Moisture Risk Assessment of Roof Constructions by Computer Simulation in comparison to the Standard Glaser-Method

Hartwig M. Künzel, Dr.-Ing*

1. INTRODUCTION

In recent years unvented roof constructions are favoured over ventilated pitched roofs because they are more cost effective and more ecological in cases where chemical wood protection becomes unnecessary. The basis of new German regulations in DIN 68800-2 concerning the application of chemical protectives in building assemblies, are vapour diffusion evaluations by the Glaser-method in DIN 4108.3 and requirements concerning the drying potential for construction moisture originating from field and laboratory tests. Because of their relevance to the vapour permeability specifications in DIN 68800-2 the results of the Glaser-method are compared to numerical simulations in the case of cathedral ceilings and the resulting implications are discussed. Furthermore the benefits and practical importance of modern simulation tools are demonstrated and an outlook concerning the development of user recommendations is given.

2. CALCULATION PROCEDURES

A clear distinction must be made between a method to assess the risk of interstitial condensation by applying severe steady-state conditions (e.g. Glaser) and numerical simulations tools which predict the transient moisture behaviour of building components under real climate conditions.

2.1 Glaser-method

The Glaser-method was designed to calculate the amount of interstitial condensate formed during a cold winter period and the theoretical amount of evaporable water in a cold summer. If the amount of condensate does not exceed specified limits and, if it is lower than the evaporable amount of water, the building assembly is considered to be on the safe side.

* Fraunhofer Institute for Building Physics
(Director: Prof. Dr. Dr. h.c. mult. Dr. E.h. mult. Karl Gertis),
D-83601 Holzkirchen

The Glaser-method does neither account for hygroscopic sorption nor for liquid transport. Therefore its application is more or less limited to light-weight structures. Since hygroscopic materials are present in most building assemblies steady state boundary conditions should be employed. Transient conditions require correct moisture storage terms e.g. a sorption isotherm. From that aspect block conditions for winter and summer are better suited than monthly mean values. It should be noted that Glaser-calculations are no simulation of reality, but a tool to determine the risk of interstitial condensation only. Problems with other moisture loads, such as construction moisture, precipitation, summer condensation or rising damp are beyond the scope of the Glaser-method.

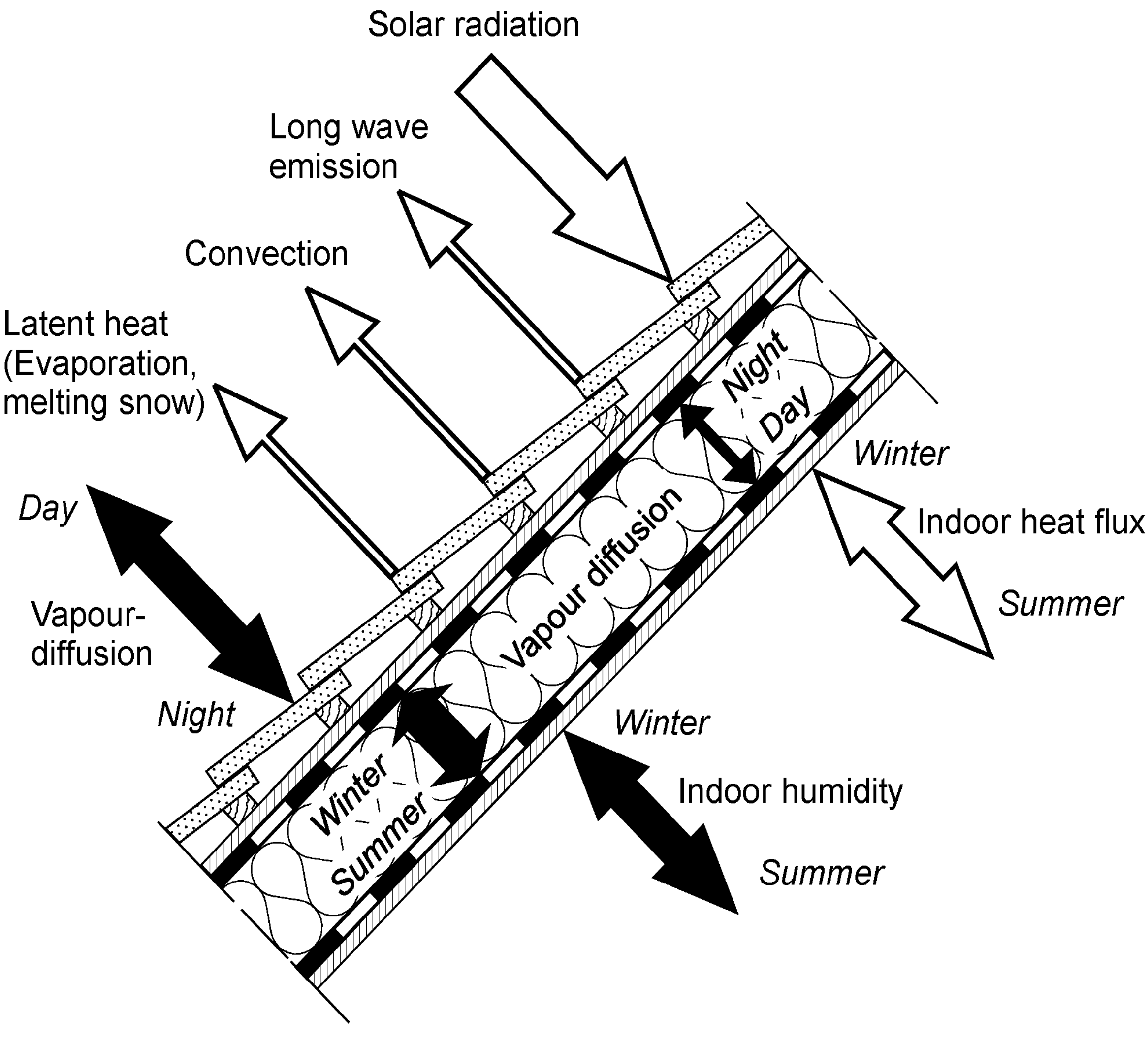

Figure 1 Transient hygrothermal loads and fluxes in and around an insulated roof assembly.

2.2 Numerical simulation tools for heat and moisture transfer

The limitations of the Glaser-method can be overcome by using modern simulation models such as Match [Pedersen 1989], or WUFI [Künzel 1995] which have both been used and experimentally validated for roof constructions. An extensive compilation of hygrothermal simulation tools can be found in Hens [1996]. In order to obtain appropriate results these calculation tools should be able to simulate the transient heat and moisture phenomena shown in Fig. 1 for the example of a fully insulated cathedral ceiling. Currently a WTA-working group is elaborating recommendations for the practical application of such calculation tools which will contain concise information on:

- fundamentals and simplifications of heat and moisture transfer for building purposes
- definition of relevant hygrothermal properties and references to data-bases
- boundary conditions (indoor and outdoor climate, surface transfer)
- initial conditions (e.g. construction moisture)
- accuracy of numerical solution (grid spacing, time steps)
- interpretation of results and plausibility checks
- documentation of calculation procedure and results.

A first draft of these guidelines is expected to be completed in summer 2000.

3. APPLICATION EXAMPLES

The following application examples are examined with the Glaser-method using block boundary conditions as defined in DIN 4108-3 and by WUFI-simulations [Künzel 1995] using hourly climatic data of a typical meteorological year from the IBP-weather station in Holzkirchen (located close to the German Alps at 680 m above sea level).

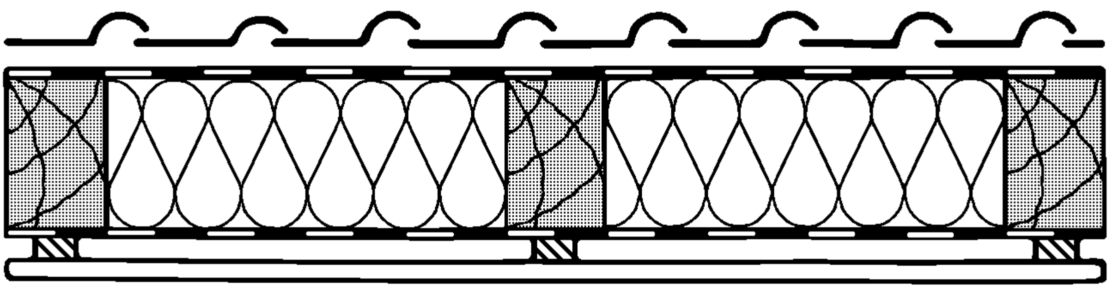

Figure 2 Typical construction of an unvented cathedral ceiling with fibre insulation between breather membrane (top) and vapour retarder (bottom).

3.1 Cathedral ceiling with breather membrane

Fig 2 shows a typical cathedral ceiling assembly. The space between the rafters is completely filled with mineral fibre insulation. The top cover of the insulation is formed by a water-tight breather membrane which acts as a second line of defense against precipitation. If the breather membrane has a vapour permeability of more than 160 perm (equivalent air layer thickness µd = 0.02 m) the vapour retarder may be omitted according to DIN 68800-2. Thus the only vapour diffusion resistance left is the gypsum board panelling with µd = 0.1 (33 perm). Glaser calculations and WUFI-simulations show that such an assembly is theoretically risk free. However, the question is what will happen if the breather membrane becomes a little less permeable by soiling, ageing or ice formation. This has been simulated by assuming a slight increase of µd of the breather membrane to 0.05 m (66 perm) and 0.1 m (33 perm).

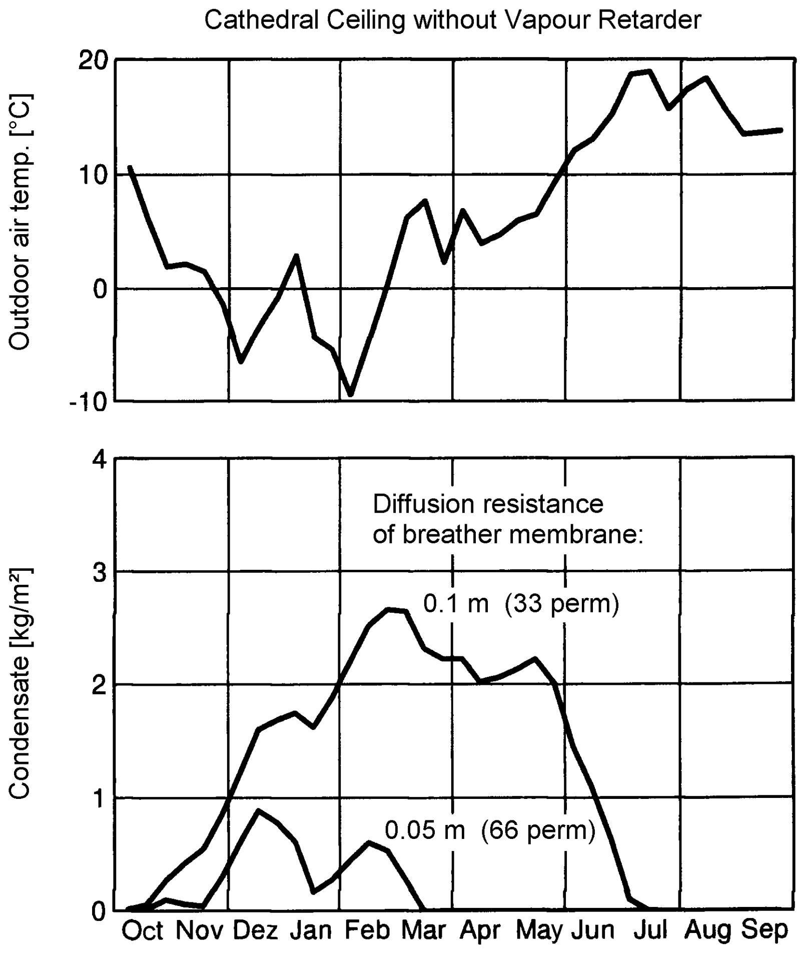

Figure 3 Measured outdoor temperature and calculated amount of condensate in the roof assembly without vapour retarder based on WUFI-simulations without solar radiation effects (worst case).

The resulting condensate that forms at the breather membrane during a typical winter period is shown in Fig. 3 together with the prevailing outdoor air temperature. For the indoor environment the standard conditions 20 °C, 50 % R.H. apply. In the case of a breather membrane with µd = 0.1 outdoor temperatures below zero lead to condensation and the maximum amount of ca. 2.5 kg/m² is well above the limit of 0.5 kg/m² in DIN 4108-3. A breather membrane with µd = 0.05 allows some dry-out of condensate during the winter period but also here the condensation limit is slightly exceeded. Fig. 4 depicts the amount of condensate determined by the Glaser-method depending on the diffusion resistance of the breather membrane (solid line). The comparison with WUFI results using Holzkirchen climate data shows a good agreement if radiation is neglected (a reasonable approximation for north orientation or snow cover), which means that the Glaser assessment is quite realistic but not much on the safe side. Since a breather membrane with a vapour diffusion resistance slightly above 0.02 m incurs too much condensation such an assembly cannot be recommended without a further vapour retarding layer.

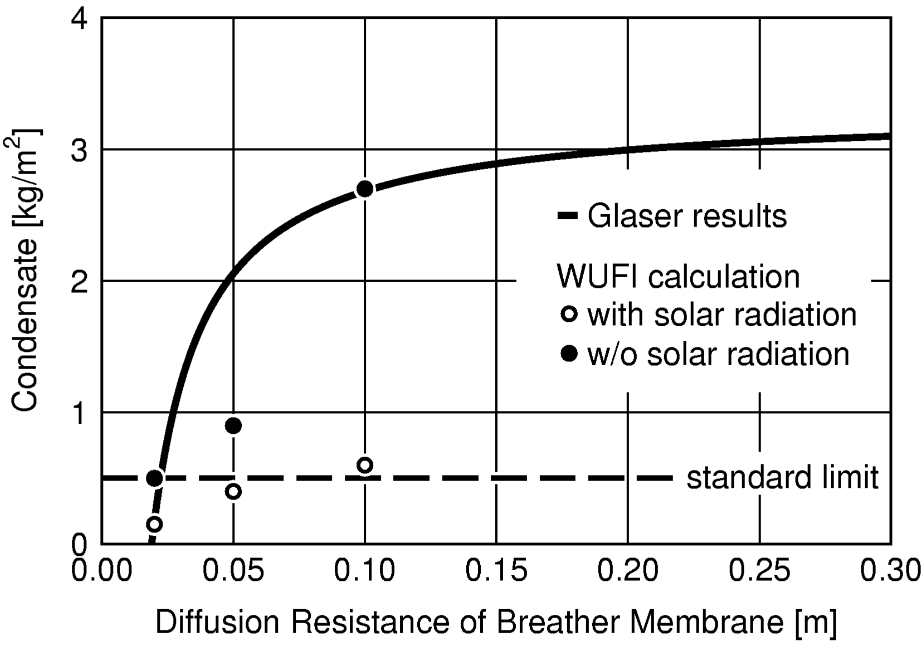

Figure 4 Interstitial condensate formed during the heating period in a cathedral ceiling without vapour retarder depending on the diffusion resistance of the breather membrane. The Glaser result (solid line) correspond to the simulation results taking the maximum amount of condensate from Figure 3 without solar radiation. If solar radiation for a south oriented roof without snow cover is considered, the condensation amount is reduced by drying intervals.

3.3 Cathedral ceiling with vapour tight top

In most rehabilitation cases sheathing and bituminous felt form the underlay of the roofing instead of breather membranes. If the space above the insulation cannot be ventilated, the only way for moisture to dry out is to the interior. Because a small amount of moisture will always enter the roof assembly through imperfections a real vapour barrier traps the moisture in the roof. Therefore a vapour retarder with a diffusion resistance around μd = 2 m (1.6 perm) should be preferred. Thus excess moisture can dry out in summer and the construction is safe as long as the drying potential is higher than the wetting potential by interstitial condensation. The Glaser-method approves such an assembly if the boundary conditions for roofs in DIN 4108-3 are employed and disapproves it for the normal boundary conditions which apply to all other building components. The difference between these boundary conditions is the solar bonus for roofs which means a higher surface temperature (20 °C instead of 12 °C) during the evaporation period.

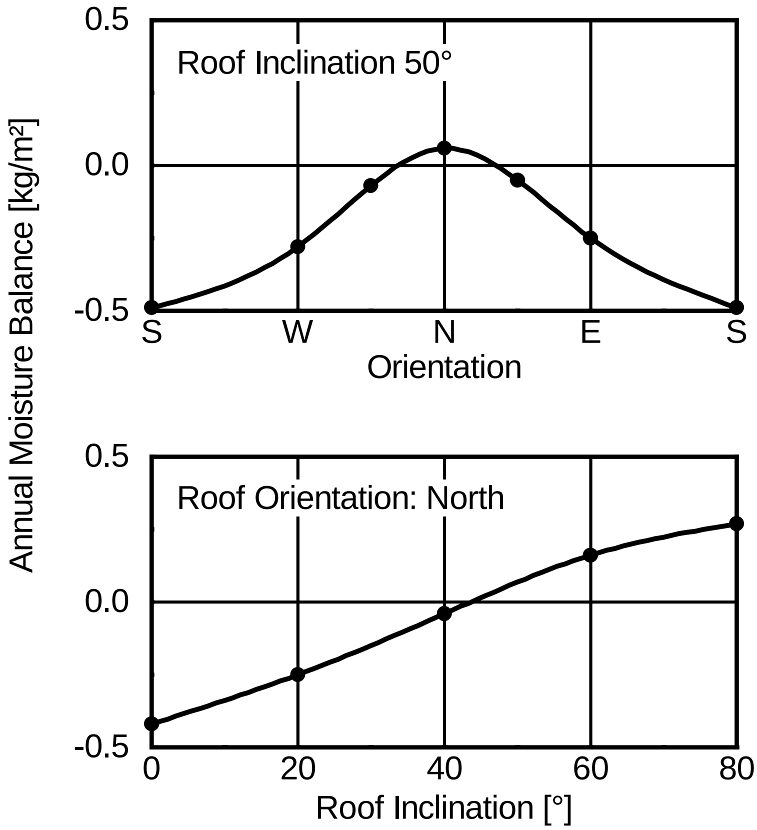

Figure 5 Annual moisture balance in a cathedral ceiling with vapour tight top and a slightly permeable vapour retarder (μd = 2 m, 1.6 perm) determined with WUFI for different orientation and inclination of the roof.

Hence, the safety of this assembly against interstitial moisture seems to depend on solar radiation effects. Therefore a parametric study with WUFI was carried out varying the orientation and inclination of the roof surface. Starting from a hygroscopic water content of the roof assembly in equilibrium with 80 % R.H. the annual moisture balance depending on the orientation and the inclination of the roof surface is depicted in Figure 5. A positive moisture balance means that the roof is accumulating moisture, a negative balance shows that the roof dries out in the first year. It seems that only a north orientation combined with an inclination above 40° represents a high risk for such an assembly. In other cases the drying potential is sufficiently high due to solar radiation as long as the roof is not severely shaded. Since the solar heat gains of a north oriented roof with high inclination are comparable to those of a wall the predictions of the Glaser-method which disapproves the assembly if it were a wall are again quite close to the WUFI-simulation results.

4. CONCLUSIONS

The examples show that the Glaser-method and the modern simulation tool WUFI come to a similar prediction concerning the interstitial condensation in roof constructions. This is not surprising, because the Glaser-method has been designed for light-weight constructions and the boundary conditions in DIN 4108-3 have been chosen to represent the severe climate in Holzkirchen. However, the simulations permit the determination of the moisture behaviour in a more realistic way including construction moisture, solar radiation effects, moisture influence on the heat transfer, etc. Especially the construction moisture problem has become more important in recent years due to tight time schedules during building erection.

Therefore it makes more sense to introduce modern simulation tools to the practitioner instead of developing an extended Glaser-method designed for all European countries. Unlike the Glaser-method hygrothermal simulation tools include sorption as well as liquid transport and are therefore also applicable to massive structures. In order to obtain reproducible results, guidelines for the handling of such simulation tools are required. The international society for building restoration and conservation (WTA) has started to fill this gap by inaugurating a working group for this purpose. These WTA-guidelines will also form a basis for normative tasks within the frame of CEN TC 89 WG 10.

5. REFERENCES

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