Leipzig Institute for Materials Research and Testing (MFPA Leipzig)
Business Division IV Building Physics
Hans-Weigel-Str. 2 b, D - 04319 Leipzig

www.mfpa-leipzig.de

Munich Technical University (TU München)
Department of Civil Engineering and Surveying
Chair of timber construction and structural design
Arcisstraße 21, D - 80333 München

www.hb.bv.tum.de

German Society for Wood Research (DGfH e.V.)
Bayerstraße 57-59/V
D - 80335 München

www.dgfh.de

Short Report

Experimental and numerical study on the hygrothermal behaviour of nonventilated wooden flat roofs using ecological products with a view to the development of damage-free and sustainable constructions

This project was supported by German Society for Wood Research (DGfH e.V.) by means of research program *Zukunft Bau* of German Federal Ministery of Transport, Building and Urban development (BMVBS) and of Federal Office for Building and Regional Planning (BBR).

Project number: Z 6 - 10.08.18.7-07.18 Project period: September 2007 - April 2009

Authors: Univ.-Prof. Dr.-Ing. Stefan Winter (TU München)
Dipl.-Ing. Claudia Fülle (MFPA Leipzig)
Dipl.-Ing. Norman Werther (TU München)

Industry partners:

Leipzig, May 2009

1 Research Project

1.1 Introduction

Flat roofs are actually strongly in demand in the industry and administration building sector, but also by private house builders.

Ventilated flat roof constructions cannot assure necessary ventilation because of the marginal roof inclination. Moreover they are not architecturally interesting on account of their height of construction.

German Standard (DIN 4108-3) demands for nonventilated flat roof constructions either insulation above the sealing or a tight vapour barrier (s_d = 100 m).
Many examples of built flat roofs have shown that constructions with tight vapour barriers can easily cause damages: Moisture coming from construction process or entering by convection cannot dry out in summer through the tight vapour barrier. A moisture-variable diffusion-checking layer can show considerable advantages here.
The collection of data and knowledge on the hygrothermal behaviour of different constructions of nonventilated wooden flat roofs by systematic outdoor experiments was therefore the key aim in the present research project.

On the basis of these experimental studies validation of further numerical calculations was carried out. These further numerical calculations were made in order to find limits of the constructions and to evaluate boundary conditions.

Following subjects have been discussed:

- How much can the usage of moisture-variable vapour checks, oriented strand boards and sealings with relatively low vapour diffusion resistance help to avoid damages ?
- Which criteria have to be complied with when using ecological insulation materials such as cellulose or oriented strand boards ?
- How much does the sealing (colour of sealing, green roof, with gravel, shaded) have an influence over the hygrothermal behaviour in the roof construction ?

With the help of these data, sustainable and rugged constructions with satisfying level of reliability have been developed. Future damages caused by missing experiences and out-dated standards can be avoided. Besides, commercial losses for construction companies can be minimised.

Furthermore, a study on built examples has been carried out in order to link the experimental study with practical experiences.

1.2 Experimental study

1.2.1 Test building in Leipzig

The experimental study was carried in an outdoor test building at MFPA Leipzig, where different nonventilated wooden flat roofs were built (figure 1).

The roof constructions differed in the inside diffusion-checking layer, the insulation material and the sealing (figure 2).

The utilised flat roof had a surface of 8 x 5,5 m.

The roof, which was inclined with 2°, was bordered by an attic. In order to avoid shading, testing surface was always at 0,5 m from the attic.

There were 8 measuring fields (4 with black PVC sealing, 4 with green roof), each of them with a surface of 3 m². The measuring fields were separated from each other by partition boards.

Furthermore, there were 3 measuring fields (with pale PVC sealing, with gravel, shaded) in order to determine the influence of sealing layer.

Figure 1 Test building in Leipzig

The interior room was air-conditioned in order to get ordinary usage conditions.

The following 11 variants have been built:

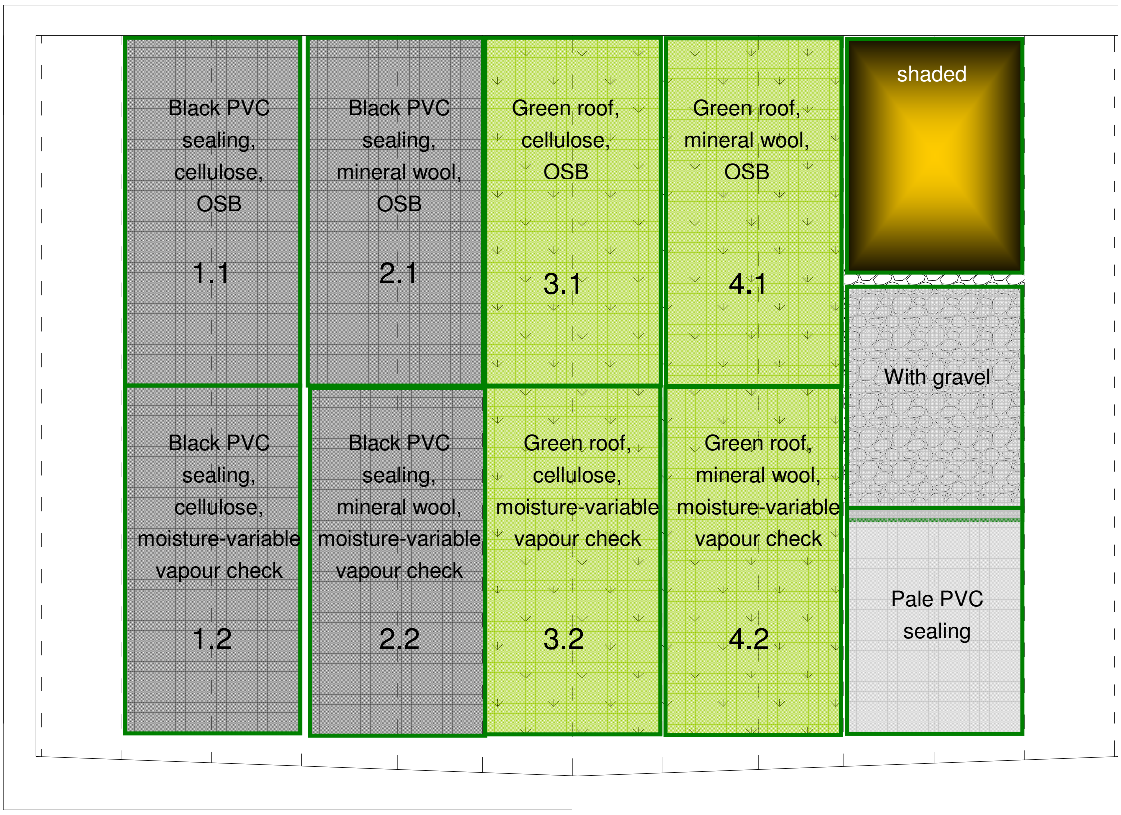

Figure 2 Test building in Leipzig, variants of roof construction

1.2.2 Measurements

The following data were recorded in the test building:

- Outdoor and indoor climate
    - Temperature and relative humidity of outer air
    - Wind direction and wind velocity
    - Vertical rain
    - Global radiation
    - Temperature and relative humidity of internal air
- Hygrothermal conditions in the roof construction
    - Temperature under the sealing
    - Temperature and relative humidity in the critical section, between insulation and OSB (upper planking)
- Moisture content
    - Moisture content of timber frame and of OSB (upper planking)

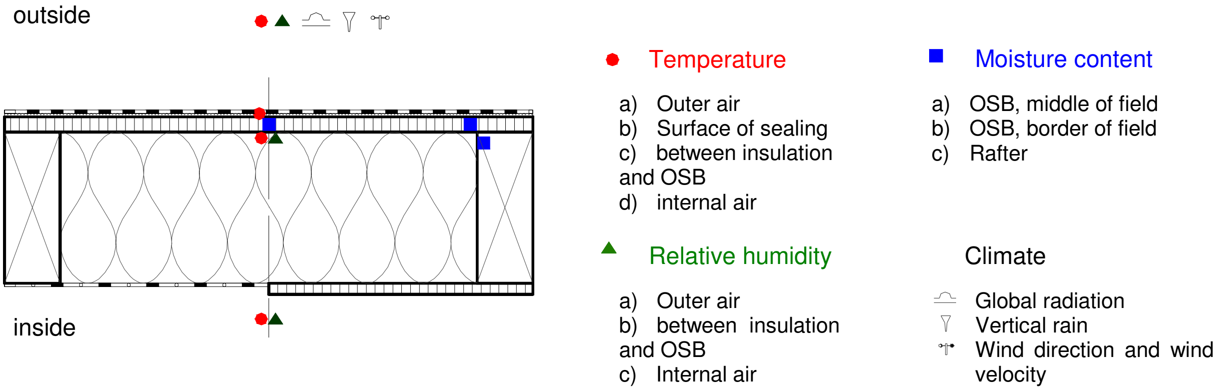

Figure 3 Placement of measuring technique

1.2.3 Evaluation criteria

Damages will occur when wooden building parts or derived timber products, such as oriented strand boards (OSB), show high moisture contents over longer periods and when the capability of drying out in summer is too low to lead away arisen moisture.

In the present research project, requirements and evaluation criteria have been derived from the application ranges of the derived timber products and from requests in order to avoid the growth of mould fungus.

Critical building parts in the examined roof constructions are the upper oriented strand boards (OSB) and the wooden rafters.

The moisture content in the upper oriented strand boards must not exceed the limiting value of 18 M-% over a longer period.

The moisture content of the rafters must not exceed the limiting value of 20 M-% over a longer period.

In order to avoid the growth of mould fungus, relative humidity in the critical section, between oriented strand boards (OSB) and insulation, must not exceed the limiting value of 80 % over a longer period.

2 Measurement results from test building

2.1 Flat roof constructions with black PVC sealing

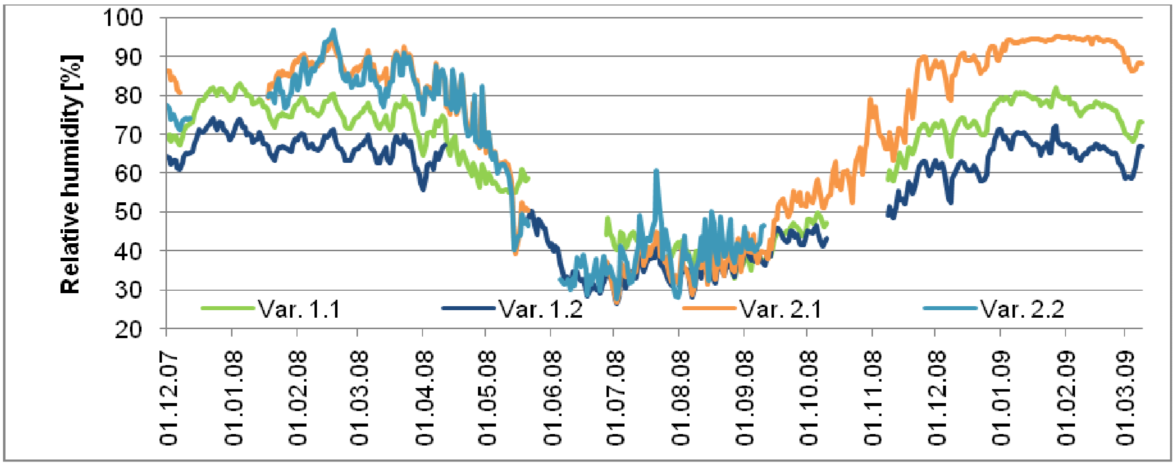

Figure 3 Relative humidity in the critical section (between insulation and upper OSB), measured mean daily values

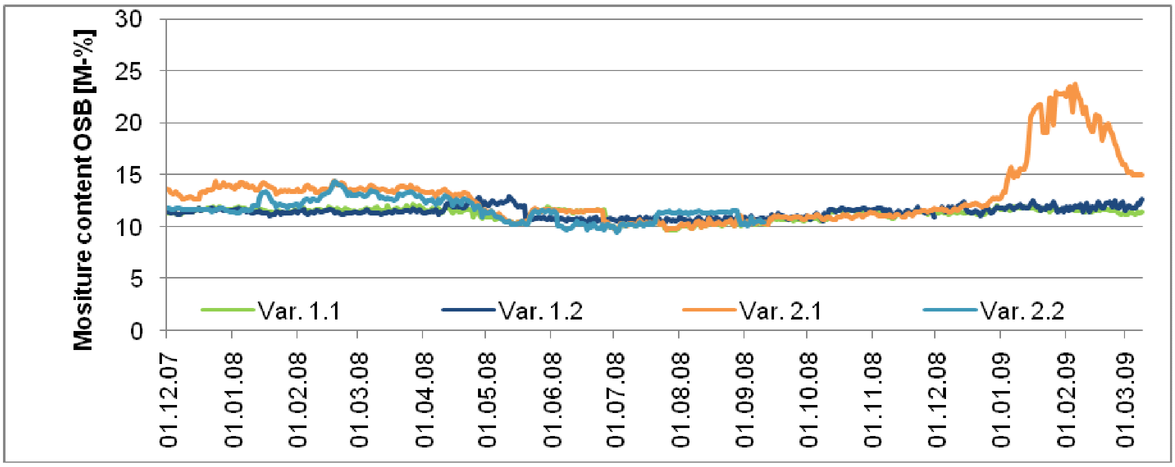

Figure 4 Moisture content in the upper OSB, measured mean daily values

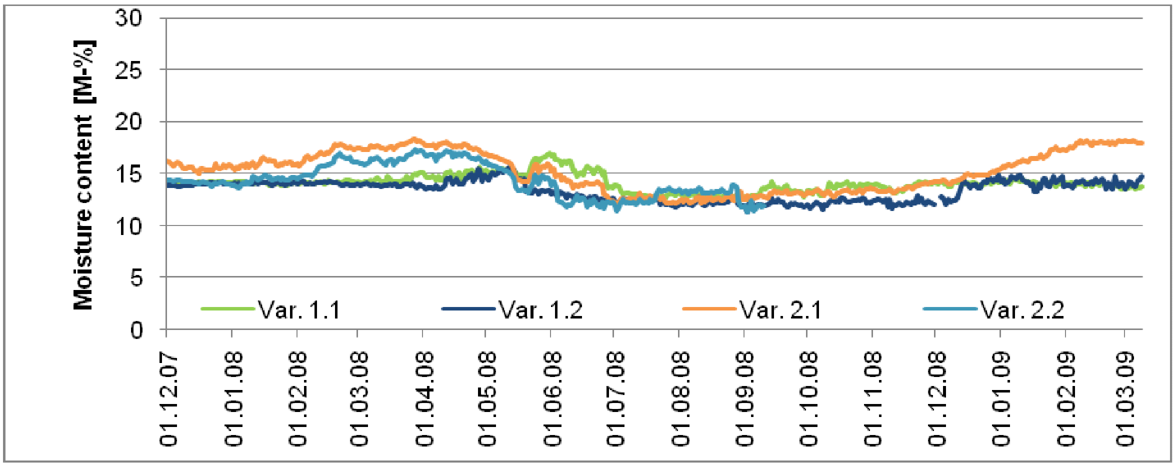

Figure 5 Moisture content in the rafters, measured mean daily values

2.2 Flat roof constructions with green roof

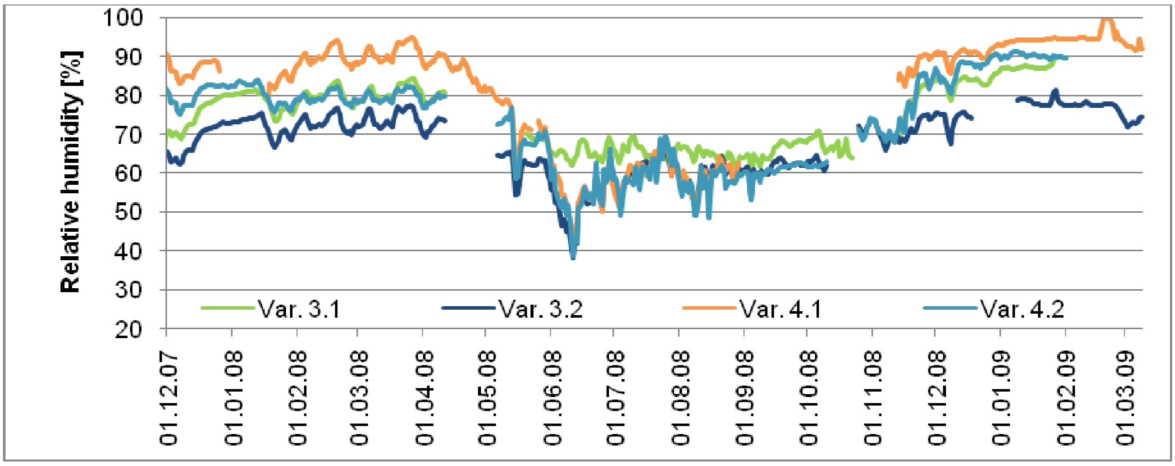

Figure 6 Relative humidity in the critical section (between insulation and upper OSB), measured mean daily values

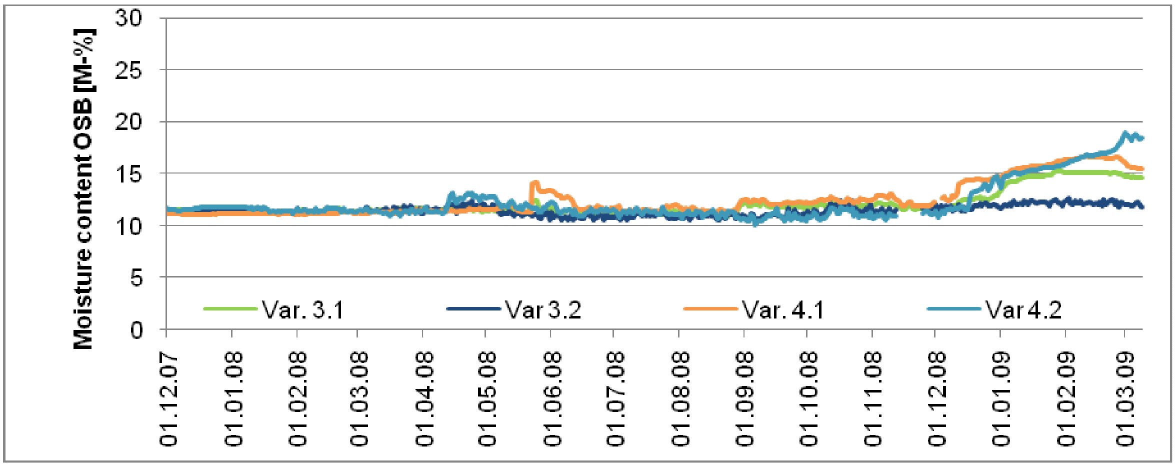

Figure 7 Moisture content in the upper OSB, measured mean daily values

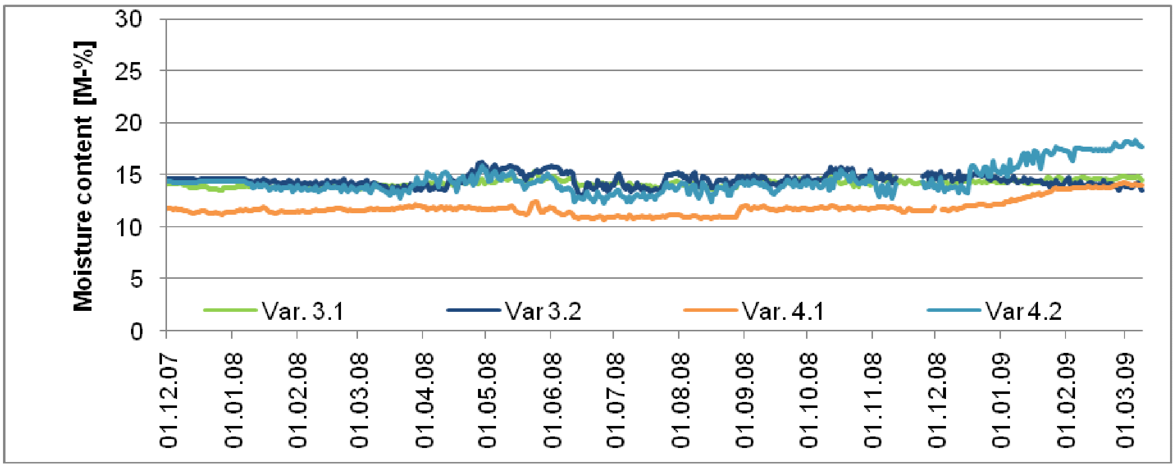

Figure 8 Moisture content in the rafters, measured mean daily values

3 Hygrothermal calculations

Numerical simulations for all construction variants were carried out with a numerical program for coupled heat and moisture transfer (WUFI). Therefore, measured data of outdoor and indoor climate were used.

Measured data and results of numerical simulation agreed very well with each other.

The following figures show, as an example, a comparison of measured data and calculation results for variant 1.2 (black PVC sealing - OSB - cellulose - moisture-variable vapour check):

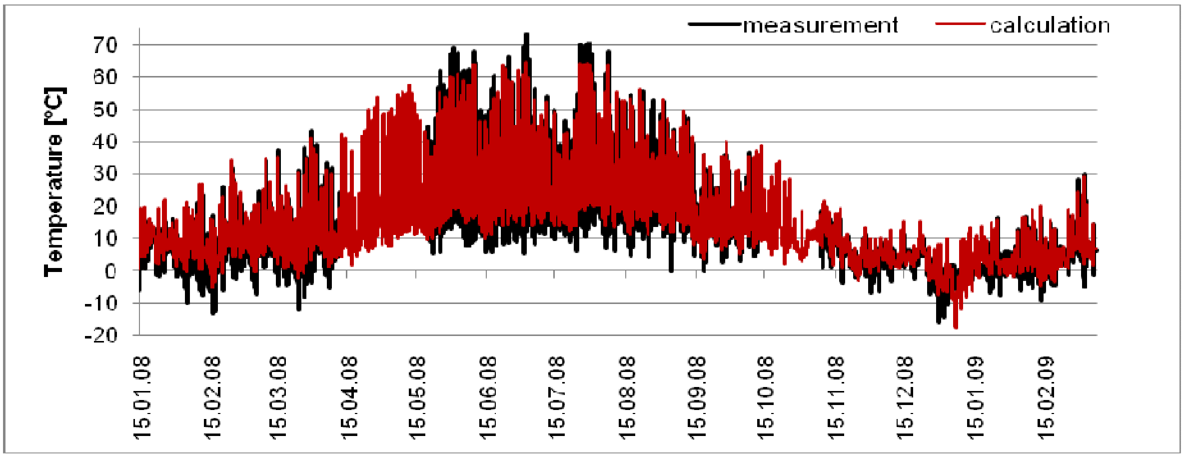

Figure 9 Temperature in the critical section (between insulation and OSB) in var. 1.2

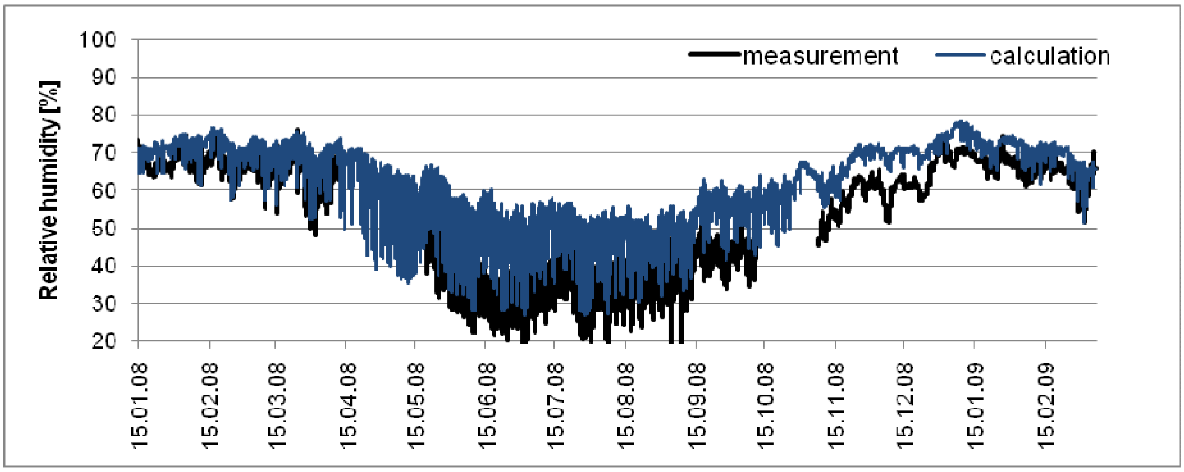

Figure 10 Relative humidity in the critical section (between insulation and OSB) in var. 1.2

On the basis of validated material data, further hygrothermal simulations (**parameter studies**) were carried out. Examined cases were:

- Variation of outer climate (calculation for climate „Holzkirchen 1991“)
- Variation of inside climate (simulation of higher internal relative humidity because of e.g. making floor)
- Consideration of convective entry of moisture (250 g/(m²·winter))
- Variation of sealing (calculation for pale PVC sealing and diffusion resistant sealing such as bitumen)
- Simulation of shading by adjacent buildings
- Simulation of superstructures (e.g. photovoltaics)

4 Conclusion

The present studies in the test building in Leipzig have shown that nonventilated wooden flat roof constructions are able to perform without damages when considering certain constructive boundary conditions. Further knowledge on limits and usage conditions of the roof constructions could be derived from extensive numerical simulations. Studies on existing buildings with wooden flat roofs supplement the measurements in the test building and the parameter studies.

The examined 8 variants differed largely concerning their hygrothermal behaviour.

The following constructions operated successfully and can therefore be recommended:

- Variant 1.2 Black PVC sealing - OSB - cellulose - moisture-variable vapour check
- Variant 1.1 Black PVC sealing - OSB - cellulose - OSB
- Variant 2.2 Black PVC sealing - OSB - mineral wool - moisture-variable vapour check
- Variant 3.2 Green roof - OSB - cellulose - moisture-variable vapour check

In singular cases, further studies must be carried out for:

- Variant 2.1 Black PVC sealing - OSB - mineral wool - OSB

The following variants cannot be recommended:

- Variant 3.1 Green roof - OSB - cellulose - OSB
- Variant 4.1 Green roof - OSB - mineral wool - OSB
- Variant 4.2 Green roof - OSB - mineral wool - moisture-variable vapour check

The following key results were gained:

- A sorptive insulation material such as cellulose is able to buffer moisture and therefore to contribute to hygric stress relief which can be caused by moisture coming from construction process or entering by convection. Therefore the sorptive insulation material must be preferred to e.g. mineral wool.
- A moisture-variable vapour check is advantageous compared to an oriented strand board because of its wider range of water vapour diffusion resistance.
- The usage of a black PVC sealing with a relatively low water vapour diffusion resistance (s_d ~ 20 m) offers key benefits concerning hygrothermal behaviour in comparison to the usage of pale PVC sealing or relatively tight sealings such as bitumen (s_d ~ 300 m).

Nonventilated wooden flat roofs remain sensitive constructions and demand higher diligence and quality control from planning to construction.

However: If one carries out a correct, airtight construction, chooses suitable materials for insulation, internal diffusion-checking layer and sealing, and considers basic demands on boundary conditions, nonventilated wooden flat roofs perform very well and operate without damages.