Requirements of inverted roofs with a drainage layer

Explanations to the application of the EN ISO 6946 of October 2003

Thermal resistance and heat transition coefficient are pointed out in the affix (D.4)

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Abstract

This contribution illustrates the application of the norm EN ISO6946 regarding the heat loss of an inverted roof for different regions of Europe. The version of the EN ISO 6946 of October 2003 [1] adds a correction to the thermal transmittance of inverted roofs due rain water flowing between the insulation and the waterproofing membrane. It is possible to calculate the extra heat loss of inverted roofs caused by rain water below the heat insulation. The extra heat loss depends on the average rate of precipitation and on which fraction of the rain water that will drain between the waterproofing membrane and the thermal insulation. This publication explores the application of the norm in different areas of Europe. Complementary climatic data and boundary conditions are given for different regions in the appendix.

Furthermore, some constructions are proposed, which have such small extra heat losses caused by rain water that they may be disregarded in the calculation.

1 Description of the building construction and the building physical basics

Different from the common flat roof constructions the thermal insulation of inverted roofs is not fixed below but above the roof-membrane. The thermal insulation in inverted roofs consists of extruded polystyrene boards. This construction has proved to work well in field application, if the tightness of the building is ascertained before the completion of the construction of the building. It is even such that the thermal insulation layer, presents an increased mechanical protection during the construction phase, and consequently the risk of disruption of the waterproofing membrane during construction can be decreased.
As a consequence of the joints between the insulation boards and the adjacent building elements a certain fraction of the rain water will reach the waterproofing membrane under the thermal insulation system. Rain water which reaches the interface between the thermal insulation and waterproofing membrane will be heated by the heat of the building itself. The roof system looses heat when the rain water runs to the roof drain. According to [1, D.4.3] the additional heat loss due to the drainage of rain water has to be considered with an correction ΔU [W/(m²·K)] to the U-value of the building.

2 Explanation to the correction procedure of EN ISO 6946, Annex D.4, for rain water flowing between the insulation and the waterproofing membrane (ΔU correction for inverted roofs)

This correction procedure is used with regard to the European norm to consider the additional rainfall leaded heat flow ΔU [W/(m^2 K)] at the energy assessment of the construction.
The amplitude of ΔU is calculated with the help of the following equation:

$$\Delta U_r = p \cdot f \cdot x \left(\frac{R_i}{R_T} \right)^2$$

with

p	=	average rate of precipitation during the heating season, based upon data relevant for the location e.g. weather station, or given through local, regional or national regulation, mm/day
f	=	drainage factor giving the fraction of p reaching the waterproofing membrane, -
x	=	factor for increased heat loss caused by rainwater flowing on the membrane (Ω×day)/(m^2·K·mm)
R_i	=	thermal resistance of the layer of XPS insulation above the waterproofing membrane, m^2·K/W
R_T	=	total thermal resistance of the construction, m^2·K/W
ΔU	=	correction to the calculated thermal transmittance of the roof element, to take into account the extra heat loss caused by rainwater flowing through joints in the insulation and reaching the waterproofing membrane, W/(m^2·K)

The variable [f] describes that fraction of the water which drains below the insulation layer on the roof membrane. This fraction depends on the water tightness of a possible drainage layer over the thermal insulation, or a possible drainage layer fixed on the roof membrane below the insulation. The approach of an average rain fall [p] of a European region can be seen in Table 1 in the appendix.

In the case of a single layer of XPS insulation, which is butt jointed and has an open covering (such as gravel), the combined drainage/heat loss factor is $f \cdot x = 0.04$. Depending on the grade and arrangement of the separation layer above the thermal insulation, the drainage factor can also be $f = 0.0$. Figure [2] shows an example of a gravel-covered inverted roof with *and* without a water drainage layer.

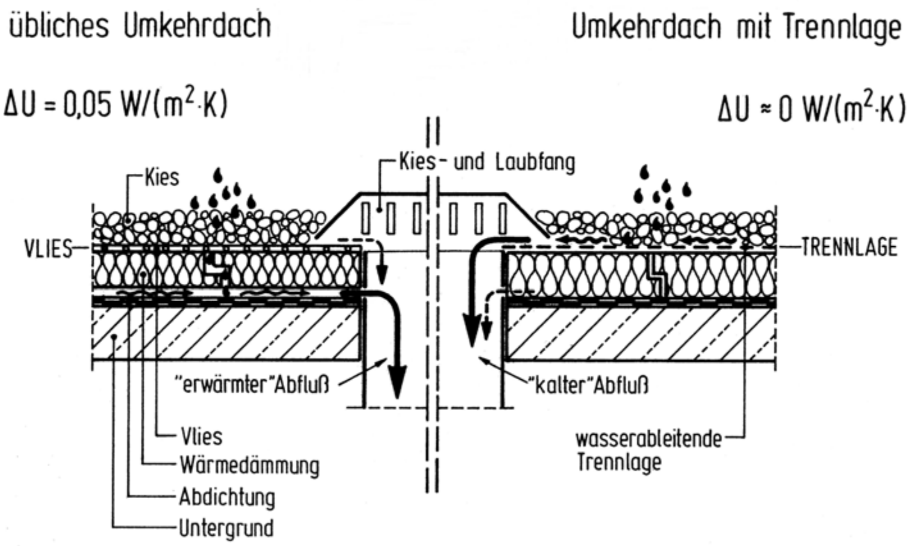

Illustration 1: gravel-covered inverted roof with (on the left) and without (right-hand side) a water draining layer [2]

The decrease of the ΔU_r- value depends on constructive details like:

- The way of arranging the thermal insulation boards (butt jointed or with tongue-and-groove joints)
- An additional water drainage layer fixed on the top of the thermal insulation.

3 Status quo of the research regarding the thermal- and humidity behaviour of inverted roofs

In the context of the research and assessment of inverted roofs, analysis were made with the help of different colleges, universities and institutes [ ].

3.1 Analysis of the humidity- behaviour of the XPS due to the diffusion abstraction of different separation layers

Tests were made in 1991 regarding modified inverted roofs with water efferent separation layers at the EMPA. The aim of these tests were the description of the demands on the separation layers under long-term loading. To calculate the humidity- behaviour of the heat insulation, the diffusion- resistance of four different separation layers were analysed.

Table 1: Materials' qualities of the acquired separation layers

Designation [-]		Thick-ness [mm]	Diffusion-resistance [10-9 m²·s·Pa)/kg]	Equivalent air space [m]
Standard fleece	A	0,66	< 0,05	< 0,01
Water efferent separation layer	B	0,15	0,10	0,02
Water efferent separation layer	C	0,50	20,5	4,1
Polyethylene (PE) sheeting	D	0,20	540	108

These acquired diffusion- resistance are applied as material characteristics to the computer- aided analysis of moisture of the inverted roofs with the help of the program MATCH [ ]. As a consequence it is possible to acquire one- dimensional heat- and moisture transmission regarding the climatic boundary values (temperature, relative humidity, insolation, clouds and wind velocity) for multilayered components with regard to the storage of heat and moisture.

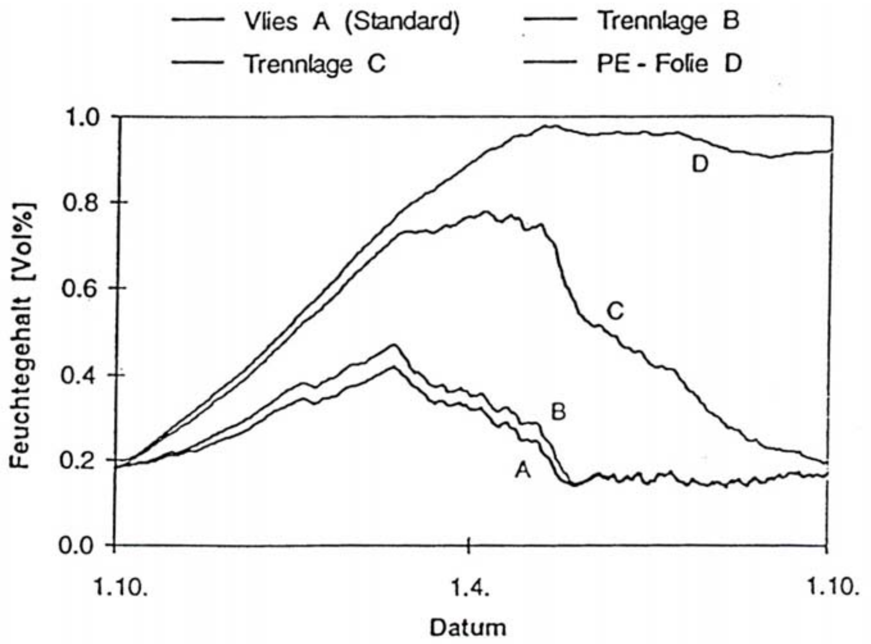

Illustration 3: Calculated distribution of moisture in the centre of the XPS-slabs [1],[4]

The distribution of the moisture content is recorded in each case for a period of one year from the start of the dew period to the finish of the evaporation period (see illustration 3).

The humidity absorption of the insulating slab in connection with the test materials A, B and C distributed in the cycle of a seasonal humidity- fluctuation. Merely, the absorbed water amount did not dry by using the PE- sheeting (type D, s_d = 108 m).
This result shows that, if using suitable materials, the water which moves into the construction during the winter period can be released to the outer air during summer. Even using an insulating material like type C with a great s_d- value (> 4,0 m) ,this material will become dry.

2.2 The drain behaviour with inconvenient climatic boundary conditions

The CSTB carried out different tests to analyse the draining behaviour in the laboratory under diverse building constructive conditions. The intention was to analyse the influence of the separation layer's way of fixing in the boundary areas. The test roof was prepared with a faced attica. The separation layer ends up to the gravel layer at test A; at test B it was fixed up to and above the attica construction.
Simulations with different climatic boundary conditions were made with a changing rain intensity, a changing wind speed and a changing wind angle of incidence. Consequently disadvantageous, nature-orientated and imitated circumstances could be realized.
The following table (3) summarizes the acquired leak rates, which were analysed with the help of a wind tunnel:

Table 3: Measured leak rates of the test roof of the CSTB

Test-number	Boundary formations	Upper drain amount Q_1 [Litre]	Lower drain amount Q_2 [Litre]	Leak rate L [%]
1	**Test version A**	1184	5,7	**0,5**
2 **2***	**Test version A**	1582 1599	17,52 22,52*	**1,1** **1,4***
5	**Test version A**	1977	58,45 Q_3 = 1,31	**2,9**
3	**Test version B**	1360	3,51	**0,3**
4 **4***	**Test version B**	1590 1609	5,98 12,49*	**0,4** **0,8***

* these leak rates were measured 13 … 16 hours after ending the irrigation

The obtained results can be abstracted like this:

- The acquired leak rates fluctuates between 0,3% and 3%. Most of the rainfall amount drains on the top of the separation layer towards the outer air.
- The maximum leak rate is about 5% by having an edge construction with no separation layer on the tallying construction parts.
- On the other side *with* a separation layer at these parts the maximum leak rate is about 1%.

- After the dismantling of the insulation slabs , great dry areas were recognized.
- The remaining water amount was small- sized (Q_3). The water's thickness was about 0,05 mm on average.

3.2 Measurement of the leak rate depending on the rainfall's intensity

A leak rate is defined as the proportion of the water which discharges under the heat insulation layer to the rainfall which drains on the opposite side (in %). It is necessary to know the leakage rate to make an assessment of the thermal behaviour of an inverted roof which includes a water efferent separation layer.

In the course of a research at the TU Berlin to determine the leak rates, an experimented roof with a water efferent separation layer (type B- EMPA) instead of a conventional fleece bearing (type A- EMPA) was build.

This layer was fixed over the top of the flint in the border area. After doing an equal irrigation of the roofage, the efferent water amount on the top of the separation layer as well as under the heat insulation were measured. Illustration 4 shows the acquired leak rates (L) as a function of the rainfall's intensity.

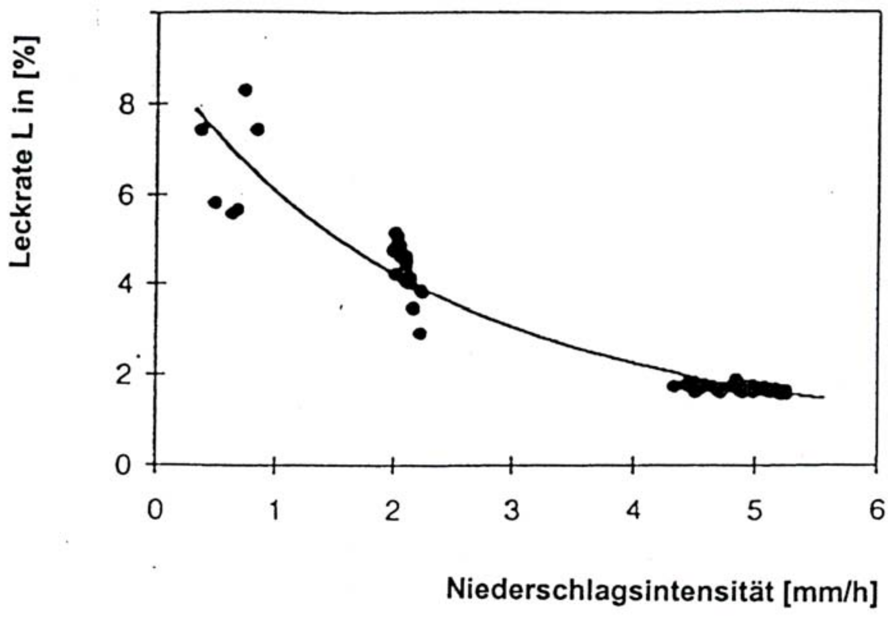

Illustration 4: Leak rates (L) depending on the rainfall's intensity measured on the test roof [mm/h]

These studies demonstrate how far the leakage rate (L) depends on the rainfall's intensity. The rate decrease in a clear way when having a great rainfall amount because a great fraction of this water discharges quickly on the top of the separation layer.

2.3 Quantification of the heat losses caused by rain fall

As well as the measurement of the leakage rate, the TU Berlin also determined the heat losses, which are carried- off because of the enthalpy on the lower seal [5], [6], [7].
At this, the amount of the draining water as well as the temperature of this water, the temperature of the rainfall and the room air temperature were noticed. This integral measurement method of the determination of this “draining- water enthalpy” reaches the heat removal largely independent from the art of the draining system.

Table 4: TU Berlin – rainfall events (RE)

	Average of one hour		**Average of one day**	**Sum of one day**
	Rainfall amount	**time**	**Rainfall amount**	**Rainfall amount**
Test series 1 (RE 1; 10 tests)	30 mm/h	90 min	1,875 mm/h	45 mm/d
Test series 2 (RE 2; 6 tests)	30 mm/h	120 min	2,5 mm/h	60 mm/d
Test series 3 (RE 3, 2 tests)	60 mm/h	90 min	3,75 mm/h	90 mm/d
Test series 4 (RE 4, 1 test)	1,7 mm/h	24 h	1,7 mm/h	40,8 mm/d

Following summary which is based on hourly average values, purposes to make a classification of these rain events.

0 - 1 mm/h	light rainfall intensity
1 - 4 mm/h	normal rainfall intensity
4 - 15 mm/h	heavy rainfall intensity
15 – 40 mm/h	extreme heavy rainfall intensity
> 40 mm/h	cloud burst

The comparability of these results regarding the different rainfall intensities has to be ensured by the consideration of the reference value *r*. The average temperature circumstances, measured at the time of draining, as well as the drained water temperature and amount and the average reference value were compiled to calculate the ΔU- value of the inverted roof including a separation layer.
From this the rainfall affective additional ΔU- value is defined with the help of following equation:

$$\Delta k = \frac{\dot{m}_u \cdot c\left(\overline{\vartheta}_{Gu} - \overline{\vartheta}_N\right)}{\overline{\vartheta}_i - \overline{\vartheta}_N} \times r = 0{,}00085 \quad \text{W/(m}^2\cdot\text{K)} \qquad (1)$$

with:

$\dot{m}_u$	Average intensity of the lower blackrush	0,07	kg/(m²·h)
c	Specific heat capacity of the water	1,1627	Wh/(kg·K)
$\overline{\vartheta}_{Gu}$	Average water temperature in the draining system, below	26,28	°C
$\overline{\vartheta}_{N}$	Average rainfall temperature	18,11	°C
$\overline{\vartheta}_{i}$	Average room air temperature	40,32	°C
r	Reference value ($\overline{R}_{Heizperiode} / \overline{R}_{Versuch}$)	0,0285	
$\overline{R}$	Average rainfall amount	-	mm/d

These results show that the average rainfall affective ΔU- value, which is acquired with the measurement of the revoked heat, amounts less than *0,001 << 0,05 W/(m²·K*). Regarding the European norm additional values ≤ 0,01 W/(m²·K) can be ignored at the appointment of the heat transfer coefficient.

4 Demands to the separation layer of inverted roofs regarding the observance of a correction value of the heat flow ΔU = 0 [W/(m²·K)]

Based on the analysis a correction value ΔU = 0 [W/(m²K) of the heat flow of inverted roofs can be reached by using a water efferent separation layer!

This layer has to meet different requirements which have to be assessed on the basis of standardized construction material tests. At this, the EN ISO 13859-1 (theme: seal- slabs) has to be the basis.

4.1 The diffusion- ability of separation layers

The diffusion behaviour of the separation layer has to be determined regarding the pr EN ISO 12572.

The s_d- value has to be < 0,1 m . Tests which were made at the FIW in Munich [] have shown that there is no difference between a 5- year old, natural weathering aged separation layer and a new one.

4.2 Durability of the water efferent separation layer

The durability has to be proved based on the EN 1297, which stipulates following laboratory tests:

- Heat treatment
- Chemical treatment in an acid, alkaline and salt ambience
- Ultraviolet radiation and

- Natural aging process.

With the help of these tests the separation layer has to be destroyed and so the durability has to be proved.

4.3 Distribution pressure on the separation layer

Due to the demands of the DIN 18195 part 5 (topic: seals against non pressurized water; in this case: the construction of a seal at building parts > 150 m) the height of the water column has to be lower than 150 mm ($w \leq 150$ mm).

In line with the tests of the TU Berlin the separation layer was examined with a distribution pressure in the field range as well as in the overlapping areas. I this connection there could no nameable water inleakage be recognized. A great part of this water was able to drain on the top of the separation layer towards the drainage- system. The impermeability of the separation layer can be additional improved by bending the slabs near to the longitudinal joints.

The casting factor of the different fleece sheeting's tightness is not the height of the static water column but the kinetic energy of the peeling rain and it's water drops. This notice is based on the perceptions of prior research projects of the BBS- Institute. On this account and on the base of the EN 1928 the height of the water column (w) has to be $\geq$ 1000 mm.

4.4 Mechanical damages of the separation layer

The analysis of the TU Berlin show that there was no damage at the separation layer caused by a perpetration of the construction (inverted roof including a gravel layer). Even there is an increased stress, no damages at the separation layer could be recognized but only a compression of the heat insulation. In consequence the demands of the slab's stability can be defined with the tensile strength of the slabs (regarding the EN 12311-1). This tensile strength should be $F \geq 100\ [N/5cm]$. The cold bending behaviour has to be proved at a temperature of θ_e-$5°C$ (compare with EN 1109).

5 Constructive requirements to the fixing of water efferent separation layers

Water efferent separation layers are fixed upon the insulating slabs instead of conventional fleece support. To gain the entire efficiency regarding the draining process, an overlap of 15 cm has to be complied, which is founded on experiments of the TU Berlin. Based on tests of the CSTB the separation layer needs to have a height of 15 cm at rising structural parts. This separation layer ought to be coated with an insulating slab, as it has to be protected against mechanical damage. Concerning this matter the commendation written in the processing guidelines of the producers should be followed additionally.

6 Summary of the requirements on the separation layer at inverted roofs

Foundation of the construction material enquiries is the EN ISO 13 859-1 (topic: seals).

<u>Building physics / mechanical requirements on the separation layer</u>

Diffusion behaviour according to pr EN ISO 12572	s_d *< 0.1 [m]*
Durability evidence according to EN 1297	
Water pressure loading according to EN 1928	*Water column w* $\geq$ *1000 mm*
Tensile strength according to EN 12311-1	*F* $\geq$ *100 [N/5cm] .*
Analysis of cold bending according to EN 1109	*at* θ_e*-5°C*

<u>Constructive requirements on the design of the separation layer</u>

laying on the entire plane

joints overlapping at least 150 mm

needs to have a height of 150 mm at the rising construction parts

7 Literature – noch mal aufarbeiten!!

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8 Noch mal überarbeiten!!

[A] Amount of precipitation of different regions