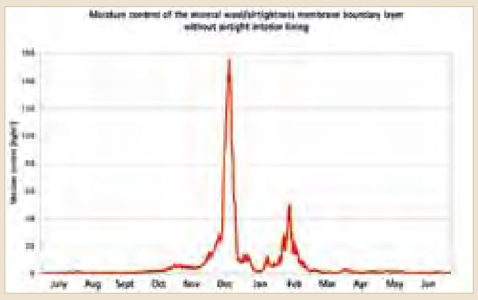
Fig. 10 + 11

Results for case 1a: 35 mm of NWF: Airtightness layer on the outside, interior lining with gaps



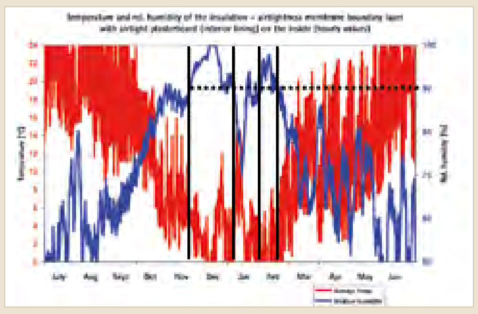
Moisture content > 90% on 157 days, condensation on 15 days
=> mould very likely



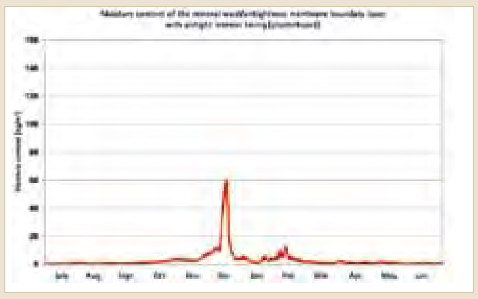
Max. moisture content at the boundary layer elevated for several months - over 150 kg/m³

Fig. 12 + 13

Results for case 1b: 35 mm of NWF: Airtightness layer on the outside, interior lining airtight



Moisture content > 90% on 84 days, condensation on 6 days
=> high risk of mould

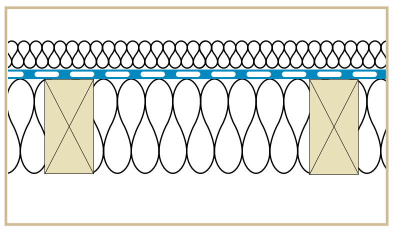


Max. moisture content at the boundary layer elevated for over 1 month – up to 60 kg/m³

Calculations:

35 mm of natural wood fibre used as outer roof insulation. Without an airtight layer (e.g. plasterboard) on the inside (case 1a)

Structure with external airtightness layer.



- Natural wood fibre 35 mm
- Diffusion-open airtightness layer (vapour resistance = 0.1 MNs/g)
- Fibrous, non-absorbent insulation material 120 mm

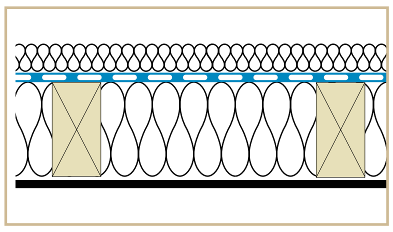
This case simulates structures with damaged plasterboard, plastered surfaces and wooden cladding.

According to the calculations shown in Fig. 10 + 11, such structures have a very high rel. humidity, significantly over 90% and even as high as to cause condensation, at the boundary layer between the thermal insulation and the external airtightness layer. The rel. humidity at the boundary layer exceeds 90% for 157 days of the year, with condensation forming for 15 days. There is a very high risk of mould growth, as the high rel. humidity occurs when the temperature is well above 0 °C. The water content in the boundary layer exceeds 150 kg/m³.

There is a risk of structural damage to such structures with damaged, leaky airtightness layers.

35 mm of natural wood fibre used as outer roof insulation. With completely airtight layer (e.g. plasterboard) on the inside (case 1b)

Structure with external airtightness layer.



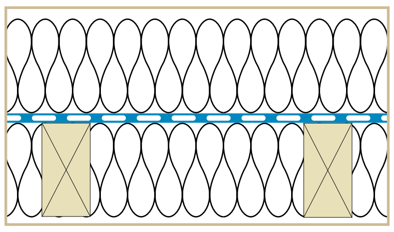
- Natural wood fibre 35 mm
- Diffusion-open airtightness layer (vapour resistance = 0.1 MNs/g)
- Fibrous, non-absorbent insulation material 120 mm
- Plasterboard (airtight) 10 mm

If the existing structure has an interior lining covering the entire surface made from plasterboard, this is considered to be airtight in the calculation, with moisture penetrating the structure only by diffusion.

As is shown in Fig. 12 this structure is found to have very high rel. humidity levels, exceeding 90% on 84 days of the year, with condensation forming on 6 days. The thermal insulation is briefly exposed to up to 60 kg/m³ of moisture at the boundary layer to the airtightness membrane (Fig. 13). In spite of the fully functional airtight interior lining, there is an increased risk of mould at the boundary between the insulation and the airtightness membrane in this case.

50-50 solution. Without an airtight layer (e.g. plasterboard) on the inside (case 2)

Structure with central airtightness layer.



- Natural wood fibre 120 mm
- Diffusion-open airtightness layer (vapour resistance = 0.1 MNs/g)
- Fibrous, non-absorbent insulation material 120 mm

If 50% of the thermal insulation (of the total thermal resistance) is located before the airtightness layer, the rel. humidity is only over 90% for one week in the winter period (see Fig. 14) without any condensation forming. There is no significant collection of moisture at the boundary layer (see Fig. 15). If there is an intact interior lining, the rel. humidity at the boundary layer between the thermal insulation and the airtightness membrane is below 90% throughout the year. Mould is thus unable to grow [3], even if there are defects in the inner airtightness layer (interior lining).

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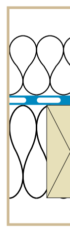

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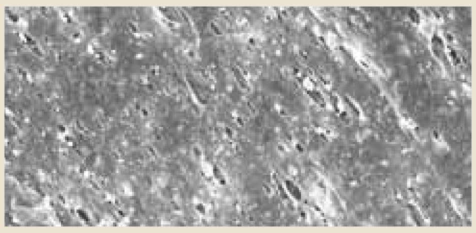
Fig. 18

Microscopic view of the monolithic non-porous TEEE film in the SOLITEX UD

Active moisture transport along the molecular chains increases the drying capacity.

Fig. 19

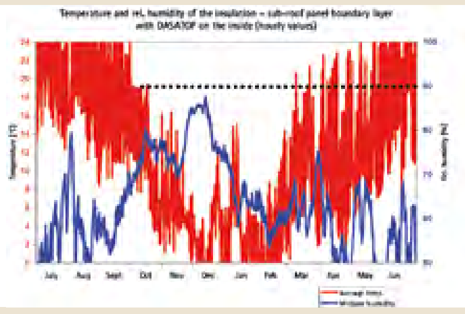
Enlarged view of a microporous functional film



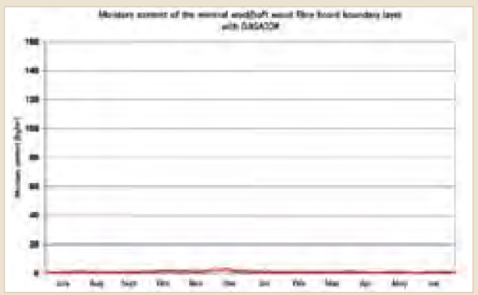
Passive moisture transport through pores (gas exchange) increases the risk of ice forming in the building element.

Fig. 20 + 21

Results for case 4: Sub-and-top solution Airtightness layer on the inside, interior lining with gaps



Humidity never > 90%, no condensation
=> mould very unlikely



Non-critical moisture content in the boundary layer

Airtightness membrane with monolithic functional film

If the airtightness layer is laid over the rafters, as is the case in cases 2 (50-50 solution) and 3 (30-70 solution), a diffusion-open airtightness membrane with a humidity variable and monolithic functional film such as pro clima SOLITEX UD or Solitex PLUS should be used. This has a suitable TEEE film and has the following advantages:

– Airtightness
The monolithic functional film in SOLITEX UD guarantees 100% airtightness. In contrast to conventional airtightness membrane with a microporous film (Fig. 18), SOLITEX UD is completely non-porous (Fig. 19).

– Diffusion openness
The monolithic TEEE film permits active moisture transport through the material of the membrane. If there is condensation on the inside in the form of water droplets on the SOLITEX UD, this is actively transported out along the molecular chains. This significantly reduces the risk of ice forming (= vapour barrier) on the airtightness membrane, relative to a membrane with microporous functional film.

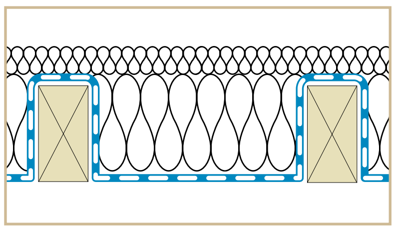
– Moisture variability
The TEEE film in SOLITEX UD is humidity variable. This means that the diffusion resistance falls to an vapour resistance value of under 0.1 MNs/g if condensation forms, providing ideal protection against the typical rise in diffusion resistance, for example, due to the pores closing due to water.

If the airtightness layer is laid over the rafters, SOLITEX UD offers the best performance with either the 50/50 or the 30/70 solution in comparison to microporous airtightness membranes.

Further information regarding the differences between monolithic and microporous membranes is available on request.

Sub-and-top solution. Without an airtight layer (e.g. plasterboard) on the inside (case 4)

Structures with the airtightness layer on the inside without interior lining



– Natural wood fibre 35 mm
– Airtightness layer laid sub-and-top
(vapour resistance = humidity variable 0.25 - 10.0 MNs/g).
– Fibrous insulating material 120 mm

The sub-and-top method of laying DASATOP refurbishment vapour check ensures reliable airtightness and protects every layer of the thermal insulation from elevated moisture levels that could cause structural damage due to its humidity variable vapour resistance value.
DASATOP can be combined with any fibrous insulation material.
No airtightness membrane above the insulation between the rafters is required. Due to the use of DASATOP, the moisture level in the thermal insulation immediately under the soft wood fibre board is too low to pose any risk of damage. The peak moisture level of 85% only occurs very briefly at temperatures around 0 °C (see Fig. 20). The moisture content is never high enough to damage the material (see Fig. 21). Under these conditions mould can neither germinate nor grow on the materials used.
Structures with DASATOP laid and stuck down to form an airtight layer are not at risk of mould damage and thus provide maximum protection for all fibrous insulation materials as well as for the structure.

Conclusion, comparison of an airtightness layer outside vs. airtightness layer and vapour check on the inside

Calculations using non-stationary simulation methods under real environmental conditions permit a realistic representation of the actual processes occurring within the structure. They can portray the risks of condensation forming and allow conclusions to be drawn about the structure's potential freedom from structural damage. If structures with external airproofing without sufficient insulation over the rafters are considered, the results indicate rel. humidity levels exceeding 90% and large amounts of condensation forming on the boundary layers between the thermal insulation and the airtightness layer. The result of this is that structures, such as that shown in case 1 are subject to a high risk of mould in the structure.

If there is no interior lining covering the entire surface without gaps there is a risk of large quantities of condensation forming within the structure. There may be air currents within the inner layer of insulation in the vicinity of partitions, for example if there are leaks in the gable masonry, allowing large amounts of condensation to form in locally cool areas, once again increasing the risk of mould.

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10 factors that provide lasting struc

1. Structures with vapour check and airtightness layers that adhere to the 1/3 to 2/3 rule (1/3 inside, 2/3 outside, see "The golden rule" on page 4) are considered to have the best possible protection.
2. The further the airtightness layer is towards the inside, the better protected the structures are. The further out the airtightness layer is, the higher the risk of problems within the structure, reducing the structure's potential freedom from structural damage.
3. An interior lining covering the entire surface without any gaps prevents moisture transport due to convection when the airtightness membrane is laid on the outside.
4. Sub-and-top solutions using DASATOP give the highest potential freedom from structural damage with any fibrous insulation material, as they

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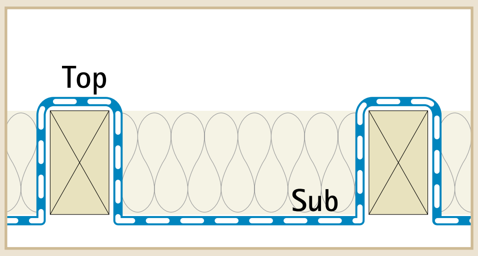
B. Sub-and-top comparison of the potential freedom from structural damage when using vapour checks with different vapour resistance values

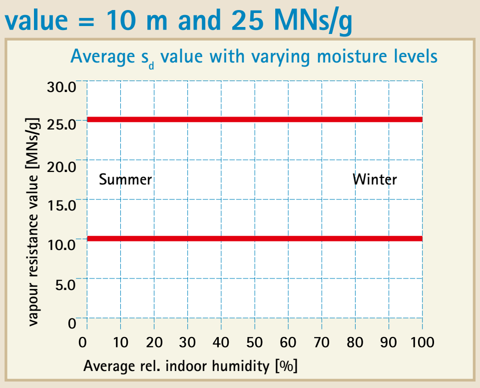
Especially good protection when carrying out renovation work with humidity variable sub-and-top membrane

Fig. 22
The sub-and-top principle



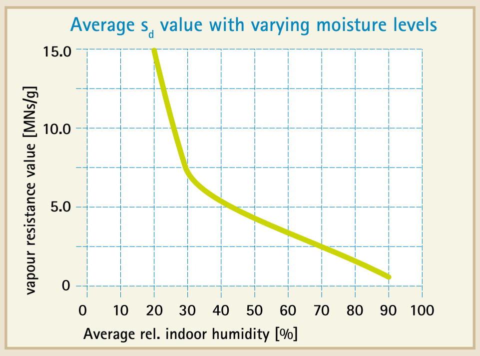
Higher diffusion resistance in the compartments (sub): Protection against moisture.
Very diffusion-open on the rafters (top): Can dry out rapidly.

Fig. 23
Membrane vapour resistance value = 10 m and 25 MNs/g



In the dry zone:
vapour resistance value = 10 or 25 MNs/g: Equivalent to a vapour check
In the damp zone:
vapour resistance value = 10 or 25 MNs/g: Equivalent to a vapour check

Fig. 24
vapour resistance value of DASATOP = 1.25-10 MNs/g



In the dry zone:
vapour resistance value = 10 MNs/g Equivalent to a vapour check
In the damp zone:
vapour resistance value = 0.25 MNs/g Equivalent to a roof lining membrane

In the first part of this study we differentiate between various systems that can be used to repair or renovate roofs from the outside. This is done by comparing diffusion-open membranes used to achieve airtightness with system solutions that are also slightly diffusion-resistant.

In the explanation below, pure sub-and-top solutions are considered. These may be laid either under the thermal insulation or over the structure's supporting structure.

We differentiate between two basic options:

1. Systems consisting of a vapour check and airtightness membrane with a humidity variable diffusion resistance

These have a variable diffusion resistance that depends on the average ambient rel. humidity. The vapour resistance value of DASATOP roof refurbishment vapour check can vary between 0.25 and 10 MNs/g (see Fig. 24), depending on the average rel. humidity in the immediate vicinity of the membrane. For information on how the moisture variability works, please refer to the study "Berechnung des Bauschadensfreiheitspotentials von Wärmedämmkonstruktionen im Holz- und Stahlbau" (Calculations of the potential for freedom from structural damage of thermal insulation in timber and steel structures) [10].

2. Systems consisting of vapour check and airtightness membrane with a constant diffusion resistance

This membrane concept uses a specialist film which has a diffusion resistance which does not change with varying rel. humidity. For example, Fig. 23 shows the diffusion resistance of two membranes with a vapour resistance value of 10 MNs/g and 25 MNs/g.

Comparative analysis of drying reserves

If a membrane is laid using the sub-and-top method, it is obvious that this should have the lowest possible diffusion resistance above the supporting structure. vapour resistance values below 0.5 MNs/g are ideal to permit a large amount of moisture to dry out of t he rafters due to the high diffusion-openness. Vapour checks for insulation between the rafters reach vapour resistance values of approx. 1.25 MNs/g at high humidity levels, providing lower potential freedom from structural damage compared to DASATOP.

If the diffusion current through a material in accordance with DIN 4108-3 [2] is recorded in a stationary state by calculating the water vapour diffusion current density g [kg/m² x h], the performance of membranes of differing diffusion resistance becomes apparent.

The water vapour diffusion current density is determined by way of the difference between the water vapour partial pressure p_i (inside) [Pa] and p_o (outside) [Pa] divided by the water vapour permeability resistance Z [m² x h x Pa/kg]. Multiplying this by 24 gives the water vapour permeability (W_{DD}) [g/m² x 24 h].

For example, the diffusion current upon reaching the dew point combined with wintery outdoor temperatures is calculated. The calculation is performed taking a value of 1,163 Pa (9.2 °C/100% rel. humidity (dew point in a standard environment)) for p_i and a value of 208 Pa (-10 °C/80% rel. humidity) for p_o.

W_{DD} values for various vapour resistance values

vapour resistance value [MNs/g]	W_{DD} [g/m² x 24 h]
0.25	~ 320
0.50	~ 160
2.50	~ 32
10.0	~ 8
5.0	~ 3
50.0	~ 0,3

The water vapour permeability is significantly reduced even by a slight increase in the vapour resistance value. This affects the safety of a structure.

This approach cannot be directly applied to non-stationary calculations, since p_i and p_o change constantly due to the real environmental data used in the calculation and depending on the position in the structure. For the drying situation, for example, the values are lower due to the lower pressure differences on each side of the membrane.

Calculation of the potential freedom from structural damage

For the calculation of structures with membranes laid using the sub-and-top method, the consideration of the dehumidification capacity of the supporting structure (in this case, rafters) is decisive. For membrane that are not in close contact with the rafters there is a risk of condensation forming above the rafters in the colder months. This needs to be able to dry out through the material of the membrane. This means that it is necessary to consider the heat and moisture currents in two dimensions. Heat and moisture currents do not only flow from the inside of the building to the outside. Diffusion currents can also occur within the structure, for example, from the sides of the rafters through suitable vapour check and airtightness membrane into the thermal insulation layer.

In order to represent the dehumidification capacity, the additional moisture is introduced via the wood moisture content of the rafters. This is taken into consideration in the calculation by assuming a material moisture content of 80 % (= 2,300 g of water per metre of rafter) and simulates moisture precipitation between the vapour check and airtightness membrane and the rafters. By analysing and calculating the drying capacity it is possible to calculate the potential freedom from structural damage in [g] H_2O/[m] rafter per annum. Normally the rafters have a moisture content of approx. 300 g per metre.

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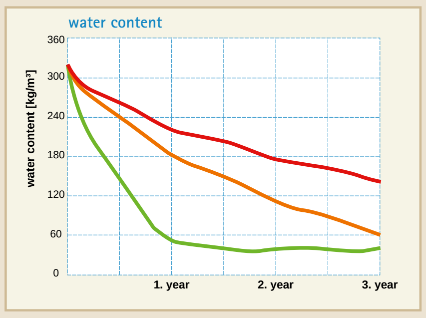
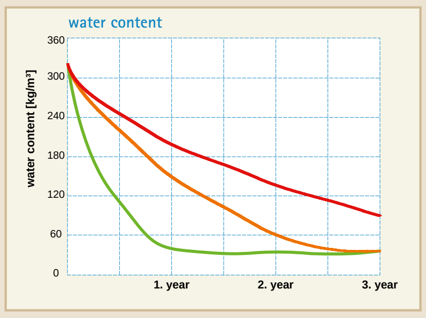
Calculation of the potential freedom from structural damage
Location: Dublin, roof

Fig. 25
Results for a diffusion-open underlay (vapour resistance = 0.5 MNs/g)



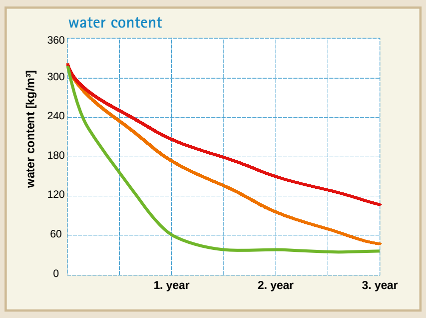
Potential freedom from structural damage: DASATOP 1,900 g/m
vapour resistance 2 m: Too low
vapour resistance 5 m: Too low

Fig. 26
Results for 60 mm Soft wood fibre board, outside (vapour resistance = 1.5 MNs/g)



Potential freedom from structural damage: DASATOP 2,100 g/m
vapour resistance 2 m: Too low
vapour resistance 5 m: Too low

Fig. 27
Results with 35 mm of polyurethane outside (vapour resistance = 17.5 MNs/g)



Potential freedom from structural damage: DASATOP 1,800 g/m
vapour resistance 2: Too low
vapour resistance 5: Too low

Structures studied

1. 40° pitched roof facing north, grey clay roof tiles

2. Rafter thickness 12 cm with full rafter insulation made from mineral wool (density = 60 kg/m³)

The indoor climate is defined as having a normal moisture load.

Case 1: Diffusion-open sub-roof
(Fig. 25)

The sub-roof in the calculation has an vapour resistance value of 0.5 MNs/g.

Case 2: Sub-roof panel made of 60 mm of natural wood fibre
(Fig. 26)

This is included as additional insulation above the rafters to prevent thermal bridges (vapour resistance value = 1.5 MNs/g).

Case 3: Sub-roof panel made of 35 mm of polyurethane
(Fig. 27)

Insulation above the rafters as in case 2, but with an vapour resistance value of 17.5 MNs/g.

each of the 3 cases is considered using 3 different vapour checks, laid using the sub-and-top method:

- DASATOP vapour check humidity variable = 0.25 to 10 MNs/g
- Vapour check, vapour resistance value = 10 MNs/g
- Vapour check, vapour resistance value = 25 MNs/g

Discussion of the results

The drying capacity of the elevated moisture contained in the rafters was investigated. This is shown comparatively for a 3-year period for each of the cases using the various vapour check membranes.

It is evident in all of the structures that the moisture held in the material of the rafters is able to escape fastest where the DASATOP is used.
Non-critical moisture levels in the rafters are reached when the level falls below the fibre saturation point of the timber. If this is used as a criterion for comparison of the drying speed, the rafters in the structure in which DASATOP is used dry out about three times as fast when compared to the same construction with a vapour check with a constant vapour resistance of 10 MNs/g. In comparison to a vapour check with an constant vapour resistance value of 25 MNs/g, DASATOP allows the moisture to dry out five times as fast from structures with external roof insulation. In structures which only use diffusion-open roof lining membranes, DASATOP even allows the moisture to dry out eight times faster, when compared to the same constructions which untilise a vapour check with a constant vapour resistance of 25 MNs/g.

Conclusion, comparison of sub-and-top-laid vapour check and airtightness systems

A humidity variable vapour check and airtightness membrane laid using the sub-and-top method is the best solution from a building physics point of view to ensure that the structure is adequately protected and offers the highest possible level of freedom from structural damage in the event of unforeseen moisture load.

Non-critical timber moisture levels are reached three or five times faster (and in some cases even eight times as fast) if DASATOP is used in the rafters, in comparison to a membrane with an vapour resistance value of 10 MNs/g or 25 MNs/g.

If laid using the sub-and-top method the membrane acts as a vapour check under the thermal insulation (sub). If laid over the rafters (top), on the other hand, the membrane may function as a more diffusion open roofing underlay which is beneficial as any moisture can dry out as quickly as possible. In that case, any moisture that accumulates on the sides of the rafters because the membrane is not in complete contact with the rafters can dry out again quickly. Humidity-variable vapour checks for insulation

between the rafters reach vapour resistance values of approx. 1.25 MNs/g at high humidity levels, providing lower potential freedom from structural damage than DASATOP.

The humidity variable diffusion resistance allows the membrane to be laid safely in all details, e.g. in trimmings, grooves and ridges or disjointed constructions. The diffusion resistance can assume an vapour resistance value of between 0.25 and 10 MNs/g anywhere on the membrane, to suit the localised situation depending on the environment. The sheets of membrane can be laid lengthwise or widthwise.

It was found that it is beneficial to install a diffusion-open membrane on the outside or to install a layer of diffusion-open external roof insulation made from fibrous insulation material.

If a membrane with a constant vapour resistance is installed using the sub-and-top method, the potential freedom from structural damage is reduced considerably. In the winter the membrane protects the thermal insulation in the sub zone from moisture penetration, acting in a similar manner to a humidity variable membrane. In the summer, however, it does not allow any additional drying out from the structure. If any condensation collects on the top of the rafters it is only able to dry out very slowly, drastically increasing the risk of structural damage.

In principle, thermal insulation structures should have the highest possible safety reserves to provide added protection against structural damage and mould in the event of unforeseen moisture stress. This also gives the installer the best possible protection from damage or liability claims. The sub-and-top method for laying vapour checks and airtightness membranes with the lowest possible vapour resistance value at high rel. humidity levels provides the best possible protection when performing roof repairs or renovation work from the outside, from a building physics point of view.

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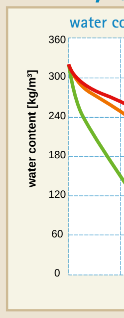

Potential freedom

Fig. 29
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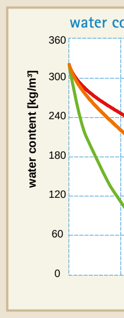

Potential freedom

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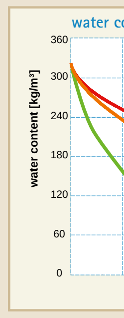

Potential freedom

The pro clima safety formula:

The higher the safety reserves in a structure, i.e. the higher the potential freedom from structural damage, the better the protection against mould in the event of unforeseen moisture stress.

Building objectives

The objective of building is not only to build energy-efficient buildings with a comfortable living environment, but in particular to build buildings with a healthy living environment. It is not only toxicological aspects that play a role in this, such as emissions from building materials, but, first and foremost, the prevention of mould both on and in the structure. Mould spores damage the immune system and promote/cause allergies and the microbial volatile organic compound (MVOCs) produced by mould can cause physical and psychological health problems. If mould is in a dry environment it presents a much lower risk to health. If the mould becomes damp again, however, the hazards are just as great as they were before.

If mould grows on an inner surface inside a building (e.g. due to thermal bridges or surface condensation) it is visible and can be removed as necessary. If mould grows within a structure, however, it can go unnoticed and be reactivated by damp each year – posing a permanent health hazard to the occupants.

The objective when building should be to achieve the highest possible levels of safety, rather than to exploit the physical safety of the structure as much as possible, in particular in terms of the risk of mould.

8 factors that provide lasting structural protection and safe processing

1. Structures with humidity variable vapour checks and airtightness membranes with a very low diffusion resistance at humidity levels of < 0.5 MNs/g are considered to have the best possible protection.
2. Sub-and-top membranes with a very low diffusion resistance in the event of moisture precipitation can be fitted over the rafters in the frost zone. The risk of ice forming is almost eliminated due to the high drying capacity and the diffusion characteristics of the structure.
3. Non-critical rafter moisture levels are achieved between three and five (and in some cases eight) times as fast using DASATOP, guaranteeing increased protection against mould.
4. The thermal insulation is protected against excessive moisture generated within the living space due to occupancy behaviour, as it is installed continuously on the warm side of the insulation layer, and as it has a vapour resistance of up to 10.2MNs/g.
5. Externally diffusion-open materials (e.g. woodfibre softboards) have higher drying reserves than structures with diffusion-resistant layers (e.g. foam insulation).
6. We recommend always performing a quality assurance assessment of the quality of the workmanship. If repair or renovation work is being carried out from outside, the airtightness be assessed by employing a pressurisation test using artificial fog, which allows leaks to be found and sealed.
7. The membrane should be fastened to the sub-and-top layer using thin battens. It may also be bonded using airtight joint adhesive. Adhesive tape does not stick to the dusty surface on old rafters.
8. The use of dark, anti-glare membranes is preferable to bright and, in particular, white membranes, due to an increased risk of accidents as well as to protect the installers eyes during the installation.

References

[1] E-DIN 4108-7: "Wärmeschutz und Energieeinsparung in Gebäuden – Teil 7: Luftdichtheit von Gebäuden, Anforderungen, Planungs- und Ausführungsempfehlungen sowie -beispiele" (Thermal Protection and Energy Economy in Buildings – Part 7: Airtightness of Buildings, Requirements, Planning and Execution Recommendations and Examples), Beuth, Berlin, 01/2009

[2] DIN 4108-3: "Wärmeschutz und Energieeinsparung in Gebäuden – Teil 3: Klimabedingter Feuchteschutz, Anforderungen, Berechnungsverfahren und Hinweise für Planung und Ausführung" (Thermal Protection and Energy Economy in Buildings – Part 3: Climate-related moisture protection; Requirements, Calculation Methods and Tips for Planning and Execution), Beuth, Berlin, 07/2001

[3] Tagung Schimmelpilze im Wohnbereich: „Schimmelpilz aus bauphysikalischer Sicht - Beurteilung durch aw-Werte oder Isoplethensysteme?" (Conference on mould in residential buildings "Mould from a building physics point of view - evaluation on the basis of aw values or isoplethene systems?"), Klaus Sedlbauer, Martin Krus, Fraunhofer IBP, Holzkirchen, 26.06.2002

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