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NATURAL MATERIALS IN BUILDING CONSTRUCTION – ANNUAL EVALUATION

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Abstract. The construction industry's focus on a low-carbon economy will result in the need for a deeper examination of natural-based building materials. From an environmental point of view, the benefits of these materials are undeniable. However, it is necessary to consider their shortcomings in other areas of design in terms of building thermal engineering. This article observes and evaluates a wall designed for a wooden building with almost zero energy demand in year-round operation and subsequent assessment in confrontation with a different composition, seemingly more advantageous in thermal resistance and humidity regime. These assemblies are under long-term examination within the pavilion research of the authors' workplace, in laboratory conditions from the interior side. At the same time, they are exposed to the realistic boundary conditions of the external environment. The paper includes an environmental assessment of two compositions, variating in the used material. The research shows that the wall composition of natural materials is more advantageous from an ecological perspective and can also show favourable effects in terms of temperature and relative humidity regulation.

Keywords: Timber-framed, natural building materials, temperature, relative humidity, environmental assessment.

1. Introduction

The acute need to improve the environment is an increasingly trending topic. Sustainable development includes many issues, among others, improvement of the building industry [1]. In order to maintain liveable conditions of the earth, it is necessary to reduce the use of materials with great primary energy demand [2].

According to the Paris agreement [3], the United Nations – 191 countries, which signed the document – are bound to keep the global temperature rise this century below 2 °C and report every five years their actions to ensure the goal.

The harmonised requirements for construction products summarises the EU Regulation No. 305/2011 of the European Parliament and Council [4], which significantly supports the use of raw and secondary materials in the building industry.

At the same time, the requirements of current legislation regarding the thermal protection of buildings [5] are equally important.

2. Experimental wall samples

This article aims to present two different wall assemblies containing various materials. Both face south orientation with 15 ° inclinations to the west, and both are exposed to the natural exterior climate, measured on the laboratory roof. The interior space uses air conditioning, and its' temperature and relative humidity are appropriately measured.

The research contains overall ten wall samples. All of them are under long-term investigation to monitor the temperature and relative humidity within the timber-framed multi-layered constructions. The monitoring is in three high levels – 0.5 m under the ceiling, in the middle of the structure height, and 0.5 m above the floor – in all material interfaces. In this paper, we present values in the middle of structures' height, apart from the interface between phenolic foam and OSB in S1, bearing in mind that we would have nothing to compare these values to in wall S1. Used are NTC thermistors with the accuracy of ± 0.2 °C for temperature and capacity probes with the precision of ± 2 % for the relative humidity.

The first wall in this paper, marked as S1 (south 1), is the only one with solely natural materials. The second, marked as S2 (south 2), was chosen for comparison, as it is the most similar to the first assembly. Both these wall constructions are diffusely open, enabling air and water penetration and thereby reducing the risk of fungi and mould settling.

Wall S1 in Figure 1 solely consists of timber frame, timber log profiles from exterior and interior and sheep wool within. S2 has the same exterior layer, followed by basalt fibre thermal insulation Isover Granulate, phenolic foam insulation Kingspan Kooltherm K5, finished by OSB. The probes are in three depths within the wall: inside under the log profile, in the middle of thermal insulation, between wool and interior log profile (S1), and between Isover Granulate and Kingspan Kooltherm (S2).

Table 1 comprises the materials of both wall assemblies with tier main physical characteristics and environmental indicators. Among them is d – thickness,

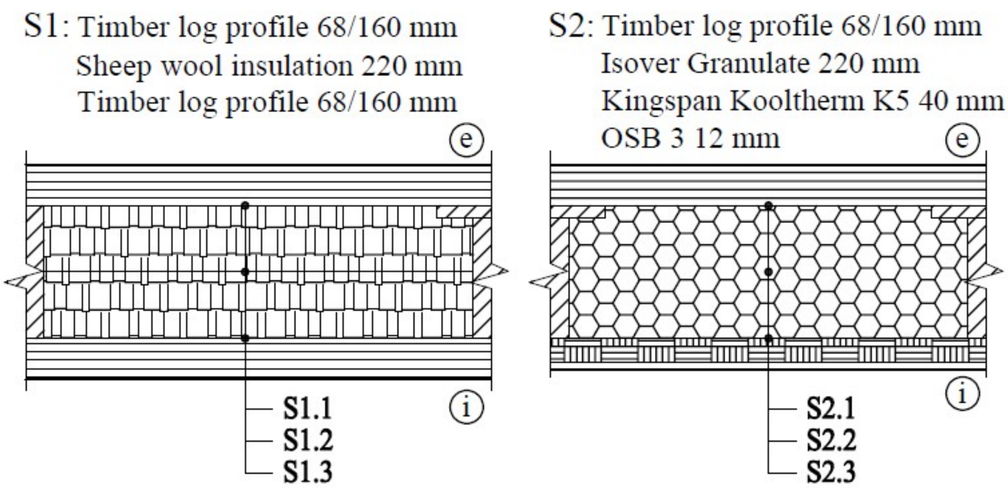

Figure 1. Left South wall 1 (S1), right South wall 2 (S2) – layers, probes placement.

Material	d [m]	λ $\left[\frac{W}{m^3 \cdot K}\right]$	μ [-]	ρ [kg/m^3]	c $\left[\frac{J}{kg \cdot K}\right]$	GWP [CO$_2$eq/kg]	PEI [MJ/kg]	AP [SO$_2$eq/kg]
Timber profile [6]	0.068	0.180	157	400	2510	0.109	1.959	0.00128
Sheep wool [7]	0.220	0.042	1.5	16	1720	0.537	19.324	0.00463
Basalt fibre TI [6]	0.220	0.040	1	50	1020	0.346	21.363	0.01413
Phenolic foam TI [8]	0.040	0.021	35	35	1400	3.821	96.515	0.01742
OSB [6]	0.012	0.130	50	650	1700	0.481	12.506	0.00210

Table 1. Layer materials of both assemblies and their main characteristics.

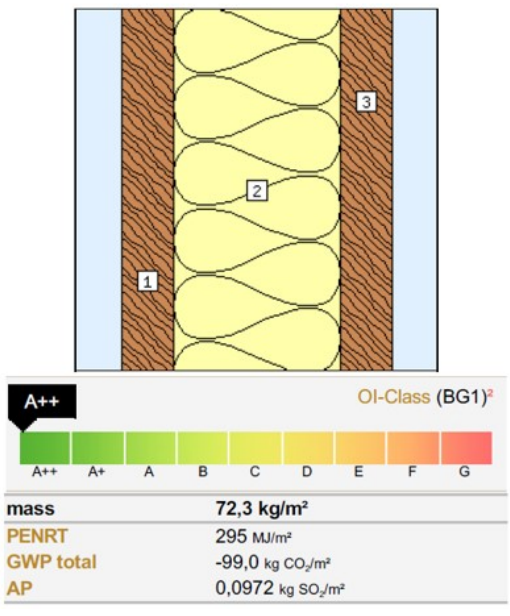

Figure 2. S1 environmental evaluation (baubook.at).

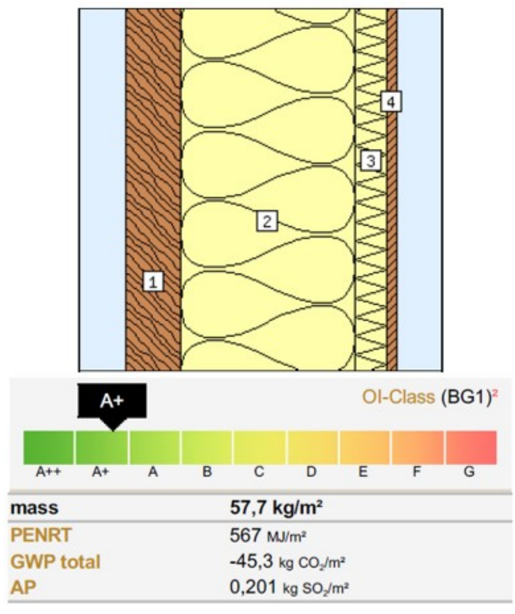

Figure 3. S2 environmental evaluation (baubook.at).

λ – thermal conductivity factor, μ – water vapour diffusion factor, ρ – bulk density, c – specific heat capacity, GWP – global warming potential, PEI – primary energy intensity, and AP – acidification potential, listed. TI stands for thermal insulation.

3. Environmental assessment

The environmental benefits of the first wall are undeniable. On the other hand, the second wall consists of more durable materials and therefore may balance the negatives. Thus rose the need to establish the environmental impact of both structures. The assessment stems from the Baubook website [9], which is

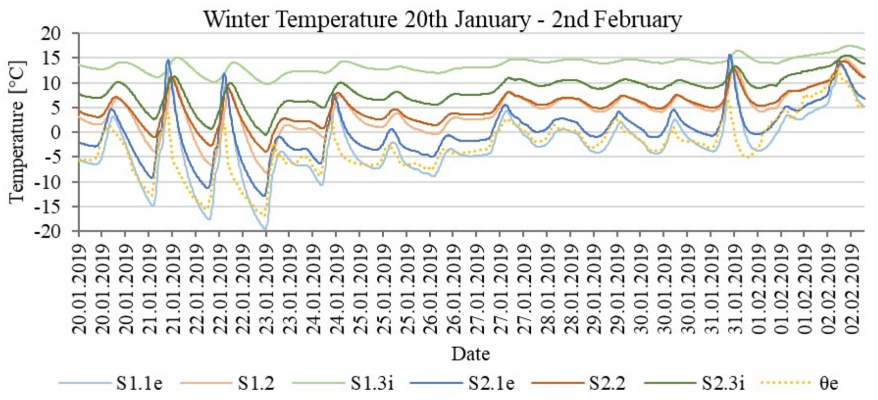

Figure 4. Comparison of the temperature in the winter period.

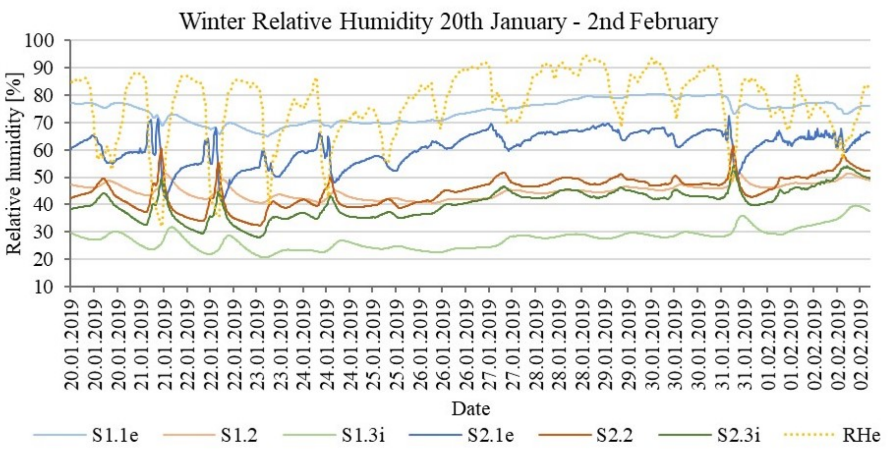

Figure 5. Comparison of the relative humidity in the winter period.

an online platform that promotes sustainable building design. This website enables the evaluation of the building structures in terms of the OI – ecology index (Ökoindex) [10] that considers the environmental indicators such as GWP, AP, and PEI. For comparison, the standard value for common wall assemblies is 70 pts/m^2 [11].

The results of the environmental assessment are in Figure 2 and Figure 3. For comparison, the U-value (heat transfer coefficient) is according to STN EN ISO 6946 [12] 0.196 W/(m$^2 \cdot$ K) for S1 and 0.145 W/(m$^2 \cdot$ K) for S2, calculated as inhomogeneous wall structure.

As shown, the wall assembly marked as S1 consisting of timber log profiles and sheep wool is classified as A++ according to OI-class, with $\Delta OI3$ value 6 pts/m^2. The structure S2 of timber log profile, basalt fibre insulation, phenolic foam insulation and oriented strand board reached value 38 pts/m^2 and thus fell to the A+ class.

4. Temperature and Relative Humidity

The temperature and relative humidity, measured in three depths of the wall (Figure 1), provided large datasets throughout the year. To simplify the comparison, these quantities are in this paper divided into three sections – winter period from 20th January to 2nd February, spring period from 19th March to 1st April, and summer period from 18th June to 1st July. Dotted lines present the temperature and relative humidity of exterior air. Interior climate was set to 20 °C temperature and 50 % relative humidity. The values in placement S1.1 or S2.1 are further referred to as the interior. In this case, we use this term only to simplify the text slightly. However, we would like to emphasise the layers between the probes placement and the interior, which we are aware of.

4.1. Winter Period

The graph in Figure 4 shows the temperature in both structures during two weeks of winter. The yellow dotted line represents the exterior air temperature. The other six lines stand for the temperature, whereas the different placements have different colours. The wall assemblies are distinguished by colour shade.

Although the temperature of S1 is from the exterior and in the middle of the wall lower than in S2, it reaches almost 5 °C higher values from the interior. That is naturally caused by the phenolic foam from the interior in the case of S2. However, S2 is ex-

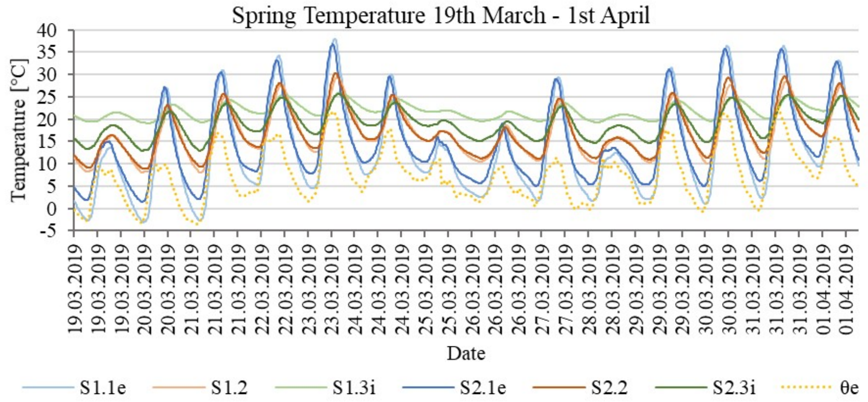

Figure 6. Comparison of the temperature in the spring period.

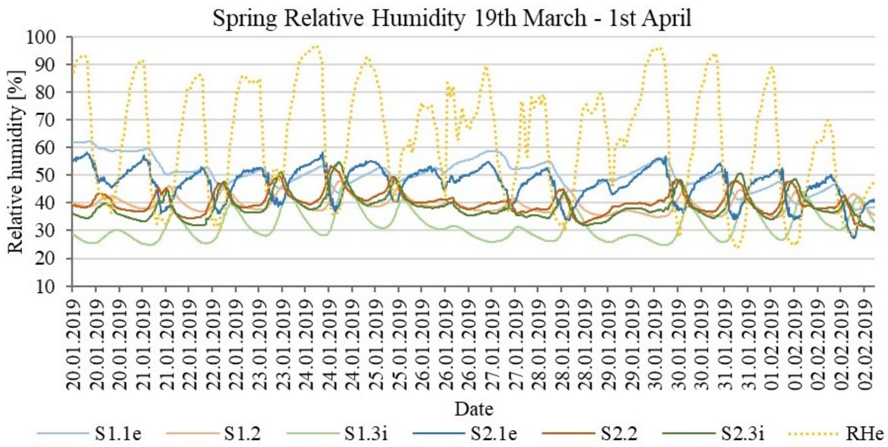

Figure 7. Comparison of the relative humidity in the spring period.

pected to reach a lower temperature under the exterior cladding due to the higher thermal performance. Another investigation consequently followed this analysis. Unfortunately, we found out that in S2 was created an air cavity, causing an additional thermal bridge. Significant is the alignment during the days where the amplitude of exterior temperature was smaller. The temperature these days was in the middle almost identical.

Figure 5 displays relative humidity in the same period. The walls and probe placement is distinguished the same way as in the case of temperature.

The regulation of relative humidity is, in the case of S1, very significant. The difference between exterior and interior relative humidity is almost 50 %, whereas in S2, only 20 %. It may sound unreasonable, but the explanation behind this statement is the following. Both assemblies are under constant interior boundary conditions, which means we can see only the influence of exterior climate. Although S1 reaches higher relative humidity from the outside, it meets the values of S2 relative humidity already in the middle of the insulation layer. The sheep wool was able to further lower the relative humidity to circa 30 %, whereas in basalt fibre, the value is around 40–50 %. This is the reason why we claim that sheep wool has the ability to regulate relative humidity better. The relative humidity in the middle is very similar in both assemblies. The variations occur under the outside and inside layers of both. Also interesting is the course of the humidity itself. The wall S1 reached steadier values throughout the whole period.

4.2. Spring Period

To represent the spring period, we have selected two weeks from 19th March to 1st April. Figure 6 shows the temperature comparison. The daily amplitude is naturally more significant. From the outside, the solar impact on the temperature of the exterior layer is evident, where the temperature in the walls is 15 °C higher than the surrounding air temperature. Other than that, the course of temperature is similar to the winter period, where the middle temperature is almost identical, and the interior temperature differs the most.

Figure 7 presents the relative humidity. The difference between exterior and interior humidity is here not so significant and gets even smaller towards the end of selected weeks. However, the internal relative humidity is again lower in the case of S1 compared to the wall S2, creating a difference of nearly 10 %.

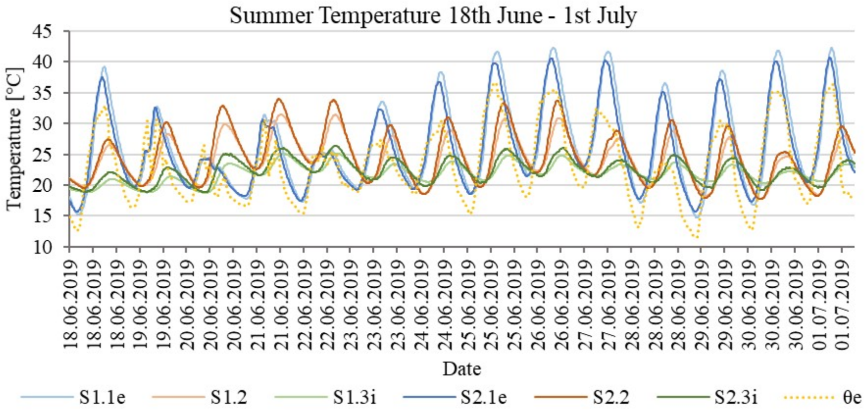

FIGURE 8. Comparison of the temperature in the summer period.

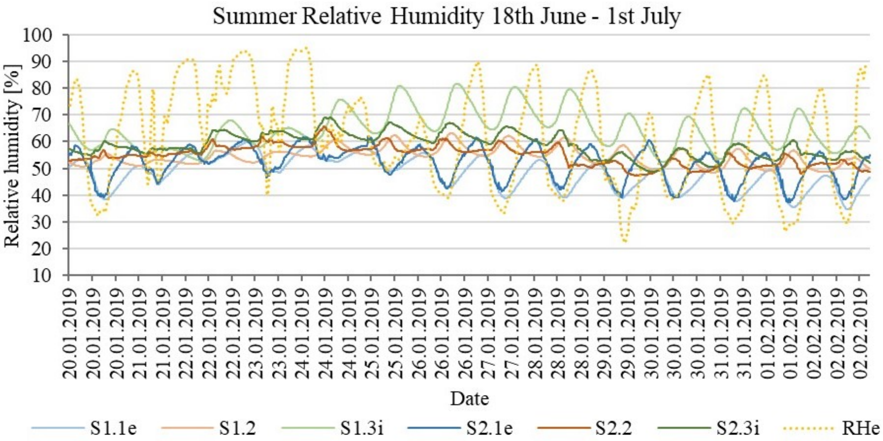

FIGURE 9. Comparison of the relative humidity in the summer period.

4.3. SUMMER PERIOD

The summer period is represented by 14 days from 18th June to 1st July. As expected, the temperature amplitude is large, with a maximum variance of 24 °C. It is displayed in Figure 8, where a noticeable temperature shift is apparent, in some cases reaching 6 hours. According to Figure 8, wall S1 is capable of higher temperature regulation. To support this statement, notice that the temperature from the outside is, in its case, higher than in S2. In contrast, already in the middle of thermal insulation is vice versa, where the S1 temperature is 3 °C lower than the S2.

Figure 9 shows the course of relative humidity during the summer period. In this case, the difference is foremost in the interior layer, caused by the air relative humidity rise due to some technical difficulties with the air conditioning. However, the relative humidity in the middle of both walls is relatively consistent, varying from 50 to 60 %.

5. CONCLUSION

Although both wall assemblies appear very similar, their difference is rather significant. The first structure consists solely of natural materials with minor adjustments to enable their use in buildings. The second wall uses a combination of natural materials – timber frame, exterior timber log profile, and oriented strand board – and synthetic materials, such as basalt fibre thermal insulation and phenolic foam to improve its thermal resistance. Nevertheless, the difference is not significant enough to balance the environmental impact.

As stated in the Section 3 (Environmental assessment), both structures fall into the highest categories in terms of Ecoindex. However, wall S2 requires almost double primary energy in comparison with S1. Moreover, the acidification and global warming potential are also double. In terms of $\Delta OI3$ is for wall S2 is more than six times greater – 38 pts/m^2 versus 6 pts/m^2 for S1.

From the perspective of used materials, wall S2 is expected to show better temperature and relative humidity results. The opposite turned out to be the case, where the first assembly showed its capability of not only competing with S2 in terms of thermal performance but, in some cases, even outstanding it. Wall S1 provides more significant temperature decrement towards the interior, obvious foremost in the summer period. The regulation of relative humidity within S1 was in some cases 30 % greater opposite to wall S2. However, it is needless to say that neither of the wall assemblies showed relative humidity values that could initialise the growth of moulds and fungi or cause material degradation.

The main conclusion of this paper is not to underestimate such wall assemblies, which can prove their worth not only in terms of environmental sustainability but also in terms of overall performance. Future research could contribute by numerical simulation of both wall structures within an actual building and deeper evaluation from an LCA point of view.

Acknowledgements

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