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The effect of thermal transmittance of building envelope and material selection of wind barrier on moisture safety of timber frame exterior wall

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ABSTRACT

The nearly zero energy buildings (nZEB) ideology of the future obliges, first and foremost, that heat losses should be reduced remarkably compared to the present levels. The current study examines the potential hygrothermal risks and their effect on highly insulated timber frame exterior walls under cold climate conditions. The focus is on the timber frame exterior walls with thermal transmittances between 0.17 and 0.08 W/(m^2 K), with different material combinations and boundary conditions, where the risk of mould growth as a performance criterion was used. A careful selection of materials allows to design moisture safe timber frame exterior walls and provide low thermal transmittance. It was found that the relative humidity and the risk of mould growth are higher and the drying out period is longer in walls with lower thermal transmittance when insulation thickness is the only changed parameter. Wind barriers with higher thermal resistance and water vapour permeability indicated a lower increase of mould growth risk in structure in the course of reduction of the thermal transmittance. Therefore, the building envelope of the future nZEB needs a careful hygrothermal design.

1. Introduction

Minimising heat loss through the building envelope is one of the key factors to ensure a very high energy performance like in nearly Zero Energy Buildings (nZEB) [1], passive houses or other national low-energy building standards. Heat loss through the building envelope depends on the thermal transmittance U (W/(m^2 K)) of plane structures (walls, roof, windows etc.) as well as on linear and point thermal transmittance of connections of structures, disconnections of insulation (i.e. thermal bridges) and air leakages of the building envelope. All of these components that have a negative influence should be minimised when the target is low heat loss through the building envelope.

Several tasks that are related to the hygrothermal performance of structures need to be solved in the design and construction process of building envelopes with thicker thermal insulation and lower thermal transmittance to guarantee the moisture safety of the building envelope. Thicker insulation (i.e. bigger volume of material in building envelope) may contain more built-in moisture, which has to dry out after the construction process. A smaller heat flow slows down the dry-out rate of moisture and it could be another factor, which influences how a highly insulated wall becomes more sensitive to moisture damages. Although the critical moisture level for mould growth increases with temperature decrease [2,3], the presence of sufficient relative humidity (RH) is the most critical factor influencing mould growth.

Kurnitski [4] and Airaksinen [5] showed higher humid conditions in highly insulated outdoor ventilated crawl spaces in Finland. Thicker thermal insulation between the living space and attic and a lack of a warm chimney have increased moisture and mould damages in Sweden [6]. In addition, houses frequently renovated with additional attic insulation have led to low temperatures in attic space and hence a higher humidity [7] in Sweden. Vinha et al. [8] showed that stricter requirements in Finland for the energy efficiency and increased thickness of thermal insulation will lead both to changes in building technology and in structures and may become a source of substantial moisture-related problems in building envelopes in the far future as a result of the climate change. Langmans et al. [9] analysed four highly insulated timber frame walls with an exterior air barrier in laboratory conditions and showed an increased moisture flow at the upper part of the walls driven by buoyancy forces. Kalamees et al. [10] have pointed out that the performance of the building service systems and moisture safety should be carefully focused on already in the preliminary stages of design while planning buildings with high energy efficiency.

Based on preceding studies, we may declare that in order to design building envelopes with a thicker thermal insulation layer and lower thermal transmittance, the designer has to solve many tasks related to the hygrothermal performance of a building

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envelope. However, after fulfilling the load-bearing requirements, other layers in the building envelope are usually designed according to the required thermal transmittance and visual appearance. But the design of hygrothermal performance of the future nZEB highly insulated building envelope, based the current knowledge and practices, or on the Glaser method [11], may most likely appear insufficient.

This study examines the potential hygrothermal risks and their impact on a highly insulated timber frame exterior wall under cold climate conditions in Estonia. The questions that are addressed in the current research are the following:

1) What is the extent and direction of the influence of increase of thermal insulation on the hygrothermal performance and moisture safety of the timber frame exterior wall?
2) What kind of material properties should be preferred to avoid favourable conditions for mould growth and humidity accumulation?

These aspects were studied by parametric simulations, carried out for a timber frame exterior wall that corresponds to the current energy performance requirements in Estonia [12]. Various types of material properties (e.g. water vapour permeability, thermal conductivity, moisture storage) and boundary conditions were studied. The risk of mould growth was used as a performance criterion to predict the acceptability of hygrothermal performance.

2. Methods

2.1. Hygrothermal simulations and material data

The dynamic hygrothermal simulation programme Delphin, developed at the Technical University of Dresden and successfully validated [13,14], was used in this study. Delphin is a simulation programme for coupled heat, moisture and matter transport in porous building materials and it is used for different applications, e.g. calculation of mould growth risks with consideration of climate impacts, structure conditions and materials modelling.

The moisture mass balance can be expressed as:

$$\frac{\partial}{\partial t}\rho^{m_{w+v}}_{\mathrm{REV}} = \frac{\partial}{\partial x}\left[j^{m_w}_{\mathrm{conv}} + j^{m_v}_{\mathrm{conv}} + j^{m_v}_{\mathrm{diff}}\right] + \sigma^{m_{w+v}}_{\mathrm{REV}} \tag{1}$$

where $\rho^{m_{w+v}}_{\mathrm{REV}}$ is moisture (water+vapour+ice) density in reference to volume kg/m^3; $\sigma^{m_{w+v}}_{\mathbf{REV}}$ is moisture source/sinks in reference to volume kg/m^{3}s; j is flux kg/m^{2}s; conv is convective; diff is diffusive; v is vapour; w is water. The energy balance is expressed by:

$$\frac{\partial}{\partial t}\rho^{U}_{\mathrm{REV}} = \frac{\partial}{\partial x}\left[j^{Q}_{\mathrm{diff}} + u_l j^{m_l}_{\mathrm{conv}} + u_g j^{m_g}_{\mathrm{conv}} + h_v j^{m_v}_{\mathrm{diff}} + h_{voc,g} j^{m_{voc,g}}_{\mathrm{diff}}\right] + \sigma^{U}_{\mathrm{REV}} \tag{2}$$

where ρ^{U}_{REV} is the internal energy density in reference volume J/m^3, $\sigma^{U}_{\mathrm{REV}}$ is energy source/sinks in reference volume W/m^3, j^{Q}_{diff} is heat conduction W/m^2, j is flux kg/m^{2}s, conv is convective, diff is diffusive, g is gas, l is liquid, u is specific internal energy J/kg, h_v is the specific enthalpy of water vapour J/kg.

The calculations with this programme were made at the point of structure that was most critical with regard to hygrothermal risks, i.e. A1 (Fig. 1). The properties of materials of studied structures (Table 2) are based on the material database of programme Delphin and on the results of laboratory measurements, performed by scientists at Tampere University of Technology [15].

2.2. Simulation of mould growth

In this research we utilised a mathematical model for the calculation of mould growth, decrease and the mould index in changing conditions, designed in Finland [16,17]. According to this model, within fluctuating humidity conditions, the total exposure time for response of growth of mould fungi is affected by the time periods of high and low humidity conditions, as well as the humidity and temperature level. In the simulation of mould growth, it is crucial to know the lowest (threshold) conditions where fungal growth is possible on different materials. The boundary curve for the risk of mould growth in the range of temperature between 5 and 40 °C on a wooden material can be described by a polynomial function:

$$\mathrm{RH}_{\mathrm{crit}} = \begin{cases} -0.00267{*}t^3 + 0.16{*}t^2 - 3.13{*}t + 100 & \text{when } t \le 20\,^\circ\mathrm{C} \\ \mathrm{RH}_{\mathrm{min}} & \text{when } t > 20\,^\circ\mathrm{C} \end{cases} \tag{3}$$

where t is temperature on the investigated material surface (°C) and RH$_{\mathrm{min}}$ represents the minimum level of relative humidity, where mould growth is possible (varies according to the sensitivity of the material) [17].

Furthermore, the importance of duration of these conditions is also significant. There are certain minimum and maximum levels for the moisture content of material, water activity or temperature, between which fungi can grow in wood. Under these favourable conditions, mould growth may start and continue at different rates. The time period, needed for the onset of mould growth and growth intensity, is mainly dependent on water activity, temperature, exposure time and surface quality of the substrate [16,17].

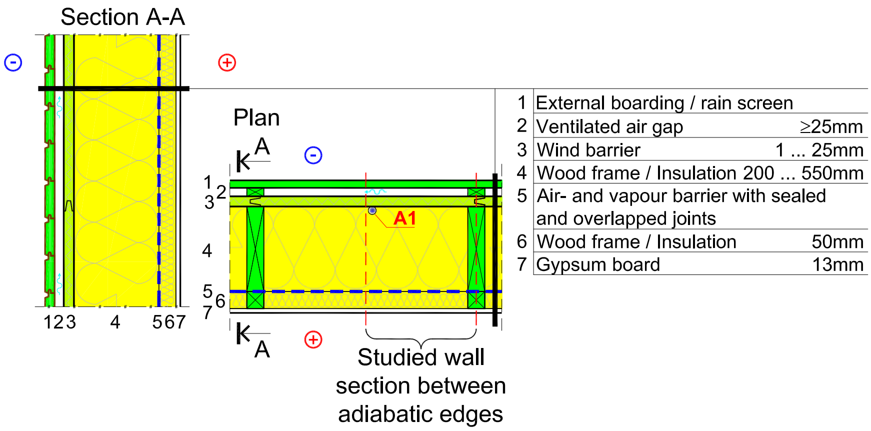

Fig. 1. Studied timber frame exterior wall.