STUDY ON THE HYGROTHERMAL PERFORMANCE OF WOODEN BASEMENT-SYSTEMS OF FLOATING HOUSES IN "PASSIVE HOUSE TECHNOLOGY"

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ABSTRACT

This paper presents results of a study concerning the hygrothermal and durability performance of timber construction wall and bottom slab assemblies built in "passive house technology" for habitable basements of floating houses.

Highly-insulated basement systems made of solid timber boards were developed, simulated and monitored and with regard to hygrothermal performance and furthermore, the probable durability investigated. The results of the simulations will be compared with in-situ measurements, which are carried out at an test set-up.

KEYWORDS

Floating houses, passive house technology, heat- & moisture transfer, durability

INTRODUCTION

The efficient use of energy due to increasing energy prices but also CO_2- emission excesses requires new forward-looking concepts. About ~ 40% of our annual energy consumption is used in buildings. In the European Union, especially Germany and Austria, low energy building concepts, like the "passive house" - standard therefore were developed, to minimize the energy demand of buildings. The term "passive house" refers to a specific construction standard. Comfortable internal space temperature is achieved in a largely "passive" way with the free heat gains of solar irradiation through openings (windows, etc.) as well as the heat emissions of the occupants and household appliances. The necessary heating energy consumption of a passive house is lower than 15 kWh/m²yr and can be achieved by heating the supply air in the ventilation system. Passive houses presume a high insulation performance of the building enclosure with U- values lower than 0,15 W/(m²K) ≈ 0.026Btu/(h-ft²-F), thermal bridge free constructions and good airtightness.

The main idea within the present ongoing research project is to create houses, which are independent from conventional energy supply. The energy performance of residental buildings (solar radiation heat gains, effectiveness of photovoltaics and solar panels, etc.) should be optimized by turing the house according to the course of the sun. Another reason for the development of floating houses is, that they could accommodate rising flood waters, like in the case of the floods in the Alps and low lying parts of Germany and the Netherlands in previous years.

The research project is currently in the initial stage and a first step towards the above mentioned objectives is therefore to find technical solutions for wall and bottom slab assemblies of floatable, highly-insulated basement systems.

DESCRIPTION OF INVESTIGATED CASES

In frame of this research project a floating basement system in "passive house" standard was developed. Different wall and bottom slab assemblies made of solid timber boards covered with varying outside insulation materials were designed and with the help of modeling software-tools (heat- & moisture simulations) analyzed and optimized. Especially the hygrothermal performance and probable durability of the wooden constructions were investigated. The light-weight timber constructions were chosen due to the fact, that a haulage over land, but also erection work of the whole basement system would be easier to accomplish, compared to normally used wall systems made of reinforced concrete .

Case 1:
polyurea sealing coating (liquid membrane);
extruded polystyrene insulation (XPS) 150mm (6˝);
bituminous adhesive;
extruded polystyrene insulation (XPS) 150mm (6˝);
bituminous adhesive;
vapor barrier;
bituminous adhesive;
solid cross-laminated timber board 125mm (5˝);
gypsum board 12.5mm (1/2˝);

Case 2:
polyurea sealing coating (liquid membrane);
spr. polyurethane foam insulation 300mm (12″);
vapor barrier;
bituminous adhesive;
solid cross-laminated timber board 125mm (5″);
gypsum board 12.5mm (1/2″);

Schematic draft of wall assemblies

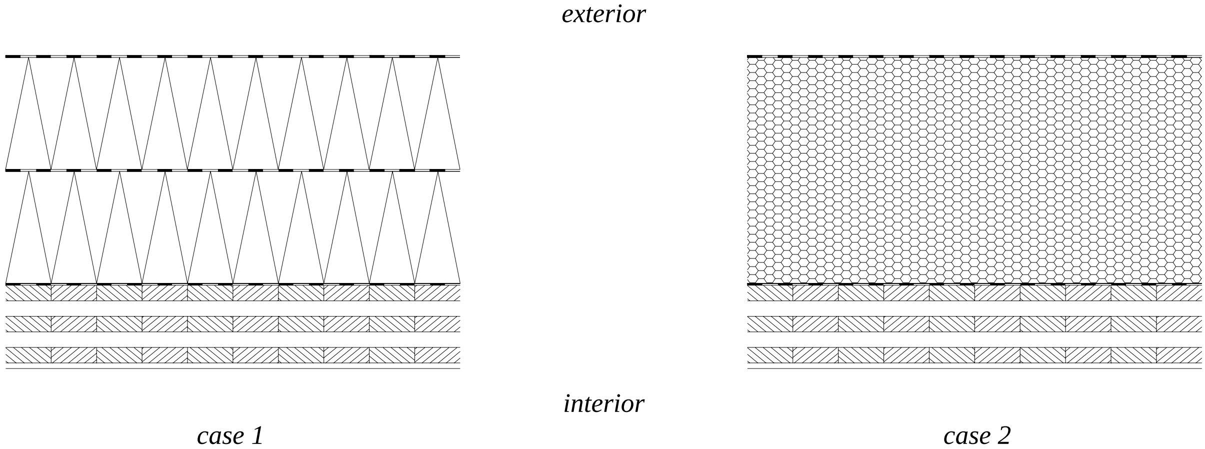

Figure 1: Schematic draft of investigated wall assemblies case 1 and 2 (not to scale)

In a second step, two test set-ups were built to analyze the adhesive strength of the outside sealing surface on the different insulation materials under real climatic conditions and to perform first in-situ measurements concerning the moisture performance of both wall systems. Parallel to these measurements further simulations with the current measured outdoor water temperatures are carried out and compared.

This paper only presents results of the preliminary simulations hence first in-situ measurement results at the moment are lacking. Especially the hygric behavior, like water content in the exterior area of the insulation layers and the relative humidity of the wooden components, was investigated to assess the potential durability of these constructions.

DESCRIPTION OF CALCULATION

Description of computer model

The simulations were carried out by using the software WUFI®. (Wärme und Feuchte instationär – Transient Heat and Moisture). This software was developed at the Fraunhofer Institute for Building Physics (Künzel, 1994) in Holzkirchen / Germany and validated using data from outdoor and laboratory tests. It allows the calculation of the transient heat and moisture transport in materials and building constructions, exposed to natural exterior and interior climate conditions.

Default program settings

The heat transfer coefficient at the exterior surface is zero, at the interior 8 W/m²K.

Boundary and initial conditions

The outside water- temperature amounts ~ 8 °C and varies in the course of one year with an amplitude of ± 4 °C. The indoor air temperature and humidity for the preliminary simulations amounts ~ 22 °C and 45 % RH. An initial temperature of 20 °C and an initial moisture content of 50 % RH in all components were chosen.

Material properties

The material properties employed in these simulations were taken from the WUFI® database.

Material	Bulk density [kg/m³]	Porosity [m³/m³]	Heat capacity [kJ/kgK]	Heat conductivity dry [W/mK]	Diffusion restistance factor dry [-]
SPF Insulation	39	0,99	1470	0,02	90
Spruce radial	455	0,73	1500	0,09	130
Spruce longitudinal	455	0,73	1500	0,09	4,30
XPS Insulation	30	0,99	1470	0,02	170
Vapor Barrier	130	0,001	2300	2,30	$1{,}5x10^6$
Gypsum board	850	0,65	850	0,2	8

DESIGNING FLOATING BASEMENTS IN “PASSIVE HOUSE” STANDARD

The main purpose of this study is, as above mentioned, to characterize the long-term hygrothermal behavior of different wall and bottom slab systems, exposed to water contact. During the design process together with the concerned partners from industry, different constructions with varying exterior insulation materials were developed and with the help of hygrothermal simulations analyzed and optimized.

SIMULATION RESULTS

First of all the water content in the whole constructions, but also in the different wall layers was investigated, to visualize the general hygric behaviour of the seletected cases. Further results concerning the thermal behavior (U- values) under real boundary conditions are also shown.

It is noted, that the analysis was conducted while subjecting a good workmanship. Especially the vapor barrier, which is limiting the vapor flow into the constructions, was supposed to be without perforations and leakage.

Case 1

The total water content (TWC) of wall assembly case 1 is showing a constant upward movement during the simulation period of the first 30 years, but it can be noticed, that the increase from about 5,525 kg/m² up to ~ 5,55 kg/m² is almost marginal. The vapor diffusion from the interior is limited by placing a vapor barrier at the outside of the solid timber boards. Furthermore it is important to control the indoor humidity at max. 50 % RH. (Lstiburek, 1994, Cheple, 2001) In modern passive houses this can be adjusted by the anyway existing mechanical ventilation system combined with an automatic air humidifier. Nevertheless there is a low vapor flow from the inside through the whole construction. Figure 2 also shows, that the water content of the outside XPS-board is slightly increasing from 0,05 kg/m³ at the beginning up to ~ 0,27 kg/m³ after 30 years.

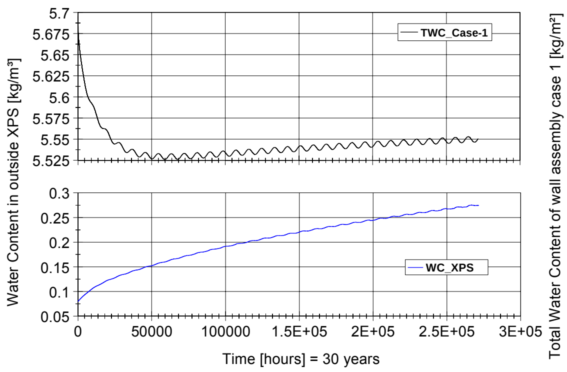

Figure 2: Total water content and water content of exterior XPS- board – case 1

It can be assumed, that this insignificant rising won`t be problematic for the whole construction, but two problems might occure:

First it is necessary to investigate the moisture accumulation in the critical section under the outside polyurea coating, because there might be a poor adhesion of the coating or a potentially freeze-thaw damage in the crossover area between water contact and outside air. On the other hand the effective insulating property influenced by the moisture accumulation must be considered.

Figure 3 depicts the relative humidity and temperature of the outside layer of the timber board and the outermost area of the exterior XPS- board.

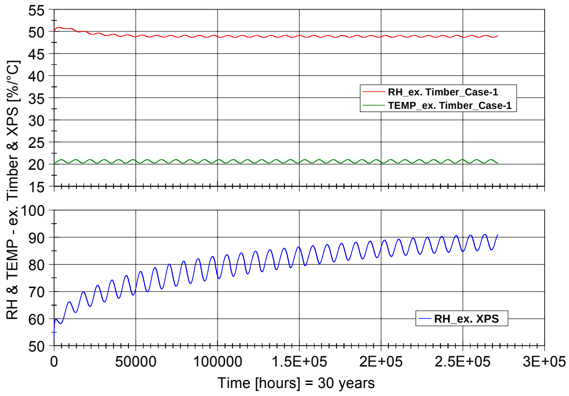

Figure 3: Relative humidity and temperature in outside layer of the timber board and the outermost area of the exteríor XPS- board – case 1

The RH in the XPS in 1mm distance to the polyurea coating increases beginning from 50 % up to about 90 % after 30 years, but the gradient is after ~ 20 years only gently inclining. We suppose, that the XPS won`t be saturated in the course of the years, so freeze-thaw damage might be neglected. Nevertheless currently the projectteam is conducting laboratory tests concerning the adhesion capacity of the exterior polyurea coating under different climatic influences, which are still ongoing.

Figure 3 also includes the RH in the outside layer of the timber board, which remains, as expected, at about 50 % and a temperature of ~ 22 °C the whole time, thus moisture related problems can be disregarded.

As above mentioned, passive houses require a well insulated building envelope with max. heat transfer values of 0.15 W/m²K. As Figure 4 shows, the effective U- value of case 1 under the given climatic impact conditions was calculated by means of a simulation. Case 1 represents an excellent thermal performance with an U- value, which varies between 0.07 and 0.069 W/(m²K) during the course of the first 30 years under the given climatic impact. The average U- value of ~ 0.0695 W/(m²K) therefore meets the high requirements of the passive house standard.

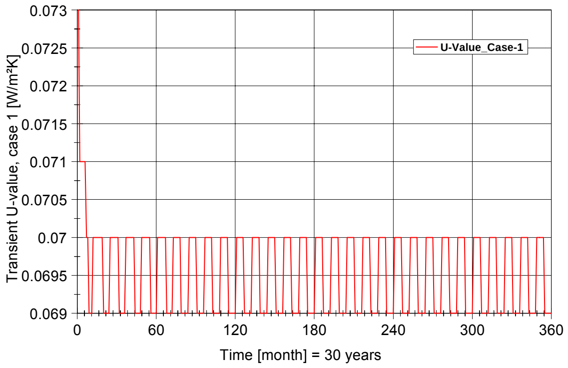

Figure 4: U- values - case 1

Figure 5: Test specimen - case 1

Case - 2

In the same way we analyzed the hygrothermal performance of case 2 (Figure 6). The total water content (TWC) of this wall variant is also showing a constant upward movement during the simulation period of the first 30 years, with a slightly steeper gradient.

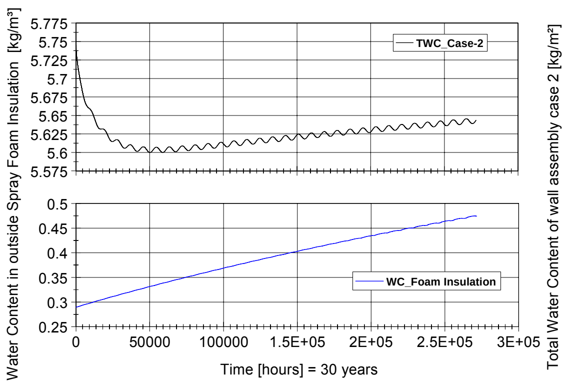

Figure 6: Total water content and water content of spray foam insulation – case 2

Starting at ~ 5.6 kg/m² the TWC increases up to ~ 5.65 kg/m² within the first 30 years, demonstrated in Figure 6. Furthermore the water content of the spray foam insulation is also rising from ~ 0.3 up to ~ 0.5 kg/m³ within the first 30 years, so it must be considered, that similar problems, a described in case 1, could occure.

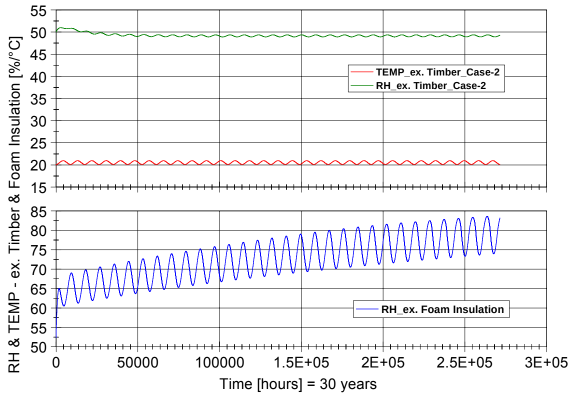

Figure 7: Relative humidity and temperature in outside layer of the timber board and the outermost area of the spray foam insulation – case 2

The simulation predicts, that the relative humidity inside the foam insulation at the interface to the polyurea coating, demonstrated in Figure 7, is increasing up to ~ 85 % while the calculation period of 30 years. It can be assumed, that this humidity content may not influence the strength (Swinton, M. et. al.) of the foam insulation, but similar to case 1 the adhesion capacity of the exterior polyurea coating on the foam insulation subsurface needs to be examined.

Considering the U- value, displayed in Figure 8, one can observe, that the heat transfer is varying between 0.074 and 0.075 W/(m²K). The insulation quality is unharmed due to the moderate moisture storage inside the insulation and is therefore showing a excellent thermal performance.

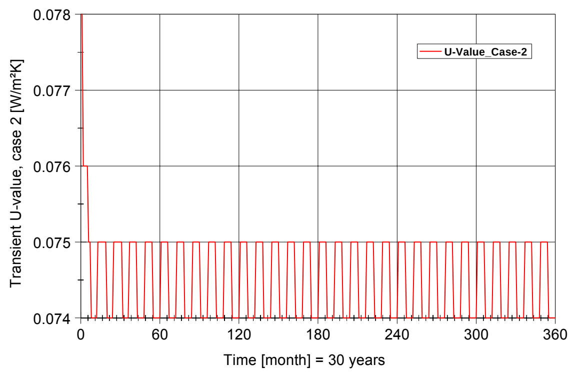

Figure 8: U- values - case 2

Figure 9: Spraying the foam insulation on the experimental set-up

IN-SITU MEASUREMENTS AND SIMULATIONS COMPARISON

Description of test set-ups

In October 2006 a small experimental set-up (square base ~ 6 m²) was built, to obtain informations about the feasibility of both wall systems in practice. This test set-up in an first approach to examine the interrelation (existing internal stresses, etc.) between the different material layers and especially to investigate the durability performance of the outside waterproofing layer, exposed to varying boundary conditions. The wall assemblies are also instrumented with measurement equipment to obtain first informations concerning the moisture perfomance of these wall systems. The measurements started with 1st of October 2006 and are still ongoing. Based on these first informations, the basement construction systems have been optimized.

Figure 10: Dipping of experimental set-up in water

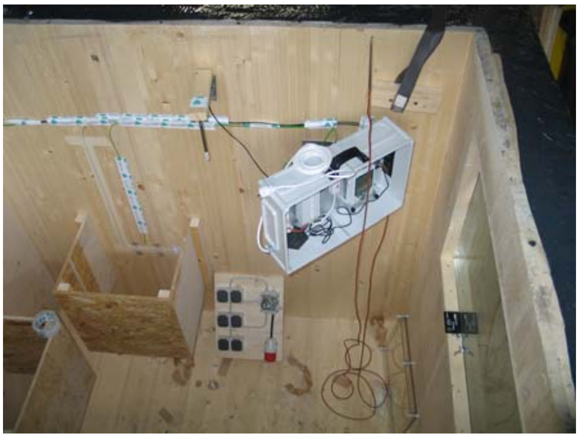

Figure 11: Wall assemblies of experimental set-up with built-in measurement equipment

The next step will be the erection of a full-scale basement in October 2007, to perform long-term measurements at selected wall assemblies under real boundary conditions. Indoor conditions of both test set-ups are, according to common passive houses, controlled constant at about ~ 22 °C and ~ 45 % RH and as well as the exterior conditions of adjacent water and ambient air continuously monitored. Due to these measurements further comparing simulations with the actually climatic data will be carried out to verify the simulation model for this special case and based on that, to analyze the long-term performance.

Figure 12: Rendering (visualization) of the full-scale test-house

DISCUSSION AND CONCLUSIONS

This paper presents first results concerning the hygrothermal behavior of different light-weight wall systems exposed to water contact. Investigations using heat and moisture-transfer simulations have shown, that both wall systems are showing a good thermal performance with U- values < 0,08 W/(m²K) and are therefore conform with the passive house technology related requirements. Further the research work has shown, that in both cases a continous moisture accumulation due to the almost constant vapor flow to the exterior part of the envelope occures, which is normally assumed to be critical. However more detailed investigations indicated, that during the simulation period of 30 years the amount of accumulating moisture with ~ 0,2 kg/m³ in the insulation layers should be quite low. Especially the potentially critical contact area of the insulation layers to the exterior waterproofing membrane should not be saturated, so freeze-thaw damage in the critical crossover area between water contact and outside air should be avoided. It is explicit noted, that the analysis was conducted while subjecting an intact, seamlessly vapor barrier. Comparing simulations with linear leakages resulted in high moisture masses in the outermost area of the insulation, so it is well known, that the quality requirements on the actually workmanship are very high and thus the projectteam is currently working about different options to improve the practical application.

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