CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 2

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Heiselberg, P. K. (Ed.) (2016). *CLIMA 2016 - proceedings of the 12th REHVA World Congress: volume 2*. Department of Civil Engineering, Aalborg University.

Field Study on Hygrothermal Performance of Highly Insulated Exterior Wall in Estonia

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Abstract

The nearly zero energy buildings (nZEB) ideology of the future obliges foremost that heat losses should be reduced remarkably compared to the present levels. The efficient way to meet these requirements is to design and build passive, highly insulated, nZEB buildings. The current study observes the hygrothermal performance of a single-family detached highly insulated house, built in Estonia. This paper presents a hygrothermal measurements data of the external wall with 3 different combinations of materials of this house, which has been in use for 2 years after construction.
The analysis indicated that thermal resistance of the wind barrier layer and water vapour permeability of the vapour barrier had the strongest influence on the RH (and hence, to mould growth risk) in the critical point of timber frame exterior wall, which is between the insulation and the wind barrier surface.
Field measurements have shown that typical household activities and performance of ventilation provide moisture excess $\Delta v = 4 \ldots 5$ g/m^3 *during winter period. This indicates that in design of highly insulated houses indoor humidity loads cannot be decreased.*
Therefore, the building envelope of the highly insulated building needs careful hygrothermal design and thorough consideration of different material properties.

Keywords - hygrothermal performance, moisture safety, low energy house, indoor climate, hygrothermal loads

1. Introduction

In the European Union (EU), buildings are responsible for 40% of energy consumption and 36% of CO_2 emissions [1,2]. The EU directive 2010/31/EU on energy performance of buildings encourages the transition from fossil fuels to renewable energy sources in the building sector and underlines the importance of reducing energy dependency and greenhouse gas emissions in the EU. Europe has adopted an ambitious vision for the energy efficiency of its buildings. By the end of 2021 all new buildings must meet nearly zero-energy building (*nZEB*) requirements.

In line with the EU directive, Estonian new energy performance regulations entered into force on July 2015 [3], establishing stricter than earlier, primary energy use requirements for *nZEB*, low-energy, new and renovated buildings in Estonia.

In addition to national requirements, there are several internationally recognized energy-performance levels. The Passive House (*PH*) standard [4] is one widely known energy performance standard, which requires thick insulation, minimized thermal bridges, air tightness, insulated glazing and heat recovery ventilation.

There are several new buildings planned and built in past few years in Estonia according to new energy efficiency requirements and following *PH* standards. The Palamuse and Valga municipalities made first steps toward *PH* already in 2009 in Estonia [5]. The first certified *PH* in Estonia is a detached house located in the southern part of Estonia in town Põlva that achieved the annual basis “plus-energy” building classification in the Estonian legislation [6]. The first year measurements in that house showed that no rain protection for structures, no moisture safety protocol during the construction period as well the high diffusion resistance of the wood fiber sheathing board increased humidity conditions in the externally insulated cross-laminated timber panels [6]. Vinha et al. [7] and Pihelo [8] have shown that decreasing of thermal transmittance of building envelope could increase the mould risk in highly insulated buildings. Therefore it is needed to pay special attention on hygrothermal performance and moisture safety of highly insulated buildings.

In this study three different test walls were built to study the hygrothermal performance of the building envelope of an energy efficient detached house in Estonia and to get the measured data for model validation of future hygrothermal simulations.

2. Methods

2.1. Description of the house and structures

The analysed 2-storie detached house (net area 170 m^2) is located at southern part of Estonia (N58°18’, E26°44’, heating degree hours S_{17}=4330°C·h). The compact design (Figure 1), well insulated structures and efficient service systems resulted to low energy house classification according to Estonian legislation [3].

External walls are made of composite beams and columns, consisting pinewood and oriented strand board (OSB) with step 625 mm, and where cellulose insulation thickness is 500 mm. Interior side of beams was covered with 22 mm OSB that gave also stability of external structures. With different combinations of wind barrier and vapour barrier three test walls were built on the northern facade of the second floor (see Table 1 and Figure 2).

Test wall TW3 without vapour barrier and sole wood fibreboard as wind barrier was the initial target wall of house modules factory because of simplicity, saving of materials and vapour permeability (permeable & ecological). As initial simulation during design phase showed the criticality of this solution, the initial design idea was improved. Additional thermal insulation was added onto the wind barrier's external side to increase the temperature and decrease the relative humidity (RH) between insulation and wind barrier (test walls TW1, TW2) and additionally polyethylene (PE) foil as vapour barrier on the inner surface of insulation was added (TW1) to decrease the vapour diffusion through the wall. Between the plastered 25 mm facade hardboard and wind barrier is ventilated 30 mm air gap. The airtightness of building envelope of the whole building was q_{50}=0.3 m^3/(h·m^2).

Figure 1. The overall view (above) and
plans of the ground (below left) and the upper floor (below right).

Table 1. The main differences of three studied test walls

Test wall	Thermal transmittance U, W/(m^{2}K)	Wind barrier	Vapour barrier
TW1	0.10	Mineral wool 30 mm + Wood fibreboard 24 mm	PE foil 0.2 mm
TW2	0.10	Mineral wool 30 mm + Wood fibreboard 24 mm	-
TW3	0.11	Wood fibreboard 24 mm	-

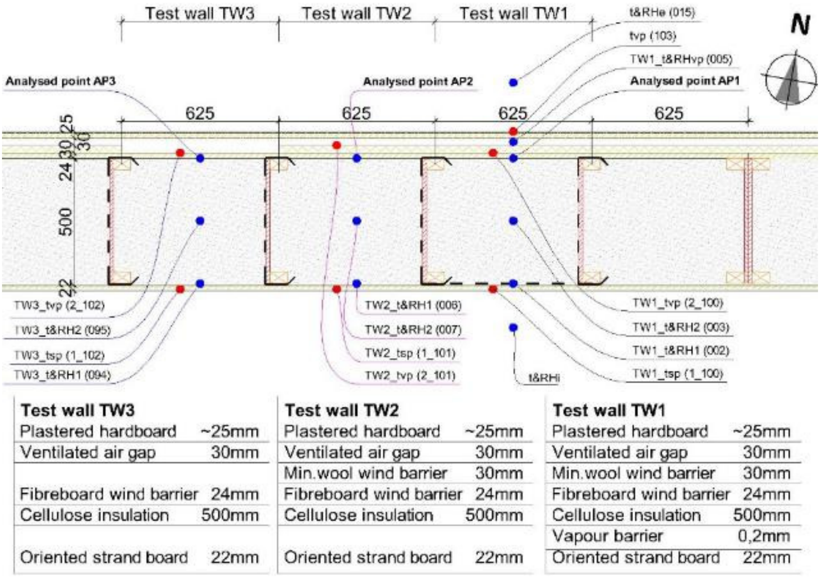

Figure 2. The horizontal section of the test walls with locations of sensors.

2.2. Measurements

In each test wall section, the hygrothermal performance is being measured with temperature and RH sensors (Ø 5 mm × 51 mm, measurement range: -40°…+100°C and 0…100%, accuracy: ±0.3°C and ±2%) and heat flux plates (range ±2000 W/m^2, accuracy: ±5%) at different positions inside the 500 mm thick cellulose insulation (see Figure 2). Measurement results are recorded at 1h interval.

The indoor climate is measured with portable sensors (range: -20°…+70°C and 10…95%, accuracy: ±0.35°C and ±3%).

3. Results

3.1. Hygrothermal performance of external wall

In the current paper measurement results of points between wind barrier and insulation are presented from test walls TW1 and TW3 because the TW2's sensor failed. Studied areas are hygrothermally the most critical locations in the light of moisture safety of highly insulated timber-frame exterior wall.

Figure 3 shows measured data of temperature and Figure 4 shows RH at the analysed points AP1 and AP3 in test walls TW1 and TW3. According to expectation, point AP1 (TW1) has higher temperature due to extra insulated wind barrier layer and with lower RH due to vapour barrier. Measurements confirmed initial simulations and the need of improvement of wall structure.

Figure 5 shows measured temperature and RH values compared to critical limit to mould growth [9]. Test wall TW3 with uninsulated wind barrier and without vapour barrier exceeds the limit of mould growth.

To study the possible growth rate of mould, Finnish mould growth model [10] was used. Because of exceeding of critical RH was short-term, the mould growth mould index M=0.2. According to mould index model, mould index M=1 is described as very small amount of mould on surface (detectable with microscope) and initial stages of local growth are possible on very low levels. Therefore, we may assume that there is no or can be just a very small mould growth in highly insulated timber frame wall, insulated with cellulose insulation, without installed vapour barrier layer and without additional insulation on wind barrier's external side.

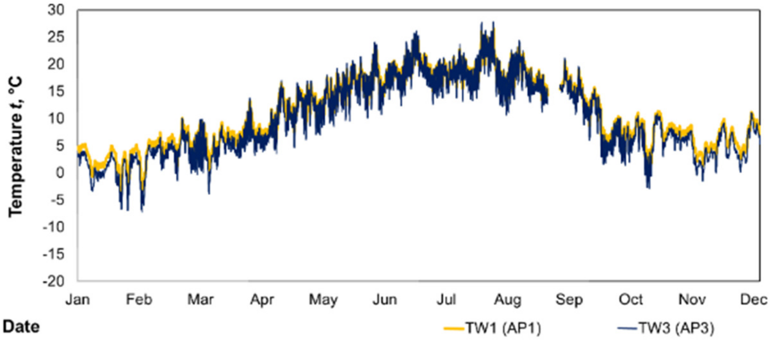

Figure 3. Temperature in test walls TW1 and TW3 at the analysed points AP1 and AP3.

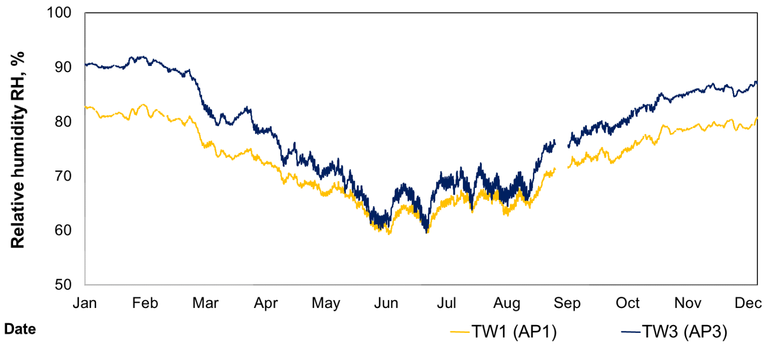

Figure 4. RH in test walls TW1 and TW3 at the analysed points AP1 and AP3.

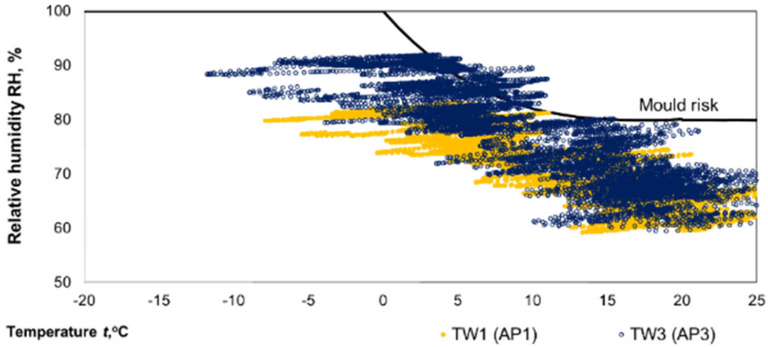

Figure 5. Temperature and RH in test walls TW1 and TW3 compared to mould risk limit at the analysed points AP1 and AP3.

3.2. Indoor hygrothermal conditions

To provide an overall view of the hygrothermal conditions, the indoor temperature and RH from the first floor living room and from the second floor storeroom (the room with studied exterior test walls) was logged.

The correlation of the indoor temperature in the living room with the outdoor temperature is displayed in Figure 6, where black markers are displaying average temperature level. The average temperature is almost within the boundary lines of II indoor climate category of standard EN 15251 [11].

The correlation of indoor RH on the outdoor temperature was also analysed, using a similar method as employed for the room temperature. In Figure 7, the hourly and daily indoor RH values from living room are divided by the outdoor air temperature.

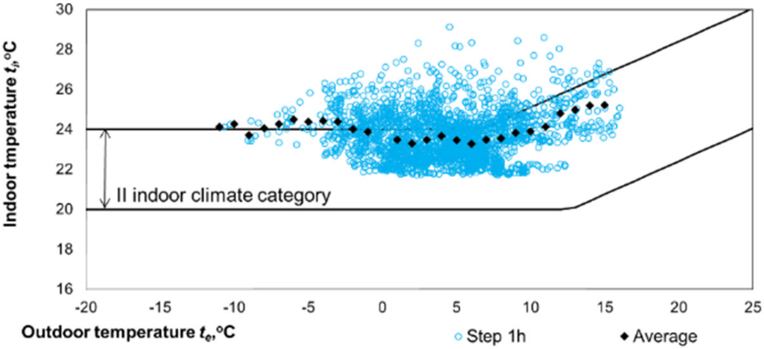

Figure 6. The dependence of the indoor temperature in the living room on the outdoor temperature.

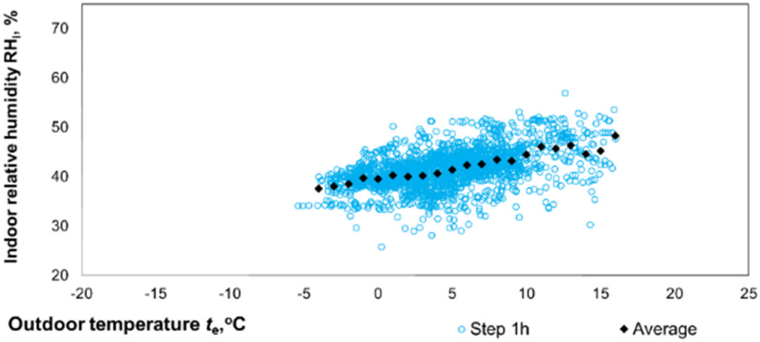

Figure 7. The dependence of the indoor RH in the living room on the outdoor temperature.

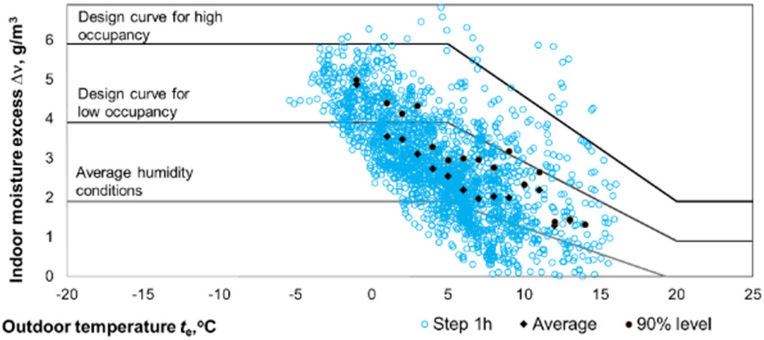

Figure 8. The dependence of the indoor moisture excess Δv (g/m^3) on the outdoor temperature with comparison of standard design curves.

The indoor moisture excess Δv (g/m^3) was selected to characterize indoor humidity loads. Figure 8 presents the moisture excess in living room during whole measurement period, and the black dotted line represents the 90% criticality level (design curve). The average moisture excess during winter was close to Δv=4 g/m^3, and the design value, corresponding to 90% critical moisture level, Δv=5 g/m^3.

4. Discussion

The analysis indicated that thermal resistance of the wind barrier layer and water vapour permeability of the vapour barrier had the strongest influence on the RH in the critical point of timber frame exterior wall between the insulation and the wind barrier surface. Also Mundt-Petersen [12] and Vinha [13] pointed out, that highly insulated timber-frame wall wind barrier layer thermal resistance and vapour permeability are having a very important role in moisture safety of building envelope.

The wall without vapour barrier and additional thermal insulation of wood fibreboard wind barrier showed some amount of mould growth risk during monitoring period. Thus the improvement of initial target design solution was reasonable.

Field measurements have shown that typical household activities and performance of ventilation provide moisture excess Δv=4…5 g/m^3 during winter period. This indicates that in design of highly insulated houses indoor humidity loads cannot be decreased. The water vapour diffusion is directed from indoors to outdoors and hygrothermally the most critical zone is between the wind barrier and the insulation layer [14].

5. Conclusions

The performance of the highly insulated building in Estonia was monitored and assessed for two years after construction, including detailed analysis of the indoor climate and hygrothermal performance of the exterior walls.

The measurements showed, that with wind barriers, having a higher thermal resistance and water vapour permeability, the increase of mould growth risk in the course of reduction of the thermal transmittance of the building envelope was lower. When the wind barrier has low thermal resistance and vapour permeability, it may need an additional thermal insulation to minimize mould formation risks in the contact surface of wind barrier and insulation layer.

Despite to test wall’s TW2 sensor failure at point AP2, we are able to continue the study of the hygrothermal performance of the house and to get comparable data for model validation of further hygrothermal simulations and investigations.

In conclusion, the building envelope of the highly insulated building needs careful hygrothermal design and thorough consideration of different material properties. Interaction has decisive importance in the process of design and construction works at the building site. Engineers and designers should include hygrothermal modelling into design practice to assure the moisture safety of structures and sustainability in the long term.

Acknowledgment

This research was supported by IUT1–15 project “Nearly-zero energy solutions and their implementation on deep renovation of buildings” (financed by the Estonian Research Council).

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