Agronomy Research **17**(S1), 1097–1106, 2019
https://doi.org/10.15159/AR.19.101

Hygrothermal analysis of masonry wall with wool glass interior insulation

K. Leiten, P. Kirotar and M. Kiviste

Estonian University of Life and Science, Institute of Forestry and Rural Engineering, Kreutzwaldi 5, EE51014 Tartu Estonia
*Correspondence: kadri.keskkyla@mail.ee

Abstract. When the external appearance of the building is fixed due to heritage requirements the interior thermal insulation is the only possible solution for thermal upgrade of the building envelope. Applying internal insulation to existing buildings is known to pose a challenge in relation to hygrothermal risks, as this can lead to high relative humidity levels, condensation and ultimately, mould growth and decay. The case study building is under historical preservation and therefore this is not allowed to be insulated from outside. The paper describes the hygrothermal assessment of applying internal glass wool insulation and vapour barrier in masonry wall with air gap. In addition to the calculations the condition investigation was also performed. Data loggers measuring temperature and RH were applied during the period of 31.01.2013–16.02.2013. The conclusions were based to theoretical calculations (case study and DIN 4108-3) and practical measurement results based on the data logger values obtained. The calculations showed that glass wool and vapour barrier insulated system were in risk on condensation but the condensed water dries out during summer time. Due to the fact that logger measurements were recorded during the time when inside plastering was still in progress the relative humidity in the room was very high. As a result of calculations it is possible to build this type of wall effectively, but in this case it was not the most reliable way because of ongoing interior fitting.

Key words: interior insulation, hygrothermal performance, energy efficiency.

INTRODUCTION

Construction is the largest energy consumption industrial sector in the world (Transition to …, 2013). Energy consumption of building sector is increasing constantly because people build more and want to live and work in energetically balanced houses. The building stock in Estonia and in EU as well, is characterised by a quite big number of old buildings needed to be retrofitted to change the energy use more efficient. EU has been worked out several roadmaps for obtaining these goals: like renovating heating systems, using more state of art lightning and home machinery, to insulate buildings envelopes and so on (Transition to …, 2013).

Among buildings additional insulation are needed in two main groups: old buildings under heritage protection and with all the restrictions connected with renovation; all other insufficiently insulated buildings. Internal insulation is obvious for this first group of houses.

Accoding to EU comments 40% of total energy is used for heating and cooling of buildings, so if we insulate houses properly the savings could be quite remarkable. In this article only the possibilities for internal insulation were investigated. Many researches have been shown that internally insulated walls (Harrestrup & Svendsen, 2015; Nielsenet al., 2012; Fantucci et al., 2017) will fulfil the requirements set to thermal conductance and moisture condensation of the envelope. Still there are many risks needed to avoid: mould growing, condensation, frost damage, decay of wooden beams ends, so there are a lot of different wall structures which need the special insulating solutions. This is essential to insulate buildings in the cold climate but this must be done correctly from the hygrothermal behaviour point of view (Rasmussen, 2011).

So a lot of different insulation solutions has been investigated by researchers. The wooden beam ends on the brick wall might be a problem because of high relative humidity causes the decay. The next research show how important is airtight sealing of timber beams embedded into the wall (Vereecken & Roels, 2017). In some studies were declared that even the content of the brick is important to take into account (T. de Mets et al., 2017), and was proven that critical saturation point of tested clay bricks differs greatly if calculations have been made by ASTM for instance. The critical saturation degree of bricks also varied between UCC (Upper Canada Collage historical bricks the value is 0.25) and Canada brick (0.87) (Straube et al., 2010).

Mold growth in cold climate has been investigated in several works and found to be a problem. Condensation risks were handled and stated that internal insulation in masonry wall poses great risks related to interstitial condensation (Fantucci et al., 2017). The thaw-freeze cycles could be a problem too. So this will be better if the moisture will not intrude to the bearing brick structure at all. And again it is needed to mention that to work out correct internal insulation solutions is really challenging, because there are so many different structures i.e. different proper insulation solutions needed (Biseniece et al., 2017; Hansen et al., 2017).

Several systems of internal thermal insulation are worked out in Germany and in other western countries and many ‘how to do’ work lists have been produced by enterprises like Gutex, King-Span, Basf SE, Multipor and so on. In Estonia however exactly the same systems can’t be applied due to different climate conditions. The investigation done in Estonia in 2013 show that the airtight vapour proof material inside gave the lowest relative humidity values in point where the condensation is the most critical. The main problem using PIR material was developing mould growth. Also it was seen that the need to use dry method decreases the relative humidity values (Klõšenko et al., 2013).

The diffusion tight synthetic foams that can hinder the vapour diffusion from indoor space perform well when there is no unintended leakage therefore a good workmanship and a perfect tightness are required during the implementation and operating stages. The most reliable way to build such tight system is to use glass-foam. It is lightweight, high-strength, moisture and fire proof low thermal conductivity but very expensive. It still remains vapour tight even when small piercing is done in surface. Less expensive way is to use other synthetic foams like polyurethane board with foil cover Kingspan SPU Sauna (Rakenna & Remontoi, 2012). The cons in these system is, that you have to seal the whole envelope to make one tight system therefore the relative humidity and ventilation has to be controlled. These systems limit the inward drying potential, leading to the moisture increase in the underlying massive masonry.

The chosen solution was cost effective, dry stud method, using glass-wool covered with OSB board and varnish it with 3 layers of bitumen mastic was supposed to make it vapour tight.

MATERIALS AND METHODS

Case study building

The case study building is situated in Estonia Tartu Veski Street 13. It was designed by architect Reinhold Guleke. In 1893 the construction was completed and taken into use by student corporation Livonia. Originally the building was one-storied and rectangular shaped. In 1958 the second story was built (National Registry of Cultural Monuments). In 1997 the building (Fig. 1) was listed as 'Cultural monument building' and therefore became under strict preservation regime (Regulation of Cultural Ministry no 12 published 20.03.1997). In 2010 the building was privatised and renovation works began. The renovated house is presented in Fig. 2.

Figure 1. Veski 13 before renovation.

Figure 2. Veski 13 after renovation.

The thickness of the masonry wall of the first wall is 600 mm and the thickness of the wall of the second floor is 450 mm and consists layers from inside to out: clay brick masonry wall 130 mm, non-ventilated air gap 50 mm, clay brick masonry wall 270 mm. Wall parts where originally were windows are thinner and there the outer clay brick masonry is only 130 mm thick and the case study was made in this part of the wall (northern side of the house) our case study was made and the calculated U-value of that wall part was U = 1.45 W m^{-2} K^{-1}.

Applied materials

The aim was to build interiorly insulated wall according to Estonian suggestions for thermal conductance. In the regulation of 'Methodology for calculating the energy performance of buildings' the U-value is not determined (Regulation of Minister of Economic Affairs and Communications no 63 'Methodology for calculating the energy performance of buildings' published 01.01.2019). On the inner side of the inner clay brick masonry wall glasswool ISOVER KL-37 200 mm between wooden frame (cross section of b = 50 mm, h = 200 mm, cc 600 mm) was applied. The wooden frame was covered from inside with OBS 3 (OSB-oriented standard board, d = 15 mm). The OSB-board was varnished with three layers bitumen mastic ICOPAL Water Renovator

Dysperbit DN. To make window frames vapour-retardant the window surroundings were sealed with tape and varnished with ICOPAL. On the mastic layer wooden laths (b = 25 mm, h = 50 mm, cc 600 mm) were placed for air gap and covered with wooden siding (d=25 mm) and lime mortar (d=25 mm). U value of this case study wall was U = 0.15 W m^{-2} K^{-1}.

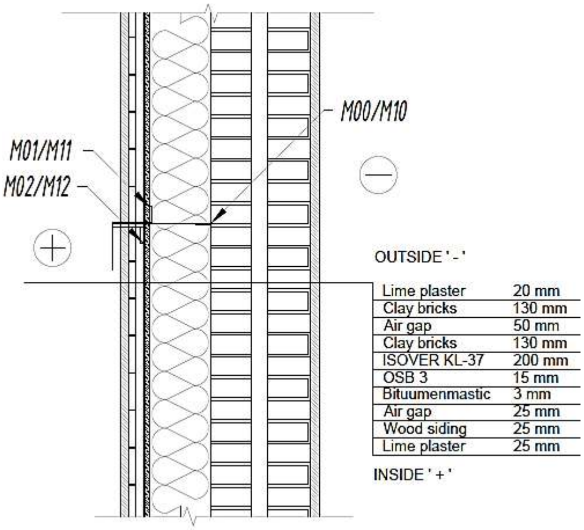
Applied devices and sensors

The measuring devices were actually applied on 07.01.2013 and taken away on 28.02.2013. Values were measured during the period of time 31.01.2013–16.02.2013 and calculated as arithmetic averages. By this time the interior insulation work of the test wall was completed except the interior lime plastering. There were three humidity absorbers on site to remove excessive relative humidity but the level of humidity was still high.

To install the devices into the wall we had to open it from inside as shown in Fig. 3. Afterwards the perimeter of excluded piece of OSB-board was sealed with silicone as seen in Fig. 4.

Figure 3. Applying sensors between layers.

Figure 4. Sealing the opening with silicone.



Lime plaster	20 mm
Clay bricks	130 mm
Air gap	50 mm
Clay bricks	130 mm
ISOVER KL-37	200 mm
OSB 3	15 mm
Bituumenmastic	3 mm
Air gap	25 mm
Wood siding	25 mm
Lime plaster	25 mm

Figure 5. The cross-section of the insulated wall and installed sensors between layers.

The temperature inside/outside was measured using sensors on the wall TMC1-HD/TMC6-HD and connected to data logger HOBO U12. Relative humidity was measured inside with HOBO U12 and ambient air values were taken from the archive of Tartu weather service (Estonian Weather Service 2013). The TMC-HD sensors measurement range is -40 °C to 100 °C. HOBO U12 has temperature range of -20 °C to 70 °C (accuracy ± 0.35 °C from 0 °C to 50 °C) and RH 5% - 95% (accuracy ± 2.5% from 10% to 90%).

Between installed layers temperature and relative humidity was measured in three points with capacitive humidity sensor FHA 646 R connected to Almemo® 2890-9 data logger. Sensors operative range is -30 to +100 °C, 5 to 98% RH (accuracy ± 2% RH in the range < 90%)

The sensor M00/M10 measuring temperature/relative humidity was applied between the wool and clay brick masonry wall, M01/M11 was placed between wool and OSB board, M02/M12 was placed on the interior side of bitumen mastic (facing the air gap). The cross-section of the wall and applied sensors are presented in Fig. 5.

Methodology

The study was carried out by two methods: simulation of hygrothermal behaviour using Glaser method based on: 1) measured values and 2) DIN 4108-3. Glaser method is a simplified procedure, based on pure diffusion moisture transport in one dimensional steady-state condition. It ignores some issues, such as moisture and heat accumulation in materials and built-in moisture, the dependence of material properties on humidity and temperature, the capillary transport of liquid water and the rising damp or wind driven rain.

Data saving interval was one hour. Calculations were done on three different bases. 1) During the time period of 31.01.2013–16.02.2013 the outside average temperature was -0.5 °C and inside +14 °C. The average relative humidity was outside 89. 9% and inside 64.7%. 2) Calculation done on the coldest day on 20.01.2013 when the ambient temperature was -28 °C. Interior temperature was +10 °C. The values of the relative humidity were accordingly 75% and 55%. 3) Calculations based on DIN 4108-3: outside temperature -10 °C, RH 80%; inside +20 °C RH 50%; period of time 2,160 h. Drying period conditions according to DIN: outside +12 °C, RH 70%; inside +12 °C, RH 70%; point of condensation +12 °C, RH 100%, time of period 2,160 h.

RESULTS AND DISCUSSION

Values measured during the period of time 31.01.2013 – 16.02.2013 were calculated as arithmetic averages. Measured values of temperature and relative humidity inside/outside in points M00/M10; M01/M11; M02/M12 are presented in Fig. 6 and Fig. 7. Until 18.02.2013 all the devices were working properly. Afterwards were some periods when some of the devices were out of order.

The relative humidity between layers depended correlatively on the inside relative humidity. There was no correlation with outside relative humidity.

The fact that relative humidity in point M11 was correlated to the inside relative humidity show that using the bitumen mastic was risky and it was not suitable vapour retarder as assumed in calculations.

In Fig. 7 the relative humidity in the point M11 was about 20% lower comparing to RH in the point M12. It leads to acknowledgment that bitumen mastic is working because only OSB board can’t make such a big difference in relative humidity values.

The temperature line in Fig 6 show us that whole masonry wall was frozen throughout measuring period. The sensor, M00, between insulation layer and masonry wall show also mainly zero degrees in the measuring period and the relative humidity sensor M10 at the same place indicated that during the measuring period the RH was above 80% as seen in Fig. 7. These numbers refer to a great risk of decay and destruction of the wall caused by moisture and freezing. As the temperature remains more constant there will not be many freeze-thaw cycles. In further studies it has to be found out how and if the layer of ice between insulation and masonry will protect the masonry from saturation. Also it would be interesting to know how far the saturation extends in masonry brick and whether the bricks get saturated in any point.

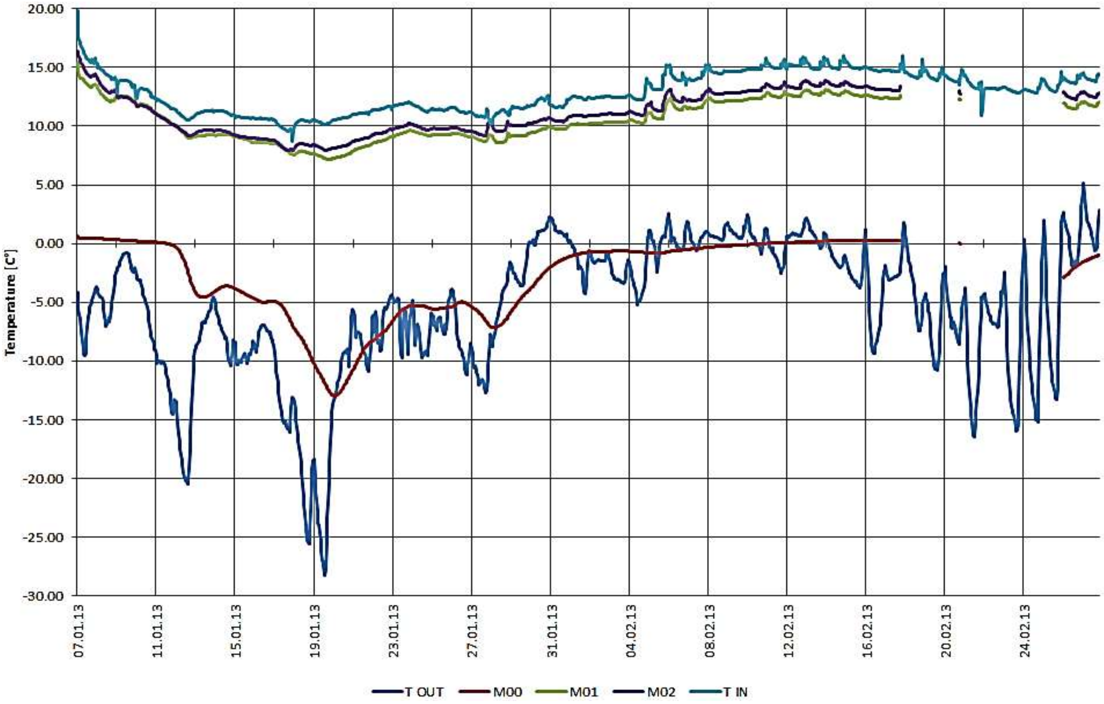


Figure 6. Measured temperature values: inside, in points M00, M01, M02 and outside.

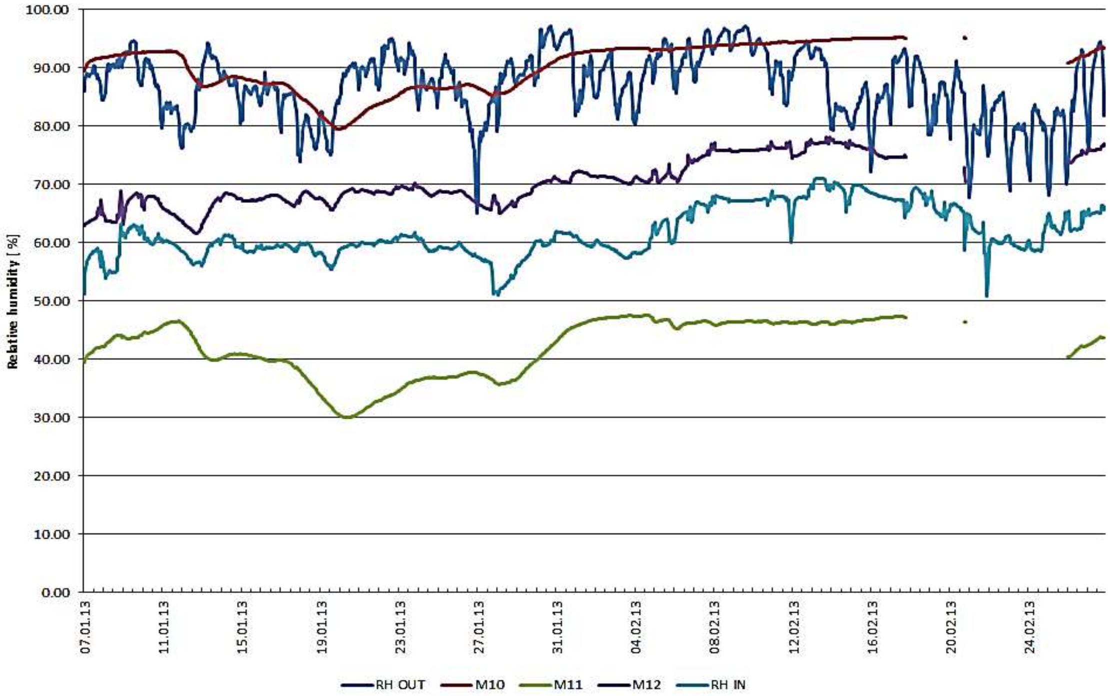


Figure 7. Measured relative humidity values: inside, in points M10, M11, M12 and outside.

It is really important to make on site tests to see if the moisture will dry out during the summer time and how strong is the correlation between exterior RH and in point M10. It would also be worth to investigate does the masonry wall`s air gap ventilation affects the evaporation.

Differences between measured and calculated temperature and relative humidity values during the period 31.01.2013–16.02.2013 are shown in Table 1 and Table 2.

Table 1. Differences between average measured and calculated temperature values

31.01.2013–16.02.2013	Temperature				
	OUTSIDE	M00	M01	M02	INSIDE
	°C	°C	°C	°C	°C
Average measured values	-0.49	-0.43	11.57	12.28	13.95
Calculated	-0.50	0.73	12.70	13.00	14.00

Table 2. Differences between average measured and calculated relative humidity values

31.01.2013–16.02.2013	Relative humidity				
	OUTSIDE	M10	M11	M12	INSIDE
	%	%	%	%	%
Average measured values	89.93	93.63	46.20	73.95	64.67
Calculated	89.90	106.50	47.70	62.2	64.70

Based on the measurements the average value of the relative humidity in point M10 was higher than 90%. The temperature in point M00 was constantly below zero. Calculations show high risk of condensation and mould growth and condensed water amount was 0.06 kg m^{-2} but according to DIN it dries out during the summer time.

During extreme winter conditions when the measured outside temperature was -28 °C the differences between calculated and measured values turned out huge (Table 3 and Table 4).

Table 3. Differences between average measured and calculated temperature values

Extreme period 20.01.13	Temperature				
	OUTSIDE	M00	M01	M02	INSIDE
	°C	°C	°C	°C	°C
Average measured values	-28.21	-11.85	7.26	7.98	10.14
Calculated	-28.00	-24.78	6.60	7.37	10.00

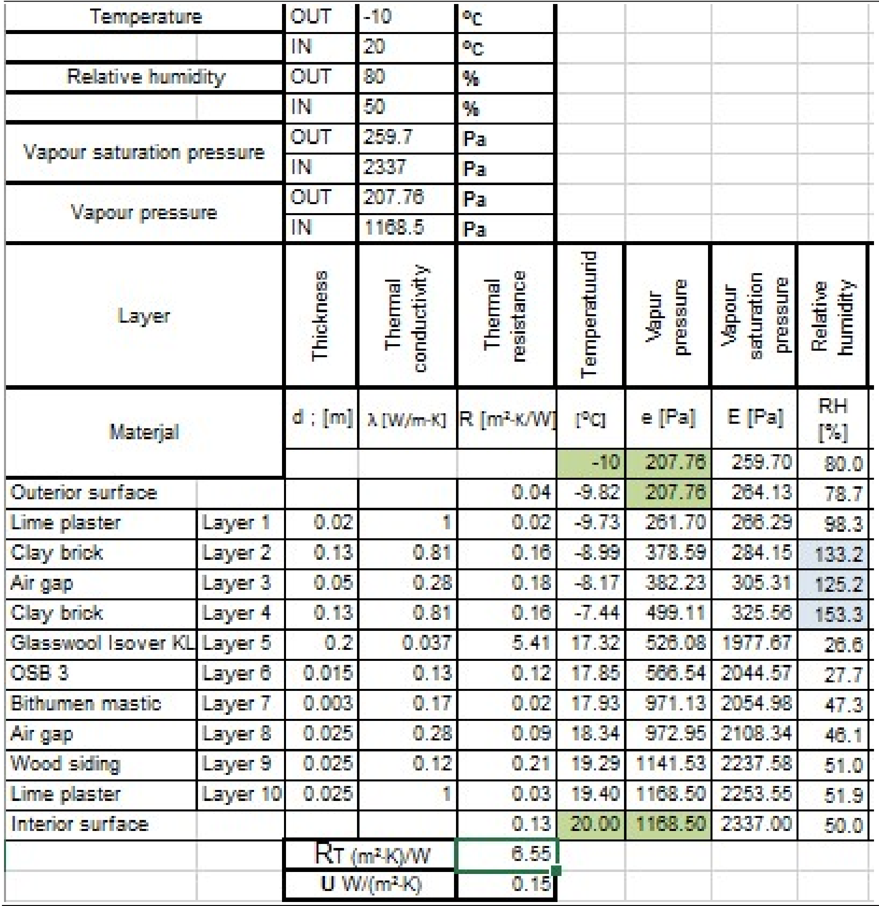
Table 4. Differences between average measured and calculated relative humidity values

Extreme period 20.01.13	Relative humidity				
	OUTSIDE	M10	M11	M12	INSIDE
	%	%	%	%	%
Average measured values	75.00	80.38	31.85	65.65	55.48
Calculated	75.00	363.00	39.60	45.90	55.00

The most extreme differences between measurements and calculation results were in point M00/M10 that was between masonry and insulation layers. It might be that the sensor was covered with ice and therefore did not give the proper temperature and relative humidity values. Even though when calculations done by DIN give condensed water amount during 24 h to be 0.024 kg m^{-2} and amount of dried out water in 24 h to be 0.017 kg m^{-2}, it is possible to predict based on calculations that the water dries out during 2160 h. As climate is always unpredictable it is impossible to know how many times extreme minus degrees during winter will be. As we have not measured the saturation of clay bricks it may occur that the clay bricks will be demolished in one winter.

The third calculations were done according to DIN 4108-3 (2017) and results are presented in Table 5.

Table 5. Calculations according to DIN



Temperature		OUT	-10	°C				
		IN	20	°C				
Relative humidity		OUT	80	%				
		IN	50	%				
Vapour saturation pressure		OUT	259.7	Pa				
		IN	2337	Pa				
Vapour pressure		OUT	207.76	Pa				
		IN	1168.5	Pa				
Layer		Thickness	Thermal conductivity	Thermal resistance	Temperatuurid	Vapur pressure	Vapour saturation pressure	Relative humidity
Materjal		d ; [m]	λ [W/m-K]	R [m²-K/W]	[°C]	e [Pa]	E [Pa]	RH [%]
					-10	207.76	259.70	80.0
Outerior surface				0.04	-9.82	207.76	264.13	78.7
Lime plaster	Layer 1	0.02	1	0.02	-9.73	261.70	266.29	98.3
Clay brick	Layer 2	0.13	0.81	0.16	-8.99	378.59	284.15	133.2
Air gap	Layer 3	0.05	0.28	0.18	-8.17	382.23	305.31	125.2
Clay brick	Layer 4	0.13	0.81	0.16	-7.44	499.11	325.56	153.3
Glasswool Isover KL	Layer 5	0.2	0.037	5.41	17.32	526.08	1977.67	26.6
OSB 3	Layer 6	0.015	0.13	0.12	17.85	566.54	2044.57	27.7
Bithumen mastic	Layer 7	0.003	0.17	0.02	17.93	971.13	2054.98	47.3
Air gap	Layer 8	0.025	0.28	0.09	18.34	972.95	2108.34	46.1
Wood siding	Layer 9	0.025	0.12	0.21	19.29	1141.53	2237.58	51.0
Lime plaster	Layer 10	0.025	1	0.03	19.40	1168.50	2253.55	51.9
Interior surface				0.13	20.00	1168.50	2337.00	50.0
		RT (m²-K)/W		6.55				
		U W/(m²-K)		0.15				

The temperature and relative humidity were inside +20 °C and 50% and outside -10 °C and 80%. The basic values given in DIN 4108-3 (2017) are marked with green colour in Table 5. According to DIN calculations whole masonry part of the wall will freeze and the water will condense in three points as seen in Table 5. The abnormal calculated relative humidity values are represented in blue colour. The amount of condensed water is 0.051 kg m^{-2}. According to DIN 4108-3 (2017) it will dry out.

As the calculations made according to DIN 4108-3 (2017) are simplified and don't take into account may aspects of hygrothermal behaviour, it is not safe to use it to predict how interior insulation will perform. There exists a lot of complex programs like WUFI, DELPHIN, COMSOL that enable us to predict more adecvately how the interiorly insulated wall will perform more adequately (Knarud & Geving, 2017) than used Glaser method.

CONCLUSION

The one dimensional calculations made according to DIN 4108-3 allowed to conclude that it is safe to build such an interiorly insulated stud wall. Calculations show that condensed water will dry out during the evaporation period. The measured values confirmed that the material technical data were correct but a layer of ice was discovered on devices removal in point M02/M12 between the layers. Without further investigations to build this type of interiorly insulated wall is not suggested.

As vapour-proof systems are proven to be reliable, but the most problematic point is how to generate the totally vapour proof layer. There is no study for a wall with interior vapour-retardant insulation is covered with hydrophilic water absorbent material minimizing onsite piercing and avoiding piercing during period on building life cycle.

ACKNOWLEDGEMENTS. The authors would like to thank the owners of the building Veski 13 Tartu and Martti-Jaan Miljan for applying the devices on site. This research was financed by a project of Zero energy and resource efficient smart buildings and districts, (2014-2020-4.01-15-0016).

REFERENCES

Biseniece, E., Žogla, G., Kamenders, A., Purvinš, R., Kašs, K., Vanaga, R. & Blumberga, A. 2017. Thermal performance of internally insulated historic brick building in cold climate: a long term case study. *Energy and Buildings* **152**, 577–586.

Bjarlov, S.P., Finken, G.R. & Odgaard, T. 2015. Retrofit with Interior Insukation on Solid Masonry Walls in Cool Temperate Climates – An Evaluation of the influence of interior Insulation Materials on Moisture Condition in the Building Envelope. *Energy Procedia* **78**, 1461–1466.

DIN 4108-3:2017-09 Thermal protection and energy economy in buildings - Part 3: Protection against moisture subject to climate conditions - Requirements and directions for design and construction p. 70 (in German).

Estonian Weather Service 2013. *http://www.ilmateenistus.ee/ilm/ilmavaatlused/vaatlusandmed/* (assessed in 2013, in Estonian).

Fantucci, S., Isaia, F., Serra, V. & Dutto, M. 2017. Insulating coat to prevent mould growth in thermal bridges. *Energy Procedia* **34**, 414–422.

Hansen, T.K., Bjarlov, S.P., Peuhkuri, R.H. & Harrestrup, M. 2017. Long term in situ measurements of hygrothermal conditions at critical points in four cases of internally insulated historic solid masonry walls. *Energy and Buildings* **172**, 235–248.

Harrestrup, M. & Svendsen, S. 2015. Full-scale test of an old heritage multi-storey building undergoing retrofitting with focus on internal insulation and moisture. *Building and Environment* **85**, 123–133.

Klõšenko, P., Arumägi, E. & Kalamees, T. 2013. „Interreg IVB Baltic Sea Region Project Co$_2$olBricks - Climate Change, Cultural Heritage & Energy Efficient Monuments“, scientific work pp. 1–26 (in Estonian).

Knarud, J.I. & Geving, S. 2017. Comparative study of hygrothermal simulations of masonry wall. *Energy Procedia* **132**, 771–776.

Mets de, T., Tilmans, A. & Loncour, X. 2017. Hygrothermal assessment of internal insulation systems of brick walls through numerical simulation and fullscale laboratory testing. Energy Procedia, 11-th Nordic Symposium on Building Physics, NSB2017, Trondheim, Norway, pp. 753–758.

National Registry of Cultural Monuments. *https://register.muinas.ee/public.php?menuID=monument* (assessed in 2013, in Estonian).

Nielsen, A., Møller, E.B., Rasmussen, T.V. & Hansen, E.J. de Place. 2012. Use of sensitivity analysis to evaluate hygrothermal conditions in solid brick walls with interior insulation. *In Proceedings of the 5th IBPC, Kyoto, Japan,* pp. 377–384.

Rakenna & Remontoi. 2012. Asennusvideo: saunan eristäminen *https://www.rakentaja.fi/tv/vid1472saunan_eristaminen.aspx* (assessed 2013, in Finnish).

Rasmussen, T.V. 2011. Retrofitting Listed Buildings: Measures, Savings and Requirements. *The Open Construction and Building Technology Journal*, **5**, pp. 174–181.

Regulation of Cultural Ministry no 12 list of 'Cultural monument building' published 20.03.1997. *https://www.riigiteataja.ee/akt/25290* (assessed in 2013, in Estonian).

Regulation of Minister of Economic Affairs and Communications no 63 'Methodology for calculating the energy performance of buildings' published 01.01.2019. *https://www.riigiteataja.ee/en/eli/ee/MKM/reg/520102014002/consolide* (assessed in january 2019, in Estonian).

Straube, J., Schumacher, C. & Mensiga, P. 2010. Assessing the Freeze-Thaw Resistance of Clay Brick for Interior Insulation Retrofit Projects, Building Science Press, CP 1013.

Transition to Sustainable Building, Strategies and Opportunities to 2050. OECD/International Energy Agency 2013.

Vereecken, E. & Roels, S. 2017. Wooden beam ends in combination with internal insulation: the importance of an airtight sealing. *Energy Procedia* **132**, 664–669.