Translated by Floris Keverling Buisman,
475 High Performance Building Supply – www.foursevenfive.com

Die neue Quadriga
Das Fachmagazin für den holzbau

The new Quadriga – the trade magazine for wood frame construction

Special edition May 200

Ventilated or not?

Protection against condensation in wooden flatroofs

Author: Robert Borsch-Laaks.
Building scientist. Aachen.

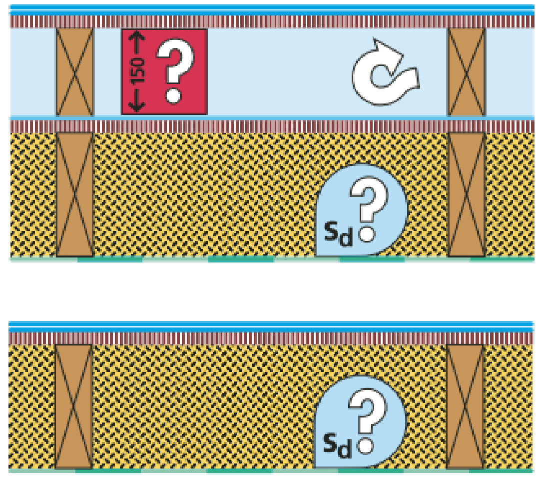

Figure 1 – Subject of this article:
Insulation is used inside the structure – off course.
Do you vent this assembly or not....hmm?-... and which kind of vapor retarder is recommended in each case?

One of the most common questions asked at the technical helpline of the building scientist is: "We have a flat roof covered by a vapor closed waterproofing layer. Should we use a vapor barrier on the interior with an Sd-value of 100m (*perm 0.03)*; or is it better to vent the roof to the exterior; or should we do both?"
Most building professionals would probably use their "gut feeling" that it would be best to ventilate under the waterproof roofing layer. By others it is stuck into their heads to follow standard practices and use vapor barrier on the interior.
But if you take the time to read the small print in the technical rulings/standards and recent publications from the building science researchers, you may have already found out that ventilated (*flat roof)* construction in many cases have been "not performing as intended". In most cases a "moisture-variable vapor retarder" is recommended. The question is, what is the correct approach based on the current building science?

Clarifying confusion terms

In the standard for "Condensation protection" (DIN 4108-3), pitched ventilated roofs have to conform to the following requirements: "Directly above the heat-insulation there should be a ventilated cavity ... Included in this classification is roof insulation that doesn't have air directly above it, but which is used in roofs that have a vented cavity structure build over the roof-underlayment or vapor open board" (paragraph 4.3.3.1).
For modern wood-construction industry this distinction is "old news", since it is common practice to insulate the entire structural cavity and then cover the insulation with a vapor open underlayment or board.
Non-the-less, it took more than 10 years to get the results of the ground breaking results of the experimental assemblies at the Fraunhofer Institute for Building Physics (IBP)[1] incorporated into the new DIN 4108 standard at the beginning of 2001. In that document, pitched roof insulation of a construction (per table 1 of the standard) with a ventilated cavity above this layer, are now also regarded as "proven safe assemblies" (see *2/2004,* p 53), ie a condensation calculation that uses the "Glaser method" is no longer required.

---

1) [Künzel/Großkinsky 1989] and [Künzel/Großkinsky 1992].
Always worth reading again and particularly suitable to convince architects and engineers, which might still specify ventilation between insulation and roofdeck. It is also the important book of reference for building scientists.{Künzel, H. 1996]

Ventilation "on top": not part of the standard, but usefull?

None-the-less, the question remains: do flat roofs with vapor closed roofing membranes benefit from ventilation of the cavity between the deck and the roofing? The standard doesn't provide a real answer, since the regulations for "non ventilated roofs with roof membranes (paragraph 4.3.3.2. b) and "vented roofs with a pitch < 5 degrees (pitch *1:12*) (paragraph 4.3.3.3) are identical. In both cases a vapor retarder with an Sd-value of 100m (*perm 0,03)* is required to avoid the need for a *(hygrothermal)* calculation of suitability. Apparently the writers of the standard, do not really trust that the ventilation of the cavity will be able remove any humidity *(red:"otherwise they could have prescribed a less impermeable vapor retarder, ie Sd around 2.3m, 1.4perms")*.
However the roofer's trade regulations (in the memorandum "subroofs, underlayments, and roof membranes) from 1997 provides a clue:
"the additional requirement for the space between (sub roof) and the roof membrane are that the eaves and ridges should have supply and exhaust openings. The requirements for ventilation openings of DIN 4108-3 for ventilated (pitched) roofs are not valid for these kinds of (flat) roofs, however in practice they have proven themselves useful and are recommended (ZVDH 2003 (*roofer's trade regulations)*)

> Infobox 1
> **From the ZVDH 2003: memorandum insulation of roofs. Paragraph 3.2.1**
>
> "Roof structures that are flat, will only have air currents in vented cavities if there are forced pressure differences cause by either wind (pressure and depressurization) or by temperature differences within the ventilated cavity….In practice these don't occur, when the roof is in a shielded (from wind) location or is surrounded by higher buildings….
> The functionality of the ventilation openings can also be compromised by snow accumulation for short periods of time.
>
> Ventilation of flat roofs is further negatively impacted by:
> - Roof bulkheads
> - Compartmentalized roof structures
> - Interrupted roof ventilation cavities
> - Unfavorable roof forms, etc.
>
> In these cases, unvented roofs are from a building science perspective more predictable.
>
> **From the standard DIN 4108-2001, paragraph 4.3.3.3:**
> "note 2: Valleys prevent the creation of ventilation openings. Such roof structures, including ones with dormers – are recommended to be constructed as unvented assemblies."

> Info box 2
> **Ventilation guidelines for flat roof ZDVH:**
> **"**Minimum section of roofs < 1.25:12 pitch
> Ventilated length up to 30ft:
> - ventilation cavity >2"high
> - eave openings >2% of vented area and located on opposite sides of vented cavity.
> - Vapor retarder interior: Perm <0.3"
>
> Note:The guidelines below are from the old standard DIN 4108:1982. The new standard doesn't include these any more! The ZVDH has these additional construction recommendations:
> - The intake/exhaust of vented cavities should also be guaranteed at skylights, openings and dormers.
> - The ventilation openings shall not be closed off, not even with vapor open membranes
> - If the vented cavity is more than 30' long, then special measures have to be implemented
> - In particular, flat roofs need a vented cavity of minimum 15cm (6") high.

When does ventilation work, when doesn't it?

In the regulation "heat insulation of roofs" the ZVDH defines a whole host of limitations, that are targeted at flat roofs in which functionality of ventilated cavities is questionable (see info box 1). The defining shortcoming is the most important factor that assures sufficient ventilation flow: the height difference within a cavity, which is the driver of thermal buoyancy.
Whether the illustrated recommendation of extremely large ventilation sections (more than 15 cm high *(6")*, see info box 2**)** is really practical is doubtful. At least these extensive regulations are no longer included in the new DIN 4108-3 standard.

"Ventilation philosophy": why so reluctant?

The building science "gut" or "brain" of the attentive reader might question why the regulations of ventilation of flat roofs in professional publications are getting increasingly indecisive? To gain insight why this is occurring we need to take a few steps back in the development surrounding this subject. The well known basis of the DIN 4108:1981 was the lab research of Prof. Liersch from the TU Berlin at the end of the 70's. In the mean time it has been forgotten that the ventilation regulations were based solely on exhausting the humidity that was the result of vapor diffusion. The quote from Prof. Liersch's presentation at the building science conference in Aachen in 1993 (see info box 3), shows how narrow the margins of safety are for this kind of ventilation to be effective.
i.e. the distinctive risk for condensation issues is caused by airflows (humidity convection) and ventilation does not provide a solution for that. For instance I have published an article [condetti & Co in 2003], page 98f, that shows this. And presently there is a well filled collection of construction damages that have been documented that prove this issue as well (see, eg, [Dahmen 1993] and [Colling 2000]).

> Info box 3
> **A quote from "inventor" of the ventilation rules, Prof. Dr. K.W. Liersch:**
> "It must be noted, that the ventilated cavity is not able – even when the ventilation is working well – to exhaust the amount of humidity that is transported into the insulation layer by convection (air leaks). When one compares the amount of humidity introduced by diffusion, it becomes clear that even relatively airtight construction, that more than 10x the amount of humidity is introduces by these air leaks….the vented cavity is in general not able to expel these quantities of humidity, which exemplify the necasssity that the flat roof assemblies should be as airtight as possible (Liersch 2003)

Back to the start: diffusion balance in flat roofs

The rule that messes most with the "gut" or the "head" of building scientists is, that "proven save assemblies" (*ie without calculations*) require the previously mentioned vapor barrier with a minimum Sd-value 100 *(max perm 0.03)*. This is often confused with a straight out mandate. A correct interpretation would be: that if the regulation is not followed that a diffusion calculation is required.
When one does such a calculation, the results are quite different than this standard suggests. To limit of humidity buildup (WT) below the maximum allowable level of 500g/m2, not a Sd of 100m (perm0.03) is required for the vapor retarder, but just one of 2m *(perm 1.6)*! The advantage of a vapor retarder with such permeability, is the obvious larger potential for inward diffusion of this construction. Image 2 shows that with an Sd of 2m *(perm 1.6)* in the standard backward diffusion period *(summer)* 836 g/m2 will "dry" out thought such a retarder. When one deducts the winter humidity build up (371 g/m2) that occurs though this membrane, then the backward drying reserve of the assembly is almost 500 g/m2.
In contrast to this, a roof assembly with an Sd 100m *(perm 0.03)* retarder, will gain just 9g/m2 of humidity in winter, but also the backward drying reserve shrinks to a paltry 17g/m2. The conventional building science rule "inside tighter than outside", for a vapor closed flat roofs needs to be changed into:
If the exterior is vapor closed, than the inside should be as vapor retarding as possible (to restrict the humidity diffusion below acceptable level) and as diffusion open as possible (to facilitate the largest possible inward drying reserve to accommodate all 'unanticipated humidity buildup' cause by convection *(airleaks)*, construction humidity etc.)

> Image 2
> **Diffusion equilibrium of a flat roof with vapor closed exterior. Perm 0.01 and 8" of insulation. Calculated per DIN 4108-3**
>
> (WV) inward drying potential
> (WT) Humidity ingress
> (WV-WT) drying reserve)
>
> Sd value (perm rating) of vapor retarder

Diffusion calculations for experts: asses you inward drying potential.
Research of wood framed construction in North America can now quantify the amount of humidity ingress caused by airleaks/convection, even with high quality airtight construction, see [Künzel, HM 1999]. Converted to German conditions, this results in an additional humidity ingress through airleaks/convection of 250g/m2. Which *(Fraunhofer)* IBP uses to determine the following recommendations:

"It is prudent, to define the relationship between the amounts of humidity/moisture that enters as vapor and diffuse backward, at least in wood frame construction."

When used in the calculated example in Figure 2 this means that the
Vapor retarder on the inside shouldn't have an Sd >4m *(perm<0.8)*
Otherwise, there will not be sufficient inward drying potential (*in summer)* to dry out the humidity ingress caused by airleaks/convection *(in winter).*

When should a roof hygroscopically be categorized as flat?
The standard stipulates that for "roof' calculations an exterior surface temperature of 20 C° should be used to account for heating of this surface in the summer season. This leads to a heightened inward diffusion. Using these numbers results in a drying potential that is more than three times higher than if the same assembly is calculated with "wall" parameters.
Publications of the IBP note that this calculation method *(based on Glaser)* is only safe/conservative in certain cases (Künzel, H.M. 1999). In particular when one has cases where the insolation on the roof is reduced (north facing roofs, shading by trees or neighboring buildings) caution is required. More trustworthy determinations can only be derived with dynamic hygroscopic calculations based on actual climate data, not with static diffusion calculation that uses the fixed climatic conditions of DIN 4108.

Dynamic calculations offer additional assurance.
Several articles published in this magazine have stressed that the engineering profession has access to dynamic calculations as an important verification methods of the safety of assemblies (5/2003 and 2/2004). One can use the IBP modeling software WUFI® to do extensive research different assemblies to investigate exterior vapor closed assemblies (Künzel, H.M. 1999 and 1998).
The goal of such models is to verify over multiple years and seasonal cycles, if humidity will accumulate within the assembly or if it doesn't. Summarizing the modeling results are:

- Hygroscopic dynamic calculations shall be conservative. It should use demanding climate data, which in Germany is the climate data from Holzkirchen, which weather station elevation height makes it more challenging (at the outskirts of the Alps).
- If the insolation available is low and vapor retarders with an Sd-value >5m *(Perm <0.8)* are used, then there is a higher chance that moisture level in the assembly increase.
- Steep pitched roofs that are north facing *(that do not receive direct sun for most of the year)* are of concern as well. If the pitch is less than 20 degrees (4:12),

Image 3
Yearly moisture calculations with a vapor closed (Perm 0.001) roofing membrane for different orientations (*bottom*) and roof pitch (*top*). Interior vapor retarder perm 1.6.
Normal interior humidity profile.

Green (*horizontal)* line: minimum drying reserve for inward diffusion *(250g/m2)*
(source: Kuenzel, H.M. 1998)

moisture balance should be acceptable *(the summer sun will be high enough in the sky to heat it the roof).*(graph 3)

- If exposed to higher interior humidity (averages over 55%) or unfavorable local conditions exist (shading), only intelligent vapor retarders can potentially provide the only solution (graph 4)
- A large influence has the color and/or build up of the roofing itself (gravel, greenroofs, etc.) Künzel H.M. 1999a

Image 4
Moisture content of north facing tin roof over 6 year seasonal cycles with different roof pitches (high int. moisture climate; 55% RH) (source: Kuenzel, H.M. 1997)

Moisture accumulation (Kg/m2) vertical
Roof pitch (degrees) horizontal axis

Vapor variable vapor retarders: The solution for troubled assemblies
More then 10 years the development of so called "vapor adaptive vapor retarders" started. These special membranes change their vapor diffusion characteristics (*vapor permeability)* depending on the relative humidity in their direct surroundings. Meanwhile several products are available; these products vapor variability profiles are shown in image 5.
When the membranes experience dry conditions (in winter), then they have Sd-values of 3-10m (*1 to 0.3 perms – inverse relationship to Sd-value).* Depending on the type of product. i.e. they offer sufficient protection by reducing the moisture content to acceptable levels in the assemblies.
When 'encapsulated' moisture *(between the vapor retarder and the roof membrane)* is driven inwards by the heated roofsurface (inward diffusion) then the relative humidty at the vapor retarder quickly reaches more than 70%. In that case the vapor variables Sd-value is drastically reduced *(perm rating increases rapidly)* compared to the dry-surrounding diffusion properties. This allows the accumulated moisture to easily move backwards into the interior.
SImilar humidity adaptive properties can also be found in wood and specific woodbased products (see articles in the series of by the same author "Jenseits on Glaser" 5/2003 till 1/2004).

Conclusion
The 'conventional' recommendations in regards to vapor for flat roofs (Venting below the deck or high Sd-values *(very low perm ratings)* on the interior) can only function, when the following specified requirements are met:

Image 5
Sd values (US perm=3.28/Sd) of vapor variable membranes from Moll (Pro Clima) and Isover – in relationship to the average RH in their surroundings.

- un-interrupted flow of ventilation currents through large openings that are free of interruptions – including at intake and exhaust opening
- no additional moisture presence from construction humidity
- Structure free of air leaks/convection transported humidity build up in insulation.

A more reliable and safe solution is in any case to do a Glaser calculation. Current best practice in that case is to have a minimum inward drying reserve of at least 250g/m2. The most reliable and secure design strategy is by using a non-ventilated assembly that uses a vapor variable vapor retarder. Additionally a dynamic hydrothermal calculation is done to proof it's effectiveness. These materials have meanwhile proven their functionality and performance in many research assemblies and have been scientifically verified, as well as have shown their performance in practice for more than 10 years *(which means +19 years since this article was written).* Experienced technical staff of the manufacturers provide qualified support for these materials (www.isover.de and www.proclima.com)

However it remains critical even with those assemblies to have correct airtight execution of the construction which conforms to current manufacturer's recommendations. It is recommended to verify this with a blowerdoor test, as well as that the high (construction) humilities are avoided.

Literature

[Colling 2000] Francois Colling: Lernen aus Schäden im Holzbau, Ursachen Vermeidung Beispiele. Fraunhofer IRB-Verlag, Stuttgart 2000]

[condetti & Co 2003] Autorenteam, condetti & Co, Details im Holzhausbau, Verlag Kastner, Wolnzach 2003
[Dahmen 1993]

Günter Dahmen: Leichte Dachkonstruktionen über Schwimmbädern – Schadenserfahrungen und Konstruktionshinweise. In: Aachener Bausachverständigentage 1993. Bauverlag, Wiesbaden und Berlin 1993
[DIN 4108-3]

NA Bau: Wärmeschutz und Energie-Einsparung in Gebäuden, Teil 3: Klimabedingter Feuchteschutz, Beuth Verlag Berlin 1981-08 (alt) 2001-07 (neu)

[Künzel, H., Großkinsky 1989] Helmut Künzel, Theo Großkinsky: Nicht belüftet und voll gedämmt: Die beste lösung
für das Steildach! In: wksb 27/ 1989 und DDH 12/89

[Künzel, H./ Großkinsky 1992] Helmut Künzel, Theo Großkinsky: Neue Erkenntnisse – Vorteile diffusionsoffener, unbelüfteter Satteldachkonstruktionen. In: Das Dachdecker-Handwerk (DDH) 14/1992.

[Künzel, H. 1996] Helmut Künzel: Dachdeckung und Dachbelüftung. Fraunhofer IRB-Verlag, Stuttgart 1996

[Künzel, H.M. 1997] Hartwig M. Künzel: Untersuchungen an unbelüfteten Blechdächern. In: Aachener ausachverständigentage 1997, Bauverlag, Wiesbaden und Berlin 1997.

[Künzel, H.M. 1998] Hartwig M. Künzel: Außen dampfdicht, vollgedämmt? In: bauen mit holz 8/98.

[Künzel, H.M. 1999] Künzel, H. M.: Dampfdiffusionsberechnung nach Glaser – Quo vadis?, IBP Mitteilungen 355, Fraunhofer Institut für Bauphysik, Stuttgart/Holzkirchen 1999

[Künzel, H.M. 1999a] Hartwig M. Künzel: Einfluss der Deckschicht auf die Temperaturverhältnisse in lachdächern, IBP Mitteilungen 354, Fraunhofer Institut für Bauphysik, Stuttgart/Holzkirchen 1999

[Künzel, H.M./Großkinsky 1998] Künzel, H. M u. Großunbelüfteter Blechdächer; auf die Dampfbremse kommt es an! In: wksb Heft 42, 1998.

[Liersch 1993] Klaus W. Liersch: Die Belüftung schuppenförmiger Bekleidungen – Einfluss auf die Dauerhaftigkeit. In: Aachener Bausachverständigentage 1993. Bauverlag, Wiesbaden und Berlin 1993

[ZVDH 2003] Zentralverband des Deutschen Dachdeckerhandwerks (Hrsg.): Regelwerk des deutschen Dachdeckerhandwerks, CD Version 3.6, Rudolf Müller Verlag, Köln 2003