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The Safe Insulation from the Inside as a Solution to the Energy and Climate Crisis

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Abstract **– During the time when the European Union is facing an energy crisis, it is essential to understand ways to overcome it more easily. As one of the consuming sectors, buildings play a crucial role in improving energy efficiency. Therefore, one of the ways to fight with energy crisis and high energy consumption in buildings is insulation from the inside. This study assesses the hygrothermal performance of masonry walls with 9 interior insulation systems (mineral wool with vapor barrier, XPS, PIR, cork, expanded cork, aerogel blanket, wood fibre plates, perlite board) exposed to different external conditions in the climate chambers. Masonry walls were tested in a steady cycle with cold box temperature 18 °C and 40 % RH), a dynamic cycle that follows daily fluctuations, a dynamic cycle with rain. Also, an identical simulation of the hygrothermal process was carried out in the DELPHIN software to compare results of both testing methods. The temperature between the thermal insulation layer and the brick wall in all thermal insulation systems is approximately 7-8 hours behind the temperature of the outdoor climatic chamber. A dynamic cycle with rain simulation has a significant impact on the hygrothermal behaviour of thermal insulation systems. The study provides valuable data on hygrothermal processes in different wall insulation systems from the inside.**

Keywords **– DELPHIN; energy consumption; energy efficiency; hygrothermal; relative humidity.**

Nomenclature		
EU	European Union	–
CO_2	Carbon dioxide	–
δ	Width	m
λ	Thermal conductivity	W/mK
U	Thermal transmittance	W/m^2K
μ	Water vapor diffusion resistance factor	–
Sd	Vapor diffusional resistance	m

1. INTRODUCTION

Along with rapid climate changes, issues related to energy efficiency and efficient use of energy are becoming more and more relevant in the European Union (EU). Therefore, the

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green deal is becoming the dominant policy in the EU, which aims both to reduce energy consumption in the EU and to increase the competitiveness of the economy. Therefore, energy efficiency improvement measures are starting to be considered sustainable and are being actively implemented in all EU countries. The set European long-term climate policy goal for 2050 is to reduce EU carbon dioxide (CO_2) emissions by 40 %, 60 % and 80 % by 2030, 2040 and 2050 [1].

From this, it can be concluded that the EU is actively working to reduce CO_2 emissions, which also leads to a decrease in energy consumption to achieve this goal. In this way, energy efficiency policies also become a means of energy independence, achieving energy independence from other countries.

The construction industry is currently facing major challenges related to energy consumption, decarbonisation and access to modern renewable technologies along with the global depletion of fossil fuels [2]. Buildings are responsible for approximately 32 % of the world's final energy consumption, 17 % of direct carbon dioxide (CO_2) emissions and one third of indirect emissions [3]. Talking about the EU, buildings consume approximately 40 % of all energy [4]. Such a high specific consumption is due to the fact that in EU countries 35 % of buildings are older than 50 years, where 75 % of the building stock are energy inefficient buildings and only 0.4–1.2 % of buildings are renovated every year [5]. In comparison, buildings in developing countries consume about 20 % of total energy consumption [6].

On the other hand, the introducing of energy efficiency requires significant funds, especially when it comes to building insulation. Large volumes of structures and high requirements for energy efficiency make these activities difficult and expensive. This is also confirmed by other authors, that one of the main barriers associated with energy efficiency is lack of funds and affordability of building renovation [7], [8]. That's why more affordable building insulation solutions are gaining popularity.

As a result of the energy crisis, the number of energy poverty residents has increased and to overcome it, is recommended to reduce consumption [8]. Therefore, insulation from the inside becomes much more relevant due to the relatively low costs, although the savings achieved are less than a complete renovation of buildings, which allows residents to insulate their homes and small office buildings. But, when considering the option of insulating from the inside, moisture problems and the risks of mold formation need to be taken into account [9]. That is why it is necessary to deepen knowledge so that insulation from the inside does not cause such difficulties.

Discussing hygrothermal processes in walls with interior insulation, thickness of the wall influences the moisture accumulation rate and moisture content in the wall was impacted by the properties of the brick wall [10]. Also, one important factor is wind driven rain, which is one of the largest sources of moisture in the walls [11]. That is why it is necessary to take into account the rain factor during building construction. In study [10] wind driven rain was dominating factor of vapor-tight insulation systems with rapid increasing in relative humidity. On the other hand, vapor-open insulation systems are impacted by the wind driven rain by increasing indoor relative humidity [12].

The study aim is to understand the hygrothermal behaviour of brick masonry walls in cold climate with internal insulation for the further development of recommendations for indoor insulation energy-saving solutions.

The paper is structured into four sections. Section 1 introduces the literature analysis. Section 2 describes the research methods. Section 3 presents some of the results obtained at the time of writing the paper. Finally, Section 4 provides the conclusion of the results and outlines expectations for the continuation of the experiment.

2. METHODS

The research is based on conducting laboratory tests in climate chambers with certain conditions and comparing the obtained results with the data obtained by the computer program *DELPHIN*. 9 thermal insulation systems from different materials are tested. Selected materials included vapor-tight (EPS, mineral wool with vapour barrier, XPS, cork, PIR, expanded cork) and vapor-open (perlite board, aerogel blanket, wood fibre) insulation systems, so comparison of both systems is possible. All those materials are covered by gypsum board as indoor finishing coat.

Vapor-open insulation systems means that the system allows water vapor to pass through. Usually, these systems are used when moisture needs to be escaped from the building. On the other hand, vapor-tight insulation systems are designed to block the passage of water vapor. Vapor-tight insulation systems are used to help control indoor microclimate. Also, vapor-tight insulation systems prevent moisture transfer from the indoors to the building constructions.

These 9 samples are placed in a 3×3 grid between two climate chambers with outdoor conditions (cold-box) and indoor conditions (hot-box). The climate in both chambers is controlled by several devices (air cooling device, air heater, air dryer, air humidifier, water nozzles), the schematic representation of the experiment can be seen in Fig. 1.

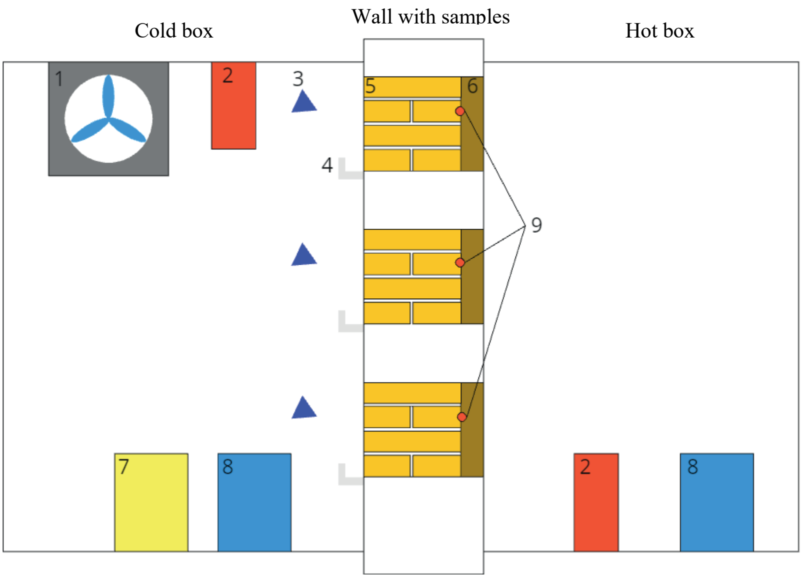

Fig. 1. Schematic of a laboratory experiment: 1 – air cooling device, 2 – air heater, 3 – water nozzles, 4 – water drain; 5 – brick wall, 6 – insulation material, 7 – air dryer, 8 – air humidifier, 9 – temperature and relative humidity measurement point.

The laboratory test will last 10 weeks and consists of five cycles, each cycle consists of 2 weeks. The first cycle is stable when the outdoor conditions and indoor conditions in the climate chambers are constant. Outdoor conditions 18 °C air temperature and 50 % relative humidity, indoor conditions 20 °C air temperature and 40 % relative humidity. Then follows the dynamic cycle, which changes the settings of the outdoor environment and changes them depending on the time. These data are taken from the month of May with the idea that they have more fluctuations of relative humidity and temperature. The daily fluctuations of dynamic cycle are shown in Fig. 2.

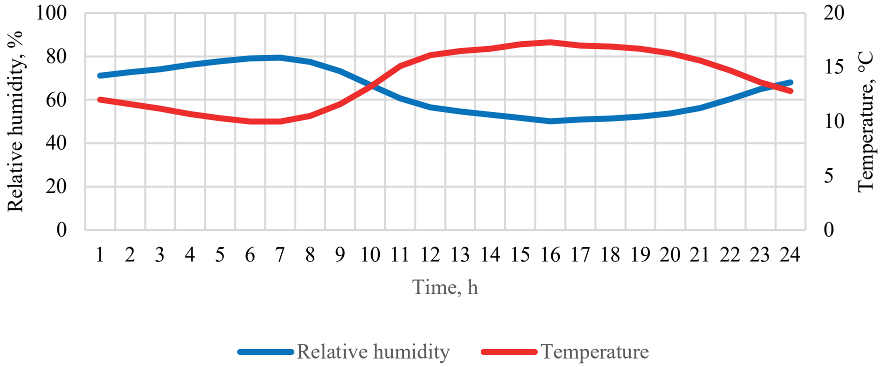

Fig. 2. Daily fluctuations in relative humidity and temperature [13].

The parameters of the outdoor conditions are chosen according to the average climatic conditions of Latvia in the month of May. May was chosen based on dynamic temperature and relative humidity fluctuations. After a dynamic cycle, a stable cycle is started, followed by a dynamic cycle with rain emission – 0.22 L/(m^{2}s). Before the beginning of the experiment, water nozzles were tested to determine the exact amount of sprayed water by collecting water in a container. Experiment finished by last stable cycle.

Relative humidity is measured by the Honeywell HIH-4000 series humidity sensors. Temperature is measured with K-type thermocouples. Sensors measure microclimate between masonry and insulation system. All data are recorded by Campbell Scientific CR1000 data logger. Relative humidity sensors measurements were calibrated according to the technical description of the humidity sensor.

For comparison of laboratory experiment mathematical simulation of hygrothermal process are used in the *DELPHIN* 6.1.6. software. Used materials in simulations are similar as possible for the laboratory experiment used materials, input data are shown in appendix Table A1. Complete identity can be obtained by separately testing each of the materials used in a laboratory experiment, and then entering this data into the *DELPHIN* database. The results of simulation data point were set to 1 h. Simulation set up for the mineral wool insulation system with vapor barrier are shown it the Fig. 3.

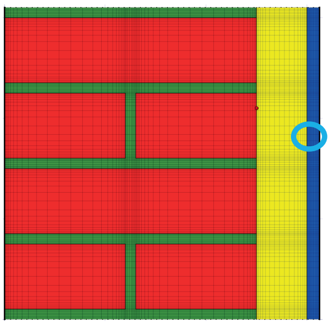

Fig. 3. Wall brick mansory with mineral wool insulation with vapor barrier in DELPHIN software: red – brick, green – mortar, yellow – insulation, blue – gypsum board, between insulation and hypsum board are vapor barrier, red dot in the blue circle – data point.

3. RESULTS

Due to the fact that the experiment is still in progress (first two cycles are completed), this paper represents the intermediate result of one insulation system. Mineral wool insulation system with vapor barrier was selected both of measured data and the simulated results. Mineral wool properties are shown in Table 1.

TABLE 1. MINERAL WOOL INSULATION SYSTEM PROPERTIES

Insulation material	Insulation type	Vapor barrier	Finishing material	Type of insulation system	Properties of insulation material				
					δ, m	λ, W/mK	U, W/m²K	μ	Sd, m
Finnfoam Tulppa	Mineral	No	Gypsum board	Vapor-tight	0.05	0.035	0.95	133	2.66
Mineral wool	Mineral	Yes	Gypsum board	Vapor-tight	0.05	0.042	0.6	623 440	64
Finnfoam FL300PX XPS	Mineral	No	Gypsum board	Vapor-tight	0.05	0.035	0.49	133	6.65
TecTem	Mineral	No	Gypsum board	Vapor-open capillary active	0.05	0.045	0.63	5	0.25
Cork	Organic	No	Gypsum board	Vapor-tight capillary active	0.045	0.04	0.58	10	0.45
Kingspan Sauna-Satu	Mineral	No	Gypsum board	Vapor-tight	0.03	0.023	0.53	∞	99
Wood fibre board	Organic	No	Gypsum board	Vapor-open capillary active	0.05	0.036	0.5	2	0.1
Expanded cork	Organic	No	Gypsum board	Vapor-tight non capillary active	0.05	0.05	0.63	10	0.5
Aerogel blanket	Innovative	No	Gypsum board	Vapor-open non capillary active	0.016	0.02	0.72	5	0.08

First of all, it is necessary to look at how the climatic chambers maintain the set parameters of RH and temperature (see Fig. 4). Gained data represents that the hot-box temperature is stable this also applies to cold box temperature. In turn, RH in the hot-box are stable except for a few peaks. This is due to the inertia of the humidifier, which at some moments slightly exceeded the set value. Cold-box RH follows the set value, but at around 163 hours of the experiment the start RH level significantly exceeds the established level. This may be due to the fact that for some unknown reason the air dryer has stopped working and the humidity has increased. After about a day everything worked and quickly returned to the set values.

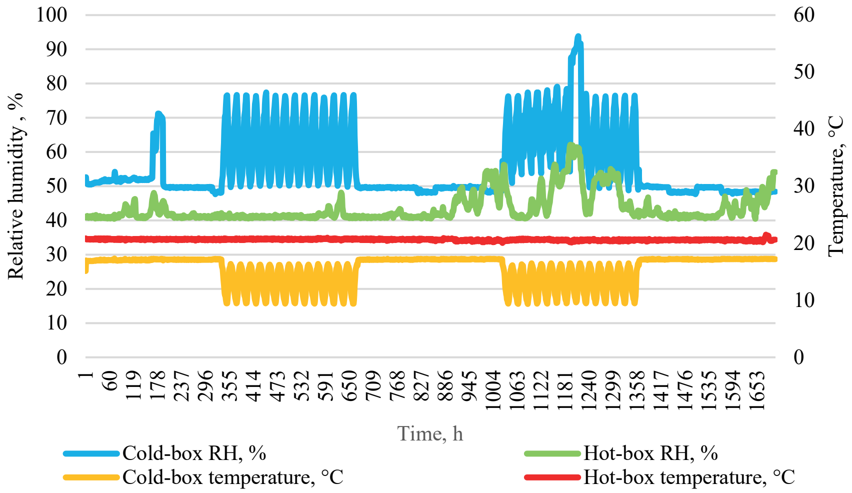

Fig. 4. Measured cold-box and hot-box temperature and relative humidity during the first two cycles.

Fig. 5 shows the measured temperature between the thermal insulation material and the masonry for selected thermal insulation systems. The temperature followed the same trend for all thermal insulation systems. The temperature for different thermal insulation systems reached different levels, which is explained by the heat transfer coefficient of each sample.

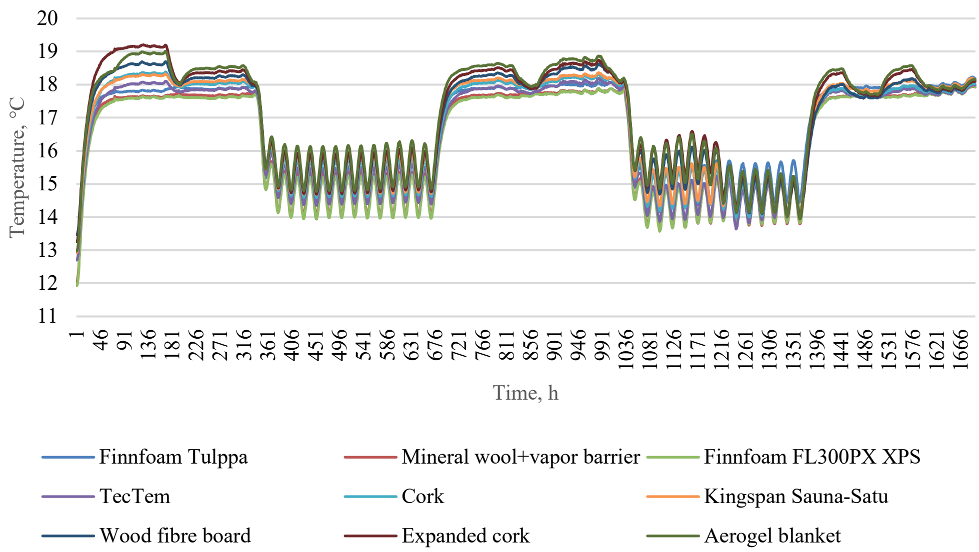

Fig. 5. Temperature between the thermal insulation layer of selected materials and the brick wall.

Fig. 6 presents the measured relative humidity between the thermal insulation material and the masonry for selected thermal insulation systems. As can be seen from the graph, the relative humidity for each thermal insulation system behaved differently and reached different values. However, water vapor permeable thermal insulation systems show similar trends among themselves. This also applies to water vapor impermeable thermal insulation systems. In general, thermal insulation systems with a higher Sd value have smaller fluctuations and effects on temperature and relative humidity between the thermal insulation layer and the brick wall.

The drying time during the stable cycles after the dynamic cycle and the dynamic cycle with rain simulation was different. After the dynamic cycle, the drying time was approximately 48 hours, while after the dynamic cycle with rain simulation, it was approximately 72 hours.

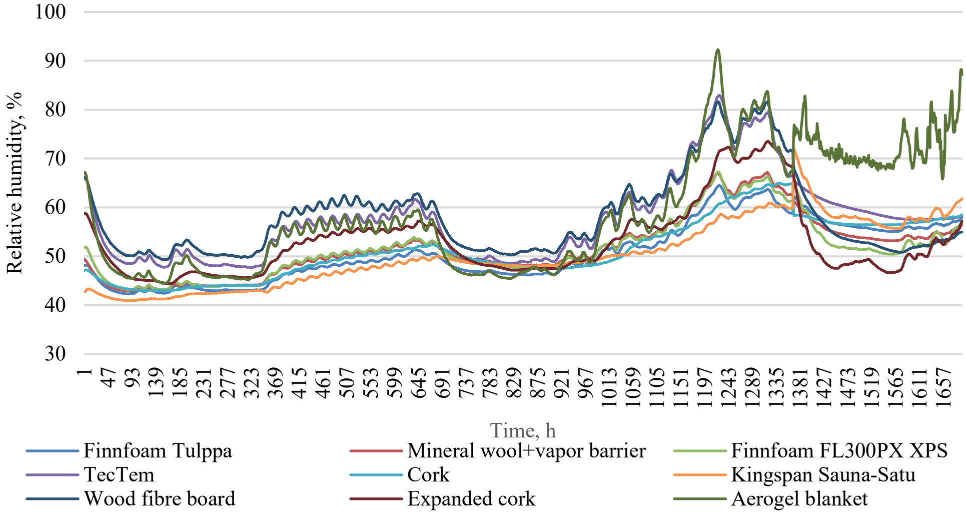

Fig. 6. Relative humidity between the thermal insulation layer of selected materials and the brick wall.

Fig. 7 the measured and simulated temperatures between the insulation layer and the brick wall reach stable parameters in both cases approximately 60 hours from the start.

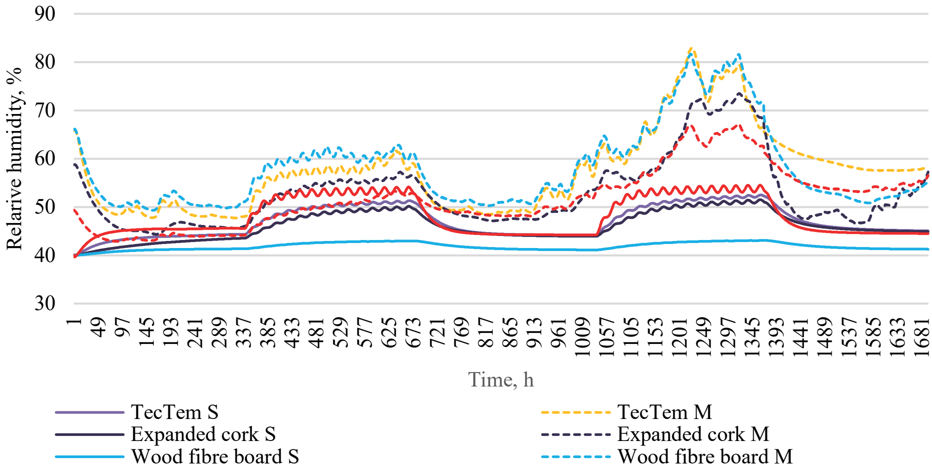

Fig. 7. Measured (M) and simulated (S) temperature between the thermal insulation layer and the brick wall for selected thermal insulation systems throughout the experiment.

The highest temperature in the simulation was achieved with the cellulose insulation system, though the measured results reached an average level. The stone wool, expanded cork, and perlite board (TecTem) insulation systems exhibit similar temperature behaviour, with values almost identical. This could be explained by the fact that the thermal conductivity coefficients of all these insulation systems are identical, resulting in similar temperature simulations. Overall, both the measured and simulated temperatures between the insulation layer and the brick wall follow the same trend, with minimal differences primarily observed in the stable cycle.

Fig. 8 presents the measured and simulated relative humidity behaviour between the insulation layer and the brick wall slightly differs. The simulated relative humidity values have a smaller amplitude, while the measured data show a larger amplitude and visually more distinct cycles. The main reason could be differences in the hygrothermal properties used in the simulation compared to those used in the laboratory experiment. The simulation results for cellulose insulation exhibit significantly smaller fluctuations. Overall, the simulated and measured values follow a similar trend, albeit with different values.

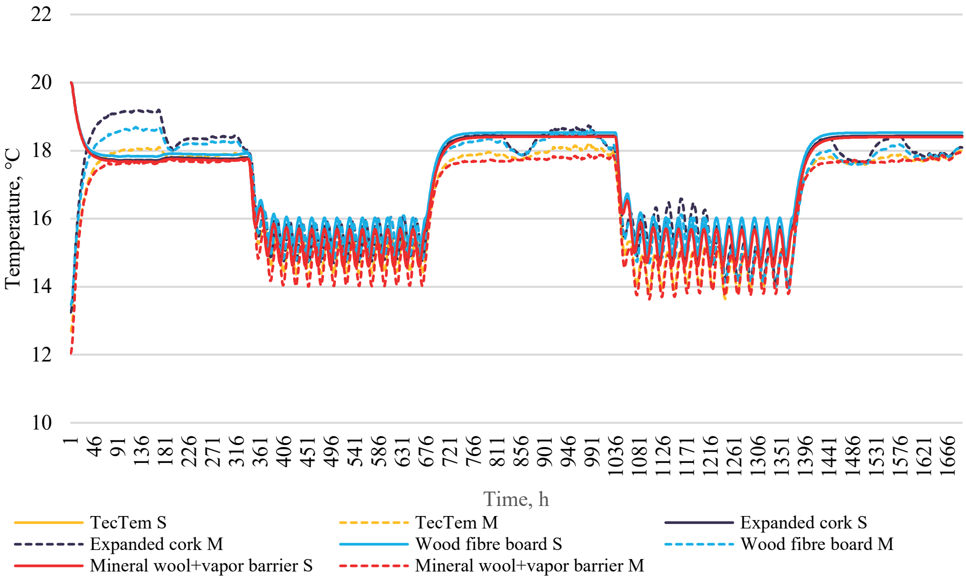

Fig. 8. Measured (M) and simulated (S) relative humidity between the thermal insulation layer and the brick wall for selected thermal insulation systems throughout the experiment

4. CONCLUSION

The obtained data shows that insulating building exterior walls from the inside is a complex task because several factors need to be analysed before implementation. The approach presented in the current study provides not only thermal energy savings but also shows potential risks. The dynamic cycle with rain simulation has a significant impact on the hygrothermal behaviour of the insulation system, because the drying time during the stable cycles after the dynamic cycle and the dynamic cycle with rain simulation was different.

Combining mathematical simulation with laboratory experiments allows for a better understanding of hygrothermal processes and the evaluation of selected constructions before building. However, mathematical simulations are sensitive to the input data and material properties.

From the study it can be concluded that insulating masonry walls from the inside requires a careful selection of materials, long-term testing and the accurate mathematical simulation for preliminary tests.

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ANNEX

TABLE A1. PROPERTIES OF MATERIALS USED FOR SIMULATION

Material	**Brick**	**Mortar**	**Gypsum board**	**Vapor barrier**	**Mineral wool with vapor barrier**	**TecTem**	**Expanded cork**	**Wood fibre board**
Name of the material in DELPHIN	Old Building Brick Rote Kaserne Potsdam	Lime cement mortar	Rigips gypsum board	BARRIER NET SD40	Mineral Foam Multipor	Rotkalk in-Boadrd 045 TecTem	Wood fibre Insulation Board	Wood Fibre Board indoor
Density, kg/m^3	2048.8	1878.5	732	110	98.5	100.3	160.8	119.1
Porosity, m^3/m^3	0.227	0.291	0.724	–	0.962	0.96	0.89	0.92
Water vapor diffusion resistance	24.04	36.91	6.85	623 440	1	8	10	1.1
Specific heat capacity of dry material, J/kgK	847	757.94	1383.88	1800	1331.02	1640	1662	1000
Thermal conductivity, W/mK	0.881	0.803	0.211	0.4	0.042	0.046	0.04	0.04
Effective saturation, m^3/m^3	0.24	0.22	0.45	0.002	0.13	0.77	0.55	0.59
Water uptake coefficient, $kg/m^2s0.5$	0.09	0.04	0.13	–	0.006	1.98	0.003	0.01