HYGRO DIODE MEMBRANE: A NEW VAPOR BARRIER

V. Korsgaard
ASHRAE Member

ABSTRACT

In recent years it has become apparent that insulated and ventilated timber flat roofs, with covering of roofing felt, of the cold roof type are exposed to excessive moisture content in the roof decking causing decay and fungal attack. It is also now recognized that the cause of this is primarily condensation of water vapor in the warm moist air entering into the roof void through leakage at joints and perforation in the vapor barrier, which cannot be avoided in practice. This convective moisture transfer caused by wind and thermal forces can be minimized by omitting vent openings in the roof covering and overhang. In this case only a small amount of moisture will pass through the vapor barrier by diffusion during a winter. During a summer the sun will heat the roof, and the moisture in the roof material will evaporate and diffuse through the fiber insulation material and condense on the relatively cold vapor barrier membrane. If the membrane would allow the condensate to pass through and evaporate to the underlying rooms, there would be no risk of moisture accumulation in the roof construction over the years. Such a membrane, which has a high diffusion resistance but will allow free water to pass through, could be named a hygro diode membrane. This paper describes such a membrane, US patent number 4,567,080, including some preliminary tests.

The hygro diode will also be suitable as a vapor barrier applied on both sides of well-insulated walls and roofs in hot humid climates with a short heating and a long air-conditioning season.

INTRODUCTION

Until a few years ago, it was generally accepted among architects and structural engineers that risky moisture content in timber flat roof constructions of the cold roof type could be avoided by placing a vapor barrier immediately above the ceiling and below the thermal insulation, in combination with vent openings in the eaves of roof vents. However, many deteriorated roofs of this type have shown that this is not the case. It is now realized that the main cause is primarily the permeation of warm moist air from underlying rooms into the roof cavity, where it condenses on the timber structures and roof deck when the roof covering is colder than the dew point of the air entering the roof cavity (Prebensen et al. 1981, Korsgaard et al. 1985). The cause for this again is that it is practically impossible to install the vapor barrier membrane completely airtight because of unavoidable leakages at joints and perforations. Large amounts of moist air can enter through small leakages due to the pressure difference generated by wind and stack effect. The quantity of moisture entering the roof cavity by convection in this way can easily be ten to a hundred times larger than

V. Korsgaard, Professor, scientific head of the Thermal Insulation Laboratory, the Technical University of Denmark, DK-2800 Lyngby.

the amount of moisture entering by diffusion through a membrane with only a modest diffusion resistance (see Figure 1).

In principle one way to prevent moisture deterioration of timber flat roofs could therefore be to omit roof vents, as the roof covering is completely airtight. However, some moisture will enter into the roof cavity by diffusion through the vapor barrier membrane itself and the unavoidable leakages at joints and perforations. Furthermore, the water content of the timber structural deck will often be high when installed and will not be able to dry out if enclosed between two very vaportight membranes. There may also be a risk that rainwater will enter through leakages over time, which ought to be detected by dripping from the ceiling before too much water has accumulated in the roof construction.

THE HYGRO DIODE MEMBRANE

The idea behind the hygro diode membrane (HDM), which is supposed to substitute for an ordinary vapor barrier, is as follows. The membrane shall have a diffusion resistance high enough to prevent the moisture content of the timber structural deck to reach risky values for fungal attack during the cold season, but it will allow the moisture to dry out during the warm season. These requests can be met by a membrane with a sufficiently high diffusion resistance, which allows free water to pass through. The mode of construction of such a membrane and the principle of function is shown in Figure 2.

The HDM consists of a fabric of glass fiber or polypropylene fiber which have good capillary suction properties. On both sides a diffusiontight skin of polyethylene is applied leaving displaced uncovered stripes. To penetrate the membrane water vapor will have to pass by diffusion in the thin layer of fabric from an uncovered stripe on one side to the displaced stripe on the other side.

During a winter, a small amount of moisture will diffuse through the membrane and be absorbed by the wood in the roof. During a summer, the sun will heat the roof, and the moisture in the wood materials will evaporate and diffuse through the mineral wool insulation and condense on the relatively cold membrane. That part of the water vapor which condenses on the uncovered stripes will by capillary suction pass through the membrane and evaporate from the uncovered stripes on the underside.

In climates with cool and/or clear nights, that part of the condensation which takes place on the vaportight strips will reevaporate during the night and condense on the supporting deck. During the next sunny period, it will evaporate, and a fraction will again condense on the uncovered stripes. During a summer, these evaporation-condensation cycles will be repeated until all the moisture in the roof construction has been dried out.

To ensure free evaporation from the HDM to the underlying room air, the ceiling should preferably be suspended or of a perforated acoustic type.

In climates with warm nights or where air-conditioning keeps the indoor temperature lower than the outdoor temperature all 24 hours, an embodiment of the HDM where a thin water absorbing layer is applied to the upper side would be preferred to ensure that the condensed water vapor will be sucked through the HDM to the underside, see Figure 2.

FIELDS OF APPLICATION OF THE HDM

Although the HDM was developed primarily to solve moisture problems in timber roofs, it might prove useful for other applications. One could be in air-conditioned houses in climates with long, hot, humid summers and short winters where the traditional vapor barrier placed on the outerside of the insulation in walls has caused moisture problems. These can probably be avoided by using the HDM as vapor barrier and placed on both sides of the insulating material.

VAPOR RESISTANCE OF THE HDM

In Figure 3 the main diffusion paths are indicated. For each path a diffusion resistance can be calculated. As the flow paths are in parallel the overall resistance R_A of a segment with the width A is calculated as three resistors in parallel. The resistance of a unit area Z_{HD} is found by multiplying this value with A, see Figure 3.

Example (see Figure 3)

δ = 70 Perm m (ng/s·m·Pa) Synthetic fiber fabric

E = 0.0005 m

Z = 0.2 Rep (TPa·m²·s/kg) 0.1 mm polyethylene film

A = 0.20 m, B = 0.05 m, C = 0.05 m

$R_1 = 0.05/70 \cdot 0.0005 = 1.43 \text{ Rep/m}^2$

$R_2 = 2 \cdot 0.20/0.05 = 8.0 \text{ Rep/m}^2$

$R_3 = 0.20/0.05 = 4.0 \text{ Rep/m}^2$

$R_A^{-1} = 2(1.43^{-1} + 8.0^{-1} + 4.0^{-1}) = 2.15$

$Z_{HD} = 2.15^{-1} \cdot 0.20 = 0.093 \text{ Rep}$

This resistance value corresponds approximately to 0.05 mm polyethylene foil.

COMPUTER PROGRAM

A computer program, which calculates the seasonal variation of moisture content (MC) of the wooden deck, has been set up for the simple roof construction shown in Figure 2. Thermal mass, moisture capacity and latent heat is not taken into consideration.

The main parameters are the indoor psychrometric conditions, the insulation thickness and the diffusion resistance of the vapor barrier. The weather data used are one hour values of air temperature, global radiation and wind velocity from the Danish Test Reference Year (TRY), see Figure 4. In Figure 5 the variation of MC is shown for the roof with 13 mm wooden deck, 0.20 m mineral wool and a HDM with Z = 0.1 Rep as a vapor barrier. The indoor temperature is 20°C, and RH is varying between approximately 40% and 60% over the year. If the MC of the wooden deck is dried out to 10% during the summer, the MC will start to increase in the middle of October and reach a maximum of approximately 11% in the middle of March. In the beginning of April the MC will again be 10%.

Similar calculations without a vapor barrier show that the MC will increase from 10% in the beginning of October to 60% in April and decrease to 10% in the beginning of July, see Figure 6. This shows that a vapor barrier is necessary to prevent the MC to reach critical values of 15-20% for fungal attack in wooden materials. If an increase of 7.5% is permissible the vapor barrier should have an effective vapor resistance of at least 0.02 Rep for the conditions mentioned.

TESTING OF THE HDM

So far only laboratory tests have been carried out. There has been found good agreement between the calculated and measured diffusion resistance.

Tests have also shown that it is possible to dry out a typical timber flat roof during a number of repeated diurnal evaporation and condensation cycles which are less than can be expected during a typical summer in a temperate coastal climate such as in Denmark.

A test hut for comparative studies of a number of different flat roof constructions, with and without the HDM, has just been finished, and monitoring has started. A prototype of the HDM has also been installed in smaller sections of a number of timber flat roofs in new industrial buildings.

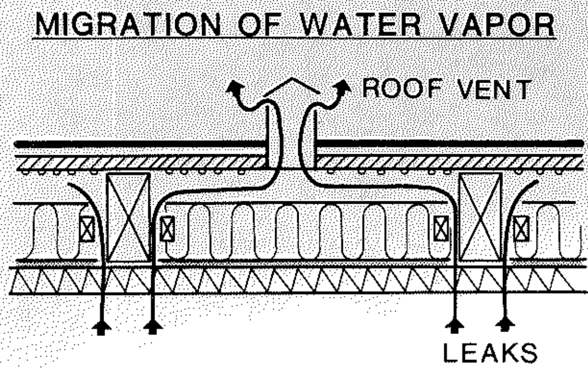
CONCLUSION

It is probably too early to state that the HDM should be used generally as a vapor barrier in buildings instead of the traditional plastic sheet, aluminium foil, or asphalt felt, although theoretical considerations and laboratory investigations seem to indicate this.

REFERENCES

Prebensen, K.; Christensen, G.; Korsgaard, V. 1981. "Combating moisture in timber flat roofs". Building Research and Practice, March/April 1981.

Korsgaard, V.; Christensen, G.; Prebensen, K.; Bunch-Nielsen, T. 1985. "Ventilation of timber flat roofs". Building Research and Practice, July/August 1985.



I WITH AIR FLOW (CONVECTION)

STACK EFFECT

OUTDOOR AIR $0^{O}C$, RH 90% DENSITY $1.290\ KG/M^3$

INDOOR AIR $20^{O}C$, RH 50% - 1.200 -

$0.090\ KG/M^3$

CEILING, HIGHT 5 M, STATIC PRESSURE 0.45 MM WG

STATIC PRESSURE CONVERTED TO VELOCITY PRESSURE:

$0.45 = \alpha \varrho V^2/2\ G \qquad V = 1.5\ M/S$

AIR LEAK PER M^2 ROOF DECK:

$100\ MM^2 \times 1.5\ M/S \backsim 0.5\ M^3/H$

MOISTURE CONTENT OF INDOOR AIR $8.8\ G/M^3$

MOISTURE CONTENT $0^{O}C$ DEW POINT 4.8 -

MIGRATION BY CONVECTION $2\ G/H \cdot PER\ M^2$

II DIFFUSION

RESISTANCE OF VAPOR BARRIER

0.05 MM POLYETHYLENE $0.75 \cdot 10^6$ S/M

MIGRATION BY DIFFUSION $0.02\ G/H\ PER\ M^2$

DIFFUSION (V=0) THROUGH $100\ MM^3$ LEAK 0.4 G/H

Figure 1. Migration of water vapor into timber flat roofs

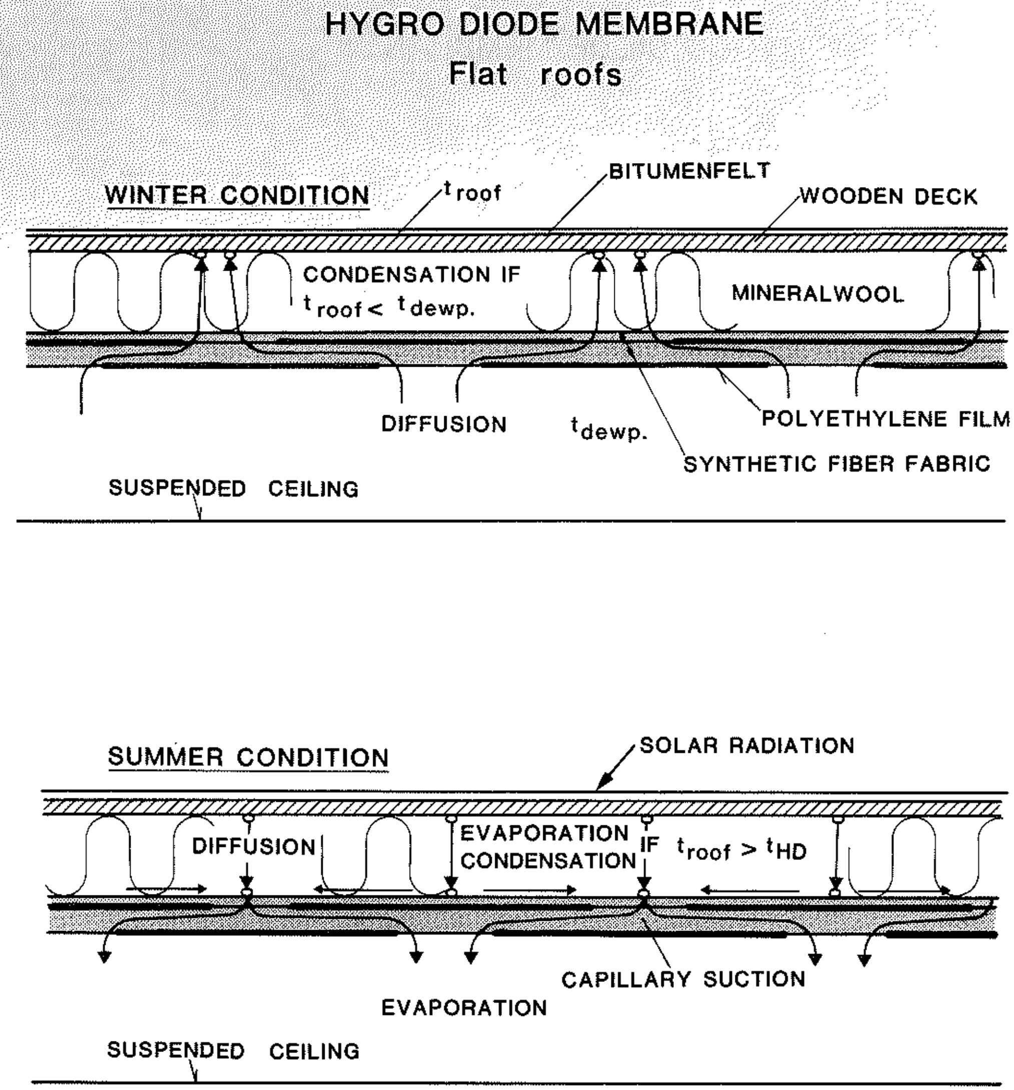
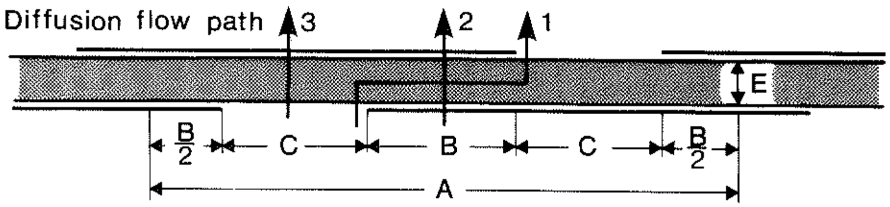


Figure 2. Principle of function of hygro diode membrane

HYGRO DIODE MEMBRANE



DIFFUSION

$G_A = (\Delta P / Z_{HD}) \cdot A$ (FICK'S LAW)

$Z_{HD} = R_A \cdot A$

WHERE G_A = MASS OF VAPOR TRANSMITTED

ΔP = DIFFERENCE OF VAPOR PRESSURE

Z_{HD} = OVERALL VAPOR RESISTANCE PER UNIT AREA

A = AREA CONSIDERED

R_A = OVERALL VAPOR RESISTANCE OF AREA A

$R_A^{-1} = 2(R_1^{-1} + R_2^{-1} + R_3^{-1})$ RESISTORS IN PARALLEL

$R_1 = B/\delta \cdot E$ RESISTANCE OF FLOW PATH 1

$R_2 = 2Z/B$ - - - - 2

$R_3 = Z/C$ - - - - 3

WHERE δ = PERMEABILITY COEFFICIENT OF FIBER FABRIC

E = THICKNESS OF FIBER FABRIC

Z = VAPOR RESISTANCE OF POLYETHYLENE FILM

B = WIDTH OF OVERLAPPING POLYETHYLENE FILM

C = WIDTH OF UNCOVERED STRIPES

Figure 3. Calculation of water vapor diffusion resistance of hygro diode membrane

TEST REFERENCE YEAR

DANISH MONTHLY VALUES

	MEAN TEMP. °C	GLOBAL RAD. WH/M^2 DAY	SUNSHINE H/DAY
JANUARY	-0.6	406	0.8
FEBRUARY	-1.1	1187	2.2
MARCH	2.6	1895	2.5
APRIL	6.6	3961	5.3
MAY	10.6	5017	6.0
JUNE	15.6	6188	8.8
JULY	16.4	5187	7.3
AUGUST	16.7	4350	7.0
SEPTEMBER	13.7	2773	4.8
OCTOBER	9.2	1415	2.8
NOVEMBER	5.0	639	1.0
DECEMBER	1.6	384	1.3
YEAR	8.1	2790	4.2
SUMMER, APR.-SEPT.	13.2	4580	6.5
WINTER, OCT.-MARCH	2.8	988	1.8

Figure 4. Monthly mean values of Danish test reference year

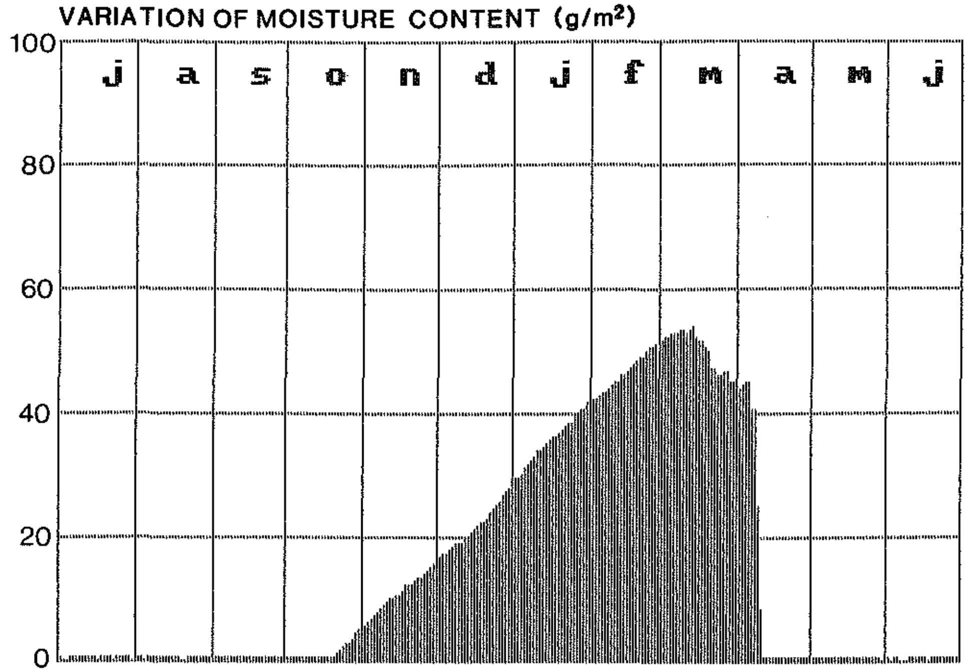


Figure 5. Seasonal variation of moisture content of wooden deck of unvented timber flat roof with hygro diode membrane (z = 0.1 rep) as vapor barrier

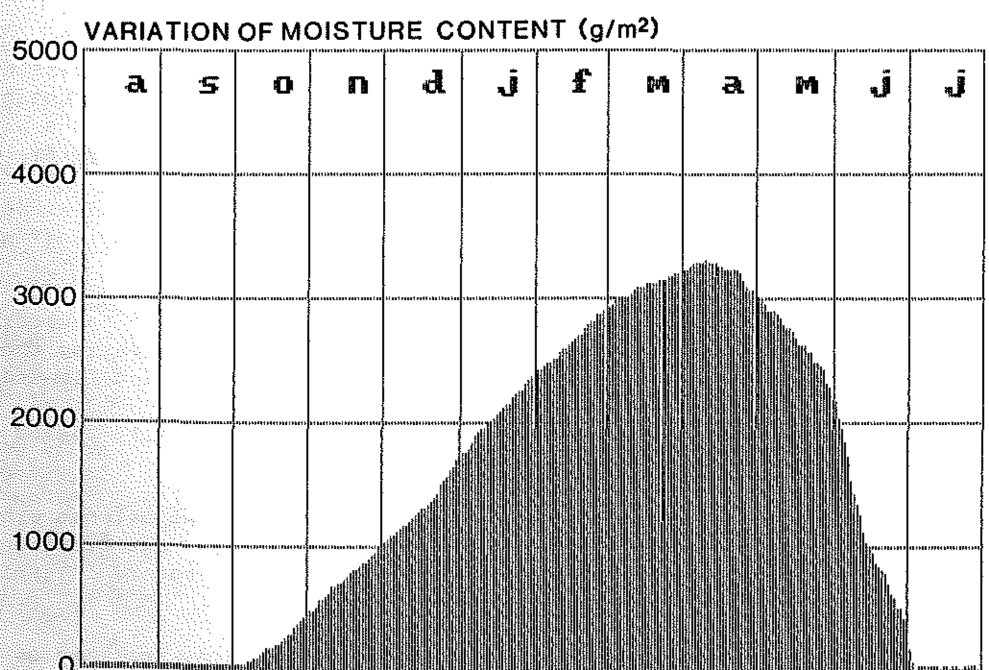


Figure 6. Seasonal variation of moisture content of wooden deck of unvented timber flat roof without a vapor barrier