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Vanek, Angela

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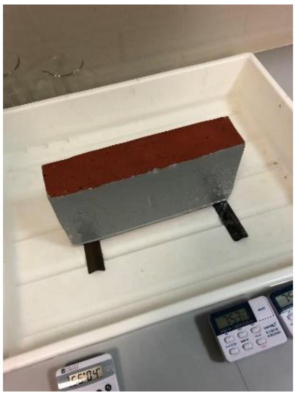

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January 2019

Technical University of Denmark

Evaluation of physical parameters of a historic wall (brick and mortar) in a test building in Dianalund

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Report conducted by: Angela Vanek

Research Assistant at Technical University of Denmark, Kgs. Lyngby, Denmark

Cover photos: Angela Vanek and Søren Peter Bjarløv

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Project leader: Associate Professor Søren Peter Bjarløv

Contact: angva@byg.dtu.dk

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Content

1. Introduction

The aim of these lab tests was to identify six material parameters of the masonry of the historic building at Dr Sellsvej 39, Building 9 in 4293 Dianalund (build in 1928) before refurbishing it with internal insulation. The brick parameters are crucial to investigate the performance of various insulation types by the mean of hydrothermal simulations with the hydrothermal simulation software “Delphin”. All tests were carried out in the laboratory at DTU.

One brick and a specimen of mortar were taken out of the wall for further use in the lab. For the brick, six material parameters were determined in the lab. The mortar samples were tested for two parameters.

2. Methodology

To test the existing historic exterior wall for its parameters, a brick was taken out the 25.5.2018, from the wall on site. This was done using a drill. The brick as well as a small sample of mortar were packed up for further investigation in the lab at DTU.

Figure 1: Removing the brick from the wall at Dr. Sellsvej 39, Building 9

Following material parameters were determined for the brick:

- Thermal conductivity (λ)
- Volume heat capacity (c_p)
- Density (ρ_d)
- Porosity (p_0)
- Water absorption coefficient (A_w)
- Capillary moisture content (W_{cap})

Following material parameters were determined for the mortar:

- Density (ρ_d)
- Porosity (p_0)

2.1. Thermal conductivity (λ) and volume heat capacity (c_p)

Both the thermal conductivity as well as the volume heat capacity were determined only for the brick as the sample of the mortar was too small for testing. To test these two parameters, the heat transfer analyzer "ISOMET (model 2104)" was used. This measurement equipment included with both a needle probe and a surface probe where the surface probe was used for these tests.

In order to measure the brick at dry conditions the brick was placed together with the mortar samples in a ventilated oven at 105 °C for 48 hours until the mass difference was smaller than one mass percent. To keep the dry conditions, the samples were placed in a desiccator at all time when not used for measurements.

As the surface probe needs to sit on a flat surface the brick's surface was grinded down to a flat surface and cleaned from all mortar. This was done on all sides beside the original outer surface of the brick that was left untreated. Furthermore, the surface probe was placed in 4 different positions of the bricks surface and the tests using the ISOMET were carried out. One test took approximately 10 minutes for the heat transfer analyzer to measure. These results were written down and an average was calculated.

Figure 2: Surface probe placed on the bricks surface

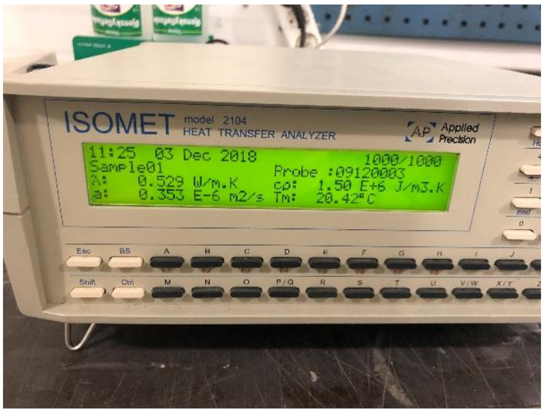

Figure 3: Display surface of the ISOMET (model 2104)

This was done in two different mean temperatures, at 10 °C [4] and at 19 °C. Before both tests the brick was conditioned to the testing temperature for more than 24 hours before the actual testing.

After testing, the samples were placed in the desiccator.

2.2. Density (ρ_d) and porosity (p_0)

Density and porosity were tested for both the brick and the mortar.

A starting weight of the brick and the mortar samples were registered and the mortar samples were placed under metal pieces to prevent them from floating during the process. The desiccator was evacuated from air by the mean of a pump and left in this state for 3 hours before demineralized water was added until all samples ware fully immersed. This state was kept for 24 hours before the samples were taken out and weighed under water. Afterwards, the samples were wiped with a damp cloth to remove the free liquid water from the samples and weighed.

All measurements were registered and the density and porosity were calculated using following formulas:

Density: $$\rho_d = \frac{m_{105}}{m_{ssd} - m_{sw}} * \rho_w$$

Porosity: $$p_0 = \frac{m_{ssd} - m_{105}}{m_{ssd} - m_{sw}}$$

To check the results for their liability, the dry density was also calculated by following formula:

Density: $$\rho_d = \frac{m_{105}}{V_{measured}}$$

It has to be noted that this test was carried after grinding the bricks surface and drying it again.

Figure 4: Brick and mortar sample in a desiccator during the density and porosity tests

2.3. Water absorption coefficient (A_w) and capillary moisture content (W_{cap})

The water absorption coefficient was determined by partial immersion following ISO 15148:2002 [1].

The brick was dried to dry conditions in a ventilated oven at 105 °C for 48 hours and weighed. Afterwards the brick was conditioned to the lab climate of approximately 19 °C and 40% RH for 48 hours and weighed. It was then registered that the weight of the sample was stabilized to within 0.1% of its total mass, which is the limit to carry out the determination of the water absorption coefficient.

This method is based on measuring a one dimensional water flow through the material, therefore the material was sealed with two layers epoxy on four of the six sides leaving the top and bottom surface unsealed. After drying (48 h) the brick was weighed.

With its initial outer surface facing downwards, the brick was placed in the water bath. The brick was then taken from the water bath, liquid water was wiped with a damped cloth and it was placed on the weight in time steps of 5 min, 30 min, 1h, 2h, 3h, 4h, 5h, 6h, 7, 8, 24h, 25, and 49.2h.

The results were immediately plotted to a graph and trend lines were added in order to see when the absorption stops. The water absorption coefficient was read out by the gradient of the trend line.

The capillary moisture content was determined by the intersection of the two trend lines combined with the height of the sample.

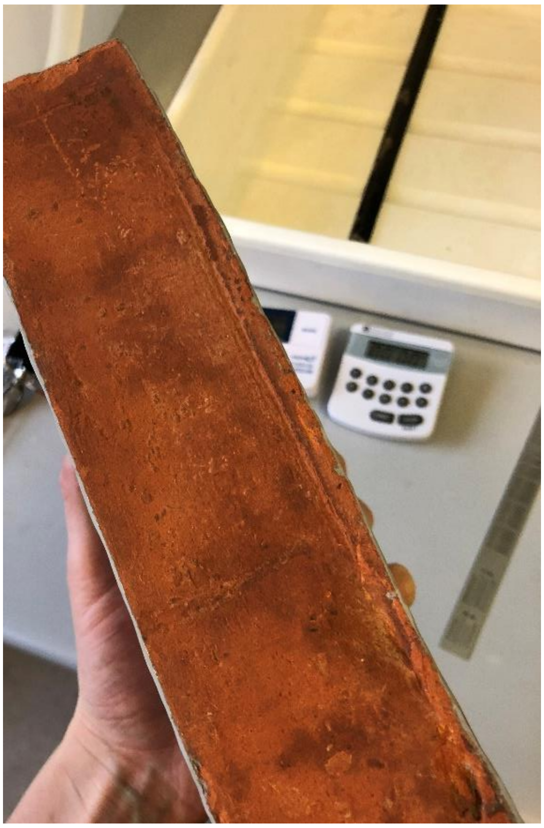

Figure 5: Exterior surface of the historic brick

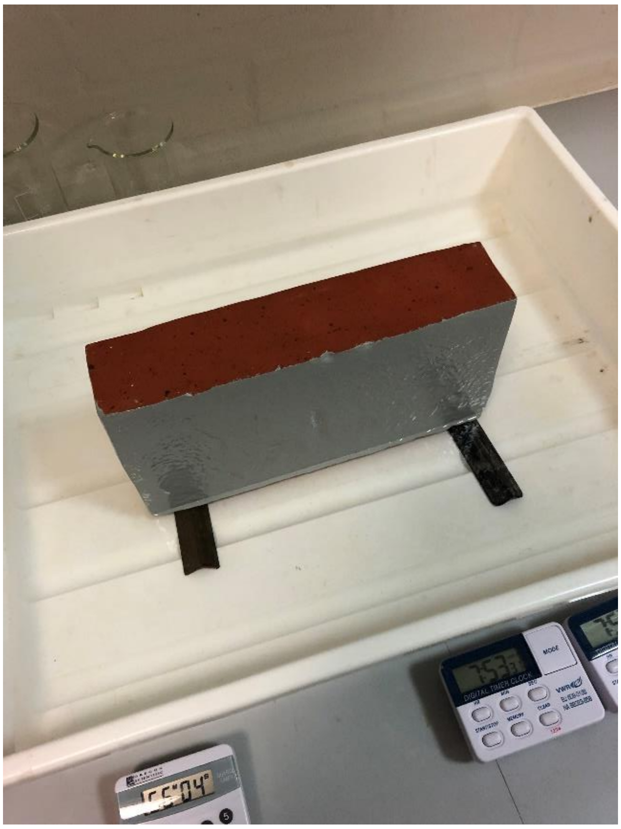

Figure 6: Partial immersion test of the historic brick with the exterior surface facing the water and sealed with epoxy on the four sides

3. Results and discussion

This section deals with the results and discussion of parameter investigations.

3.1. Thermal conductivity (λ) and volume heat capacity (c_p)

Both the thermal conductivity as well as the heat capacity were tested in 2 different climates. This was done, with reference to DS/EN 1745:2012 [4] those tests should be carried out at a mean temperature of 10 °C but it was not possible caused by lack of stabilized refrigerator capacity and high hysteresis and the fact that the experiment demanded opening and closing the door several times. It was decided to redo the test in a climate chamber with a constant temperature. Here the only possibility was to use a climate chamber with a constant temperature of 19 °C. However, the difference in the obtained results were slightly higher. λ 0.546 to 0.535 and c_p 1.50 to 1.48.

Table 1: Thermal conductivity of the brick sample DL (Dianalund) tested at 10 and 19 °C

Thermal conductivity λ [W/mK]			
Sample		**DL**	DL
Condition		**19 °C**	10 °C
Date		**3.12.18**	30.11.18
Position	1	**0.529**	0.523
	2	**0.567**	0.548
	3	**0.537**	0.505
	4	**0.552**	0.564
	∑	**0.546**	0.535

Table 2: Volume heat capacity of the brick sample DL (Dianalund) tested at 10 and 19 °C

Volume heat capacity c_p [J/m³K] *E+6			
Sample		**DL**	DL
Condition		**19 °C**	10 °C
Date		**3.12.18**	30.11.18
Position	1	**1.50**	1.46
	2	**1.50**	1.49
	3	**1.49**	1.48
	4	**1.51**	1.49
	∑	**1.50**	1.48

3.2. Density (ρ_d) and porosity (p_0)

Table 3 sums up the results for both dry density and open porosity of the brick and mortar samples. DL (Dianalund) represents the results of the brick sample and DL_M (Dianalund mortar) represents the results of the average of the two mortar samples.

From the results it is seen that the density of the brick represents a dense brick in comparison to the average brick that is produced in Denmark nowadays (1200 – 1800kg/m^3). The mortar samples represent, with its dry density a regular lime and lime-cement mortar.

Table 3: Apparent density and open porosity of the brick DL (Dianalund) and mortar DL1_M and DL2_M (Dianalund mortar 1 and Dianalund mortar 2) samples

			DL	DL1_M	DL2_M	DL_M
Dry density:	ρ_d	[kg/m^3]	**1857**	1755	1806	**1780**
Open porosity:	p_0	[m^3/m^3]	**0.303**	0.326	0.315	**0.321**

The test measurement of the dry density for the brick DL gave a result of 1906 kg/m^3. This deviation can be explained by the test sample of the brick not being entirely uniform in size and led to a small error in measuring the length, width and height of it.

3.3. Water absorption coefficient (A_w) and capillary moisture content (W_{cap})

The water uptake coefficient A_w is expressed as the slope of the first trend line (blue) and therefore is 0.237 kg/m^{2}s$^{1/2}$. This represents a brick that has a fast water uptake in comparison to all brick from the Delphin database.

The capillary moisture content W_{cap} was calculated by the gain in weight per kg after the water absorption test in comparison to its weight before, divided by the bricks height using following equation:

$$W_{cap} = \frac{\Delta m_t}{h_{DL}} = \frac{24.88}{0.11} = 226.19\ kg/m^3$$

where h_{DL} is the height of the brick sample in m.

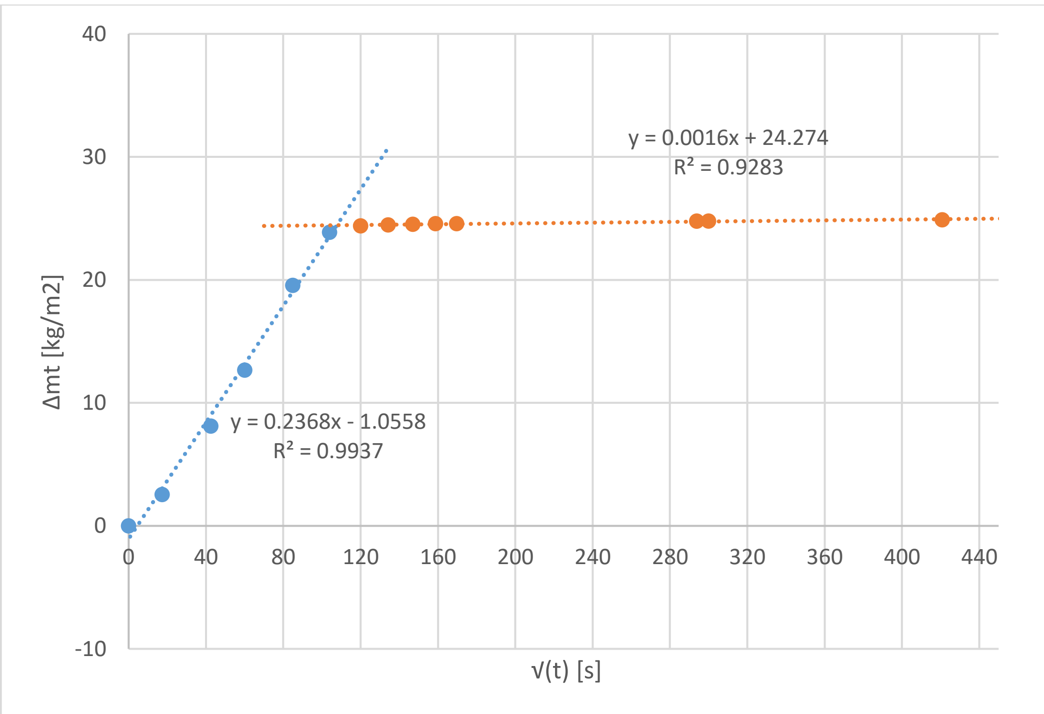

Figure 1: Water absorption curve of the brick "DL"

4. References

[1] ISO 15148:2002 "Hygrothermal performance of building materials and products – Determination of water absorption coefficient by partial immersion"

[2] DS/EN 772-13 "Methods of test for masonry units – Part 13: Determination of net and gross dry density of masonry units (except for natural stone)

[3] DS/EN 1936:2007 "Natural stone test methods – Determination of real density and apparent density, and of total and open porosity"

[4] DS/EN 1745:2012 "Masonry and masonry products – Methods for determining thermal properties"

5. Appendices

5.1. Appendix A - Density (ρ_d) and porosity (p_0)

		calc.	DL	DL1_M	DL2_M	comment
m_{105}	[g]	-	2325.4	71.28	21.8	
m_{before}	[g]	-	50	50	50	
m_{after}	[g]	-	50	50	50	
m_h	[g]	-	1454.1	43.97	13.55	
Tara	[g]	-	-	60.7	22.8	
m_s+Tara	[g]	-	-	145.2	48.4	
m_s	[g]	-	2703.6	84.5	25.6	
ρ_f	[kg/m³]	$m_d/(V_b-V_0)*100$	266.4	260.5	263.7	
ρ_d	**[kg/m³]**	**$m_d/(m_s-m_h)*\rho_{rh}$**	**1857**	**1755**	**1806**	
ρ_s	[kg/m³]	m_s/V_b*100	215.9	208.1	212.0	
p0	**[m³/m³]**	**$(m_s-m_d)/(m_s-m_h)$**	**0.303**	**0.326**	**0.315**	
V0	ml=cm³	$(m_s-m_d)/\rho_{rh}*1000$	378.96	13.25	3.81	
Vb	ml=cm³	$(m_s-m_h)/\rho_{rh}*1000$	1252.00	40.61	12.07	
m_{105}	[g]		2324.0	-	-	After grinding
$V_{measured}$	[m³]	l x w x h	0.001219	-	-	After grinding

5.2. Appendix B - Water absorption coefficient (A_w) and capillary moisture content (W_{cap})

test period:	18.12.2018 - 19.12.2018		sample
		calc.	DL
$m_{contr.}$	[g]	-	50
T_{room}	[°C]	-	18.4
m_i	[kg]	-	2.3528
A	[m^2]	l x w	0.01108
m_t	[kg]	-	2.62
Δ m_t	[kg]	(mt-mi)/A	24.45
Δ m'_0	[kg/m^2]	read from graph	-1.0558
Δ m'_{tf}	[kg/m^2]	read from graph	24.45
Type A			
A_w	[kg/(m^2*√s)]	(delta mtf'-delta m0')/sqroot(t)	0.237
W_w		(delta mtf'-delta m0')/sqroot(t)	17.846

start time: 18.12.2018 10:37

m	m	t	t	Δm_t	√(t)
[g]	[kg]	[min]	[s]	[kg/m2]	[s]
2352.8	2.3528	0	0	0.00	0.00
2381.1	2.3811	5	300	3.31	17.32
2442.6	2.4426	30	1800	10.49	42.43
2493.0	2.4930	60	3600	16.38	60.00
2569.5	2.5695	120	7200	25.32	84.85
2617.4	2.6174	180	10800	30.91	103.92
2623.0	2.6230	240	14400	31.57	120.00
2624.0	2.6240	300	18000	31.68	134.16
2624.6	2.6246	360	21600	31.75	146.97
2625.0	2.6250	420	25200	31.80	158.75
2625.2	2.6252	480	28800	31.82	169.71
2627.4	2.6274	1440	86400	32.08	293.94
2627.4	2.6274	1500	90000	32.08	300.00
2628.6	2.6286	2952	177120	32.22	420.86